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Contents

Postemergence Control of Crabgrass in Transition Zone Turf Using MSMA and Fenoxaprop

PETER H. DERNOEDEN and JACK D. FRY

ABSTRACT

The objective of this study was to compare the effectiveness of single and sequential applications of monosodium methanearsonate (MSMA) with single applications of fenoxaprop {(±)-2[4-((6-chloro-2-benozoxazolyl}oxy) phenoxy] propanoic acid} for postemergence control of crabgrass (Digitaria spp.). MSMA applied at 2.2 kg ha^{-1} twice on a 14-day interval or 1.1 kg ha^{-1} applied three times on a 7-day interval provided exceptional (99 percent) control of mature (i.e., three or more tillers) crabgrass, but elicited unacceptable levels of discoloration. When MSMA was applied at 0.6 kg ha^{-1} three times on a 7-day interval or at 1.1 kg ha^{-1} twice on a 14-day interval, fair (78 to 79 percent) to good (88 percent) control was achieved without unacceptable discoloration of turf. However, a single MSMA application at 2.2 kg ha^{-1}, did not effectively control crabgrass. Fenoxaprop (0.28 kg ha^{-1}) provided fair (78 percent) to excellent (93 percent) levels of control when applied to mature crabgrass. The erratic performance of fenoxaprop in control of mature crabgrass was attributed to environmental conditions as such conditions affected the vigor of crabgrass. Single applications of fenoxaprop (0.20 and 0.28 kg ha^{-1}) in early summer when crabgrass was relatively immature provided exceptional (91 to 99 percent) control and eliminated weeds as a problem for the remainder of the season. Effective control of mature crabgrass with fenoxaprop (0.28 or 0.56 kg ha^{-1}) can be achieved if rainfall or irrigation is not limiting and crabgrass is growing vigorously.

Weed control in turfgrass is best accomplished by maintaining a dense stand through employment of sound cultural practices. However, because of budget limitations, proper mowing frequency, fertility, and other management inputs in low maintenance, highway turfgrass areas are often neglected. Budget restrictions, as well as mechanical disturbances, environmental and biotic stresses, and poor soil conditions invariably lead to deterioration of turfgrass stand density and weed invasion. For these reasons, herbicides are used to supplement cultural practices in controlling weeds. Weed control in highway turfs is important because it provides the following benefits:

1. Helps improve turfgrass stand density by reducing competition from other plants,
2. Reduces mowing frequency in summer when weed species are growing more rapidly than cool-season turfgrass species,
3. Reduces potential weed problems in adjacent farmland and other property, and
4. Improves aesthetic quality.

Among the most common weeds found in turfgrass areas are smooth [Digitaria ischaemum (Schreb.) Muhl] and hairy [Digitaria sanguinalis (L.) Scop] crabgrass. Crabgrass is particularly troublesome in the transition zone where turfgrass density frequently deteriorates because neither cool- nor warm-season grasses are well adapted to the region. Crabgrass is effectively controlled with preemergence herbicides (1), but these chemicals are often too expensive to use on extensive highway turfgrass areas. When postemergence crabgrass control becomes necessary, methanearsonates such as MSMA are often used. However, effective crabgrass control with these herbicides has been erratic, and their use is normally accompanied by objectionable levels of turfgrass discoloration (2,3). In recent years, fenoxaprop has shown promise as a new, postemergence herbicide (2-8).

In addition to crabgrass, fenoxaprop effectively controls fall panicum (Panicum dichotomiflorum Michx.) and goosegrass [Eleusine indica (L.) Gaertn] (Dernoeden, unpublished data) and was observed to control johnsongrass [Sorghum halepense (L.) Pers.] in a highway demonstration test conducted in Maryland in 1984 (Jesse Crook, unpublished data). The objectives of these studies were to

1. Determine the application rates and sequential application schedules needed to achieve effective crabgrass control with MSMA, and
2. Compare crabgrass control with single and sequential applications of MSMA with single applications of fenoxaprop.

Other important parameters were to determine the influence of rate and timing of applications, as well as to assess the effects of cultural practices on how well fenoxaprop controls crabgrass.

MATERIALS AND METHODS

All studies were conducted at the University of Maryland Turfgrass Research Facility in Silver Spring, Maryland, between 1982 and 1984. The turf was a mature stand of Citation perennial ryegrass (Lolium perenne L.) grown on a Chillum silt loam (fine-silty, mixed, mesic Typic Hapludult) with a pH

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of 6.3 and 2.3 percent organic matter. A natural heavy infestation of mostly smooth and some hairy crabgrass existed at the site. Herbicides were applied with a CO_2 pressurized sprayer that delivered 280 L ha^{-1} in 1982 and 468 L ha^{-1} in 1983 and 1984. Turf was maintained at a 4.0- to 7.0-cm height throughout the test years. The plot area was fertilized with a total of 150 kg N ha^{-1} from urea each autumn.

Visual estimates of percent plot area covered by crabgrass were made in September of each year on a scale of 0 to 100 percent. Percent of control was calculated by dividing the percent of crabgrass cover in treated plots by the mean percent of crabgrass cover in untreated plots. An acceptable level of crabgrass control for low-maintenance turf was considered to be greater than 80 percent. Phytotoxicity, in the form of turf discoloration, was visually estimated by using a scale of 0 to 5: 0 = green, healthy turf; 3 = unacceptable discoloration; and 5 = brown turf. All data were analyzed by using the analysis of variance, and significantly different means were separated by using Bayes least significant difference multiple comparison test. Preliminary results of some of these tests were reported previously (2,5-6).

1982 Tests

Two tests conducted in 1982 compared various rates and application intervals of MSMA with a single application of fenoxaprop. Various rates of fenoxaprop applied alone or tank-mixed with crop oil were also evaluated in a separate study. The statistical design used in the first test was a completely randomized block with four replications, and plot size was 1.5 by 1.5 m. A randomized complete block with three replications and 1.5- by 5.0-m plots was used in the second test involving crop oil.

In the first test, MSMA was applied either twice (2.2 kg ha^{-1}) on a 14-day interval or three times (0.6, 1.1, and 2.2 kg ha^{-1}) on a 7-day interval. Fenoxaprop was only applied once. Herbicide applications began July 12 when crabgrass was in the two- to four-tiller stage. Rain showers occurred within 5 hr of the second application of herbicide on July 19; no rain occurred within 72 hr of all other application dates. The area was occasionally irrigated to prevent severe drought stress.

In the second study, various rates of fenoxaprop alone or tank-mixed with crop oil were applied to determine if oil would improve herbicide efficacy. The oil used was AT Plus 411 F (80 percent nonphytotoxic oil plus 20 percent nonionic surfactant) and was tank-mixed at a rate of 2.3 L ha^{-1}. Sprays were applied on August 16 when crabgrass was in the four- to eight-tiller stage. The test area was irrigated before herbicide application and thereafter to prevent drought stress.

1983 Test

Results of 1982 tests suggested that dry soil conditions and mowing within 48 hr of application may adversely affect the performance of fenoxaprop. Because of these observations, turf was not mowed within 72 hr before or after herbicide application, and the 1983 test area was irrigated before herbicide application and thereafter as needed to prevent severe drought stress. No rain or irrigation occurred within the 72-hr period following herbicide application. Herbicide applications were initiated on July 21 when crabgrass was in the three- to six-tiller stage. Fenoxaprop was applied once or sequentially, and MSMA was applied sequentially at intervals and at rates similar to those used in 1982. Plot size was 1.5 by 1.5 m, and the plots were arranged in a randomized complete block with four replications.

1984 Test

Fenoxaprop and MSMA were applied at various rates on three dates (Table 1). On June 13 crabgrass was in the one- to three-leaf stage and was below the turf canopy. On July 2 crabgrass was above the turf canopy and in the two- to four-leaf stage, and on July 16 crabgrass was in the four-leaf to two-tiller stage. No rain occurred within 48 hr of the first two applications, but rain fell 7 hr following application on July 16. In a second 1984 test, only two rates of fenoxaprop (0.28 and 0.56 kg ha^{-1}) were applied on August 7 in an adjacent area. Turf was mowed at each site within 48 hr before or after herbicide applications, and frequent rainstroms during the test period negated any need to irrigate. Plot size and statistical design were the same in both 1984 tests as those used in 1983.

TABLE 1 Timing of Postemergence Treatments for the Control of Crabgrass With a Single Application of Fenoxaprop and MSMA in 1984

Herbicide	Rate (kg ai ha^{-1})	Date Applied	Crabgrass,[a] % Cover	Crabgrass,[a] % Control
Fenoxaprop	0.13	June 13	49cd[b]	37
Fenoxaprop	0.20	June 13	30ef	62
Fenoxaprop	0.20	July 2	7gh	91
Fenoxaprop	0.28	July 2	1h	98
Fenoxaprop	0.28	July 16	1h	99
Fenoxaprop	0.44	July 16	0h	100
MSMA	1.1	June 13	64bc	18
MSMA	2.2	June 13	72ab	7
MSMA	2.2	July 2	44de	44
MSMA	2.2	July 16	45de	42
Untreated	–	–	78a	–

Note: ai = active ingredient.

[a]Crabgrass cover was visually rated on September 11, 1984.

[b]Means in the column followed by the same letter are not significantly different at the p = 0.05 level according to the Bayes LSD.

RESULTS AND DISCUSSION

Results of 1982 Test

Data collected on September 10 indicated that one application of fenoxaprop (0.28 kg ha^{-1}), two applications of MSMA at 22.2 kg ha^{-1} on a 14-day interval, and three applications of MSMA at 1.1 or 2.2 kg ha^{-1} on a 7-day interval provided effective crabgrass control (Table 2). Phytotoxicity ratings collected on July 19, 1 week after the first application revealed that 2.2 kg ha^{-1} of MSMA provided an unacceptable level of discoloration. The 0.6 kg ha^{-1} and 1.1 kg ha^{-1} rates of MSMA applied three times on a 7-day interval provided fair and excellent crabgrass control, respectively, without causing unacceptable levels of discoloration. Fenoxaprop (0.17 kg ha^{-1}) provided fair control, and neither rate tested caused turf discoloration.

All rates of fenoxaprop applied alone or tank-mixed with oil and applied to mature crabgrass on August 16 provided excellent crabgrass control (Table 3). The improved effectiveness of fenoxaprop from the August 16 application compared with the July 12 application (Table 2) was not immediately understood. Fenoxaprop appears to be a slow-acting, systemic herbicide. About 10 days after application of fenoxaprop, crabgrass begins to turn yellow and

TABLE 2 Postemergence Crabgrass Control and Phytotoxic Effects of MSMA and Fenoxaprop

Herbicide	Rate (kg ai ha^{-1})	Applications: Interval (days)	Applications: No.	Phytotoxicity[a] July 19	Crabgrass,[b] %: Cover	Crabgrass,[b] %: Control
MSMA	2.2	14	2	3.0c[c]	1a	99
MSMA	0.6	7	3	1.0a	11b	78
MSMA	1.1	7	3	2.4bc	1a	99
MSMA	2.2	7	3	3.6d	0a	100
Fenoxaprop	0.17	–	1	1.2ab	11b	76
Fenoxaprop	0.28	–	1	1.0a	8ab	85
Untreated control	–	–	–	1.2ab	50c	–

Note: Applications were initiated on July 12, 1982, when crabgrass was in the two- to 4-tiller stage.

[a]Phytotoxicity was visually determined using a 0 to 5 scale: 0 = green, healthy turf; 3 = unacceptable discoloration; and 5 = brown turf.

[b]Crabgrass cover was visually rated on September 10, 1982.

[c]Means following the same letter in the same column are not significantly different at p = 0.05 level according to the Bayes LSD.

TABLE 3 Postemergence Crabgrass Control With Various Rates of Fenoxaprop Applied Alone or Tank-Mixed With Crop Oil

Herbicide	Rate (kg ai ha^{-1})	Crabgrass,[a] %: Cover	Crabgrass,[a] %: Control
Fenoxaprop	0.17	1a[c]	94
Fenoxaprop	0.17 + oil[b]	1a	96
Fenoxaprop	0.28	<1a	99
Fenoxaprop	0.28 + oil	<1a	99
Fenoxaprop	0.56	<1a	99
Untreated control	–	23b	–

Note: Herbicide treatments were applied August 16, 1982, when crabgrass was in the four- to eight-tiller stage.

[a]Crabgrass cover was visually rated on September 17, 1982.

[b]Crop oil was applied at a rate of 2.3 L ha^{-1}.

[c]Means following the same letter in the same column are not significantly different at p = 0.05 level according to the Bayes LSD.

subsequently crabgrass plants develop a purple-red color, and die 2 to 3 weeks after application. Following the July 12 application (Table 2), however, some of the purple-colored plants recuperated by producing new tillers from axillary buds. Failure to achieve more effective control after the July 12 application was attributed to treated plants having been mowed within 48 hr of application; this possibly reduced the translocation of sufficient amounts of herbicides to meristematic tissues to provide effective control. Reduced efficacy, however, may also have between caused by dry soil conditions throughout the period before and following the July 12 application.

Results of 1983 Test

In this test the effectiveness of single and sequential applications of various rates of MSMA and fenoxaprop to mature crabgrass (i.e., three- to six-tiller stage) was again assessed (Table 4). The results of MSMA use were similar to those observed in 1982 (Table 2). MSMA applied at 1.1 kg ha^{-1} two to three times on a 7- or 14-day interval or 2.2 kg ha^{-1} MSMA applied twice on a 14-day interval effectively controlled mature crabgrass. Turf treated with 2.2 kg ha^{-1} MSMA exhibited unacceptable levels of discoloration for 2 weeks (i.e., July 28 and August 4) following application (Table 4). Unacceptable discoloration was also observed 1 week following the second application (7-day interval) of 1.1 kg ha^{-1} MSMA on August 4. As was observed in 1982 (Table 2), 0.6 kg ha^{-1} MSMA (applied three times on a 7-day interval) and 1.1 kg ha^{-1} (applied two times on a 14-day interval) provided 79 and 88 percent crabgrass control without causing an unacceptable level of discoloration.

Single and sequential applications of fenoxaprop significantly reduced crabgrass populations, but the level of control was unacceptable (Table 4). During July 1983 only 2.3 cm of precipitation occurred, and

TABLE 4 Postemergence Crabgrass Control and Phytotoxic Effects of MSMA and Fenoxaprop

Herbicide	Rate (kg ai ha^{-1})	Applications: Interval (days)	Applications: No.	Phytotoxicity[a]: July 28	Phytotoxicity[a]: August 4	Crabgrass,[b] %: Cover	Crabgrass,[b] %: Control
MSMA	0.6	7	3	0.0a[c]	1.5c	13a	79
MSMA	1.1	7	3	1.0ab	3.8ef	<1a	99
MSMA	1.1	14	2	0.8ab	1.2bc	8a	88
MSMA	2.2	14	2	3.1b	3.2de	<1a	99
Fenoxaprop	0.09	14	2	0.0a	0.5ab	17a	73
Fenoxaprop	0.17	–	1	0.0a	0.2ab	46cd	26
Fenoxaprop	0.17	14	2	0.0a	0.2ab	16ab	74
Fenoxaprop	0.28	–	1	0.2a	0.2ab	17ab	73
Untreated control	–	–	–	0.0a	0.0a	62de	–

Note: Applications were initiated on July 21, 1983, when crabgrass was in the three- to six-tiller stage.

[a]Phytotoxicity was visually determined using a 0 to 5 scale: 0 = green, healthy turf; 3 = unacceptable discoloration; and 5 = brown turf.

[b]Crabgrass cover was visually rated on September 13, 1983.

[c]Means following the same letter in the same column are not significantly different at p = 0.05 level according to the Bayes LSD.

during July and August, the mean daily maximum temperature was 33°C. Despite irrigating the plot area 24 hr before herbicide application, it is believed that the stressful environmental conditions before and during the test period prevented effective uptake and translocation of fenoxaprop in the crabgrass. Watschke (8) also has observed a marked reduction in the efficacy of crabgrass control by fenoxaprop when applied under conditions of drought stress. These and other data (Table 3) therefore indicate that rates exceeding 0.28 kg ha^{-1} of fenoxaprop will be needed to effectively control mature crabgrass (i.e., three or more tillers), particularly during periods of high-temperature stress and limited rainfall.

Results of 1984 Test

Previous testing substantiated that sequential applications of MSMA (1.1 and 2.2 kg ha^{-1}) effectively controlled mature crabgrass, but fenoxaprop performed erratically (Tables 2-4). The objective of tests conducted in 1984 was to determine if a single application of MSMA and fenoxaprop in early summer would eliminate crabgrass for the remainder of the season.

A single application of MSMA (1.1 and 2.2 kg ha^{-1} on June 13 or 2.2 kg ha^{-1} on July 2 or 16) did not effectively control crabgrass (Table 1). However, the July 2 and 16 applications of fenoxaprop were extremely effective in eliminating crabgrass for the remainder of the growing season. When fenoxaprop was applied on June 13, the 0.20 kg ha^{-1} rate effectively controlled the existing crabgrass, although crabgrass plants were below the perennial ryegrass canopy. On August 24 it was observed that crabgrass in the plots treated with fenoxaprop (0.20 kg ha^{-1}) on June 13 generally possessed three to five tillers, whereas crabgrass plants in the untreated plots were in the eight- to ten-tiller stage (data not given). Hence, crabgrass developing in the plots treated at the 0.20 kg ha^{-1} rate germinated following the June 13 application, which resulted in what appeared to have been ineffective (62 percent) control (Table 1).

Fenoxaprop was also applied to an adjacent perennial ryegrass test area on August 7, 1984. At that time, crabgrass was in the three- to five-tiller stage. Crabgrass coverage was rated on September 11, 1984, and the 0.28 kg ha^{-1} rate provided 93 percent control; the 0.56 kg ha^{-1} rate provided 97 percent control (data not given). In past studies (Tables 2-4), however, late July applications of fenoxaprop failed to provide satisfactory crabgrass control. Late-season failures were attributed to drought hardening of crabgrass, which reduced herbicide effectiveness, particularly against mature crabgrass with three or more tillers. In 1984 environmental conditions in Maryland were less stressful; that is, there was a generally lower daytime temperature (mean maximum = 29.6°C) and above average rainfall in July (11.4 cm). Hence, it appears that environmental conditions, as they affect the vigor of crabgrass, will influence the performance of fenoxaprop in late summer.

SUMMARY

In summary, MSMA applied twice at 1.1 or 2.2 kg ha^{-1} on a 14-day interval provided effective control of mature crabgrass (i.e., three or more tillers), but may cause an unacceptable level of discoloration. However, a single application of MSMA (2.2 kg ha^{-1}) in early summer did not effectively control crabgrass. A single application of fenoxaprop provided erratic control when applied to mature crabgrass. When fenoxaprop was applied at 0.20 or 0.28 kg ha^{-1} in early summer, extremely effective control was achieved. Fenoxaprop may effectively control mature crabgrass at 0.28 or 0.56 kg ha^{-1}, but only when rainfall is not limiting and crabgrass is growing vigorously.

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A Vegetation Management Program for Alabama Highway Roadsides

EDWARD C. DIXON and RAY DICKENS

ABSTRACT

The Alabama Highway Department is engaged in the management of approximately 105,000 acres of roadside. Diverse ecology and temperate climate promote species diversity. Turf is composed of tall fescue, Pensacola bahiagrass, and bermudagrass. Weeds and brush caused up to five costly mechanical mowings a year. To alleviate short-term and costly mechanical controls a chemical-mechanical management approach was adopted. All of the 105,000 acres are mowed at least once and sprayed approximately two times. Broadcast herbicide treatments using single dormant applications of sulfometuron where bermudagrass is present and later site-specific applications of monosodium methanearsonate (MSMA), 2,4-D amine, diuron, and dicamba alone or in combination have been effective in controlling broadleaf and grassy weeds and in promoting bermudagrass release. This release program is the result of research in cooperation with Auburn University and has promoted 35,000 acres of monostand bermudagrass. Nonselective weed control on paving and structures is accomplished with applications of diuron, glyphosate, hexazinone, and sulfometuron as site-specific treatments alone or in tank-mix combination. Brush and woody species are controlled with 2,4-D amine dicamba combinations or glyphosate or fosamine. Application techniques have been updated to current state-of-the-art equipment. Intensive training, applicator certification, and literature and policy developments have increased the performance and effectiveness of personnel. Environmental safety and aesthetic end results are highly emphasized. These developments have been demonstrated to have tangible economic benefit by reallocating work loads and reducing mowing, resulting in projected savings of $1,500,000 per year.

As managers of the highway landscape, landscape engineers are increasingly confronted with complex and challenging issues. They are burdened and yet encouraged in this challenge by raised consciousness on environmental issues, economic- and resource-oriented maintenance activities, and ever-changing technology.

PHILOSOPHY

Some background of Alabama's program should preface any further discussion, which, for the most part, will be related to chemical vegetation management. General factors that have influenced the present roadside philosophy in Alabama include

1. Methods and materials employed in erosion control;
2. Interstate highway construction, which, by its nature, necessitated studies and standards for species selection for trees, shrubs, turf, and other vegetation; bifurcations and scenic corridors; and also mowing limits;
3. A state maintenance management system instituted in 1973; and
4. Budget limitations and related economic factors followed by the inclusion of a statewide herbicide program in 1977.

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BACKGROUND AND HISTORY

Alabama is a temperate state with a mean average temperature of 64°F and a mean average rainfall of 56 in. Soil types found in the state are predominantly coastal plains, piedmont plateau, prairie, limestone valley-uplands, and Appalachian plateau, so a diverse cross section of adapted and natural vegetation is present.

Historically and currently the state has used slash and loblolly seedling pine plantings and other forest plantings for slope-erosion control, and, to a lesser degree, adaptive hardwoods such as yellow poplar, oak, sycamore, willow, redbud, dogwood, maple, and sweetgum. Grasses include tall fescue, common and hybrid bermudagrass, and Pensacola bahiagrass. Legumes include reseeding crimson clover, Kobe lespedeza, crown vetch, and several others. Geographically, the extreme northern portion of the state is still largely planted in tall fescue; one-fourth to one-fifth of the southern portion of the state is planted in Pensacola bahiagrass--common bermudagrass combination turf. The remainder of the state is a mixture of Pensacola bahiagrass; common bermudagrass is the predominant species due to a highly successful release program.

Until the early 1970s, the Alabama Highway Department relied on extensive mowing and hand labor for control of vegetation along its roadsides. The economic crunch, along with the allure of such non-labor-resource-intensive control measures as herbicide treatments (until that time roadsides were mowed up to 4 to 5 times a year); mowing limit adjustments (increased natural succession areas); as well as pressures from kudzu, johnsongrass, and other noxious weed infestations, caused the department to take a new direction and philosophy toward vegetation management, which led to the current program.

ALABAMA'S CURRENT PROGRAM

The state of Alabama has 11,085 road miles of state and federal highways, of which, 866 road miles are Interstate highway. This mileage represents an approximate total of 105,000 acres of maintainable roadside. From a roadside maintenance point of view, the state currently budgets approximately two mowings or 48,280 acres on Interstate class roads and approximately one mowing or 100,870 acres on all other road classes. Broadcast herbicide treatment is accomplished at a total of 230,700 acres, or approximately two times the total maintainable acres.

Mowing is accomplished, if needed, in the late spring and early summer after wildflowers and clovers have seeded. Subsequent to a preemergent herbicide application, some mowing is preempted or delayed until fall.

Roadside vegetation 18 in. high in areas designated for mowing precipitates a mowing. Mowers are set to a minimum of 6 in. Current mowing limits are delineated as follows:

1. Undivided highways with 100-ft or less of right-of-way (ROW). In flat areas, mowing should be accomplished from pavement edge to right-of-way line.
2. Undivided highways with more than 100 ft of right-of-way and multilane divided highways. In flat areas, mowing should be accomplished 35 to 50 ft from the edge of the pavement or a greater distance where required to maintain a safe sight distance or to maintain a clean area around traffic signs beyond the normal limits. This mowing should follow the natural contours of the ground and should include all areas in which drainage is to be maintained.
3. Medians less than 80 ft wide should be entirely mowed, except for landscaped areas and plants set for purposes of screening headlight glare.
4. Median widths 80 ft or greater are to be mowed 35 to 50 ft from the edge of the pavement and in accordance with other roadside mowing standards (e.g., up to areas delineated for natural succession).
5. In developed urban areas next to residences or businesses, in rural areas next to cultivated farmland or scenic views, and at road intersections where sight distance is required, mowing should be accomplished from edge of pavement to the right-of-way line.
6. Areas within the ramps of diamond interchanges should be entirely mowed. The standard mowing width of 35 to 50 ft should be used for areas from outside of the ramps to the right-of-way line. Other interchanges are to be mowed in accordance with standard mowing limits.
7. On fill sections where guardrail exists, mowing should be accomplished a maximum of 15 ft, or one mower swath, beyond the guardrail if it can be done safely. Herbicides and chemicals will reduce the need for trimming under and around the guardrail.
8. On fill sections with slopes steeper than 3:1, without guardrail, mowing should be accomplished a maximum of 15 ft down the front slope from the shoulder edge.
9. On cut sections that have a slope deeper than 3:1, mowing should be accomplished from the edge of the pavement to a minimum of 10 ft up the back slope.
10. On all back slopes where Sericea lespedeza is planted, mowing should be accomplished a minimum of 10 ft.

Today Alabama's chemical vegetation management program centers on an aggressive bermudagrass release program using a dormant-season herbicide treatment. Other control areas are kudzu and brush control, crack and joint treatments, paved shoulder treatments, guardrail, posts and bridge structure treatments, and spot noxious weed control. The current herbicide program is outlined by season as follows:

I. January and February
  - A. Winter weed control in bermudagrass turf. (Recommended for roadsides with full bermudagrass coverage established at least 18 months. Do not shut off at guardrails.)
    1. Oust® (sulfometuron) @ 0.38 to 1.12 oz active ingredient (ai)/acre

II. March and April
  - A. Spot spray guardrails, posts, bridge abutments. (Do not use these treatments where the likelihood of erosion is present.)
    1. Diuron 80 W @ 4 lb ai/acre, or
    2. Roundup® (glyphosate) @ 3 lb ai/100 gal water (not for guardrail).
  - B. Longitudinal joints
    1. Velpar® L (hexazinone) @ 6 lb ai/acre
    2. Roundup® (glyphosate) @ 1.5 lb ai/acre, plus Oust® (sulfometuron) @ 3 oz ai/acre. (Use in 50 gal or less/acre carrier.)

III. Late May through September after mowing or dormant treatment
  - A. Broadcast treatment
    1. High-volume sprayers
      - a. Monosodium methanearsonate (MSMA) @ 2.25 to 3 lb ai/acre
      - b. Diuron 4L or diuron 80 W @ 1.2 to 1.6 lb ai/acre
      - c. 2,4-D amine @ 1.5 to 2 lb ai/acre
      - d. Banvel® 720 (1.9 ai 2,4-D amine + 1.0 lb ai dicamba/acre) @ 0.71 lb ai 2,4-D amine + 0.38 lb ai dicamba/acre to 0.95 lb ai 2,4-D amine + 0.5 lb ai dicamba/acre
      - e. Combination treatments
        MSMA @ 2.25 lb ai/acre + 2,4-D amine @ 1.5 lb ai/acre, or
        MSMA @ 2.25 lb ai/acre + diuron 4L @ 1.2 lb ai/acre, or
        MSMA @ 2.25 lb ai/acre + diuron 80 W @ 1.2 lb ai/acre, or
        MSMA @ 2.25 lb ai/acre + 2,4-D amine @ 0.71 lb ai/acre + dicamba @ 0.38 ai/acre
    2. Low-volume sprayers
      MSMA @ 1.5 lb ai to 2.25 lb ai/acre
  - B. Spot treatment of paved shoulders and longitudinal cracks
    1. Velpar® L (hexazinone) @ 4 to 5 lb ai/acre
    2. Roundup® (glyphosate) @ 3 lb ai/acre (for greater than 50 gal/acre volume), Roundup® (glyphosate) @ 1.5 lb ai/acre, plus 1 qt 90 percent ai nonionic surfactant/acre (for 50 gal or less application/acre)
  - C. Spot brush, kudzu, and structure (handgun)
    1. Banvel® 720 (1.9 lb ai 2,4-D amine + 1.0 ai lb dicamba/gal) @ 1.9 lb ai 2,4-D amine + 1.0 ai dicamba/100 gal mix

2. Roundup® (glyphosate) 6 lb ai/100 gal mix
D. Spot selective weed control (handgun)
1. MSMA @ 3.75 lb ai/100 gal mix
2. Banvel® 720 2,4-D amine @ 0.95 lb ai + dicamba @ 0.5 lb ai/100 gal mix
3. 2,4-D amine @ 3 lb ai/100 gal mix

IV. September, October, and Dormant Season
A. Foliar brush treatment
1. Banvel® 720 @ 1.9 lb ai 2,4-D amine + 1.0 lb ai dicamba/acre
2. Krenite® S (fosamine) @ 8 lb ai/100 gal mix (handgun)
B. Fresh cut stump treatment
1. Banvel® CST (dicamba @ 1.0 lb ai/gal) undiluted on fresh cut stumps
2. Banvel® 720 (1.9 lb ai 2,4-D amine + 1.0 lb ai dicamba/gal) diluted 50:50 with water on fresh cut stumps.

All herbicide solutions applied to Alabama highway roadsides contain a polyvinyl polymer drift control additive.

A nonionic superfactant is added wherever label instructions call for its inclusion in the mix or where additional herbicide activity is desired.

WARM-SEASON RELEASE

As a direct result of research in cooperation with Auburn University, the Alabama Highway Department has implemented a dormant and warm-growing-season grass release program.

As a result of this program, the department has progressed from essentially no acreages of monostand common bermudagrass to current acreages of 35,000 plus acres of this more desirable roadside species, as indicated by February-March broadcast herbicide treatments (see Figure 1).

Note that discussion of herbicides in this paper is not a recommendation for their use. If herbicides are handled, applied, or disposed of improperly, they can harm humans, domestic animals, desirable plants, pollinating insects, fish, and other wildlife, as well as contaminate water supplies. Herbicides should be used only when needed and should be handled with care. The directions should be carefully followed and all precautions on the container label should be heeded.

APPLICATION TECHNIQUES

In 1977 the Alabama Highway Department used high-pressure, high-volume handgun applicators as well as low-volume span-sprayers developed by Ring-Around

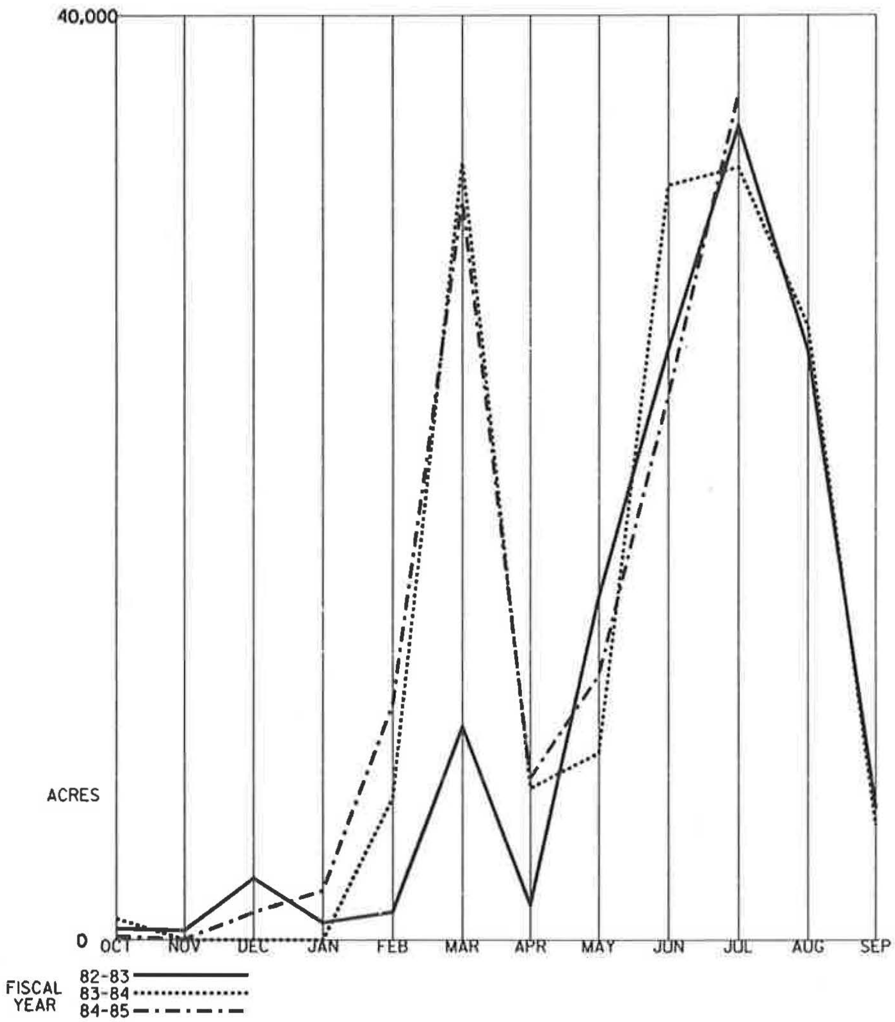

FIGURE 1 Comparison of broadcast herbicide treatment from FY 1982-1983 to FY 1984-1985.

Products. These applicators afforded a then up-to-date method of applying 2,4-D and MSMA, the principal building blocks of the vegetation management program. At that time, considerable problems were encountered with off-target damage when using 2,4-D in agricultural areas due to spray droplet size and adjacency to spray operations.

Today the Alabama Highway Department uses 28 high-volume boomless type trucks, some equipped with microprocessor computer injection as well as Dickey-John radar pressure-volume-speed controllers to ensure a more accurate application.

Tractor sprayers, equipped with Dickey-John controllers and conventional agricultural boom spray apparatus, are also used for off-road applications. High-volume handgun application is used for brush control and spot-weed control applications.

PROBLEMS

Although the use of Oust® (sulfometuron methyl) has figured heavily into the bermudagrass release program as a dormant-season treatment, its use has not been without problems. Several off-target movement claims and application on areas without proper bermudagrass cover has caused the department to use lower rates, move application dates back, and place heavier constraints on equipment and roadside composition requirements. These measures have been effective in alleviating this problem.

The department must constantly be aware of damage claims; at present, this problem has virtually been eliminated by (a) increasing spray droplet size (boomless type truck), (b) including drift-control agents in all spray mixes, (c) better educating the public, and (d) providing prompt and courteous relations and investigating complaints thoroughly. A close advisory relationship is maintained with the Alabama Department of Agriculture and Industries, which regulates pesticides and pesticide application and also investigates any alleged misapplication of products.

Environmental groups have opposed the program or have approached the department in an adversarial role. Their concerns are addressed by a firm statement of the facts and an explanation of the tangible benefits of the program.

TRAINING

The department trains more than 200 personnel yearly in the use of herbicides and about program requirements. The training takes place at nine locations throughout the state and lasts 6 to 8 hours. A yearly Roadside Vegetation Management Seminar is sponsored jointly by industry and the Alabama Highway Department.

Certification is stressed for every division and all district personnel associated with the program; currently 75 people statewide are certified. A comprehensive Roadside Manual as an improvement over current literature has been completed and has been used as a training and practice aid in implementing the policies and procedures of the vegetation management program.

RESEARCH AND SUPPORT

Auburn University, primarily the Department of Agronomy, is relied on heavily for continuing federal and jointly funded research projects, as well as extensive in-house research.

The vegetation management program affords the Alabama Highway Department the opportunity to evaluate new materials and equipment as they become available for testing and thus to develop information for decision making before being bombarded by vendors with high-pressure sales campaigns. This approach of screening new products in small-scale replicated

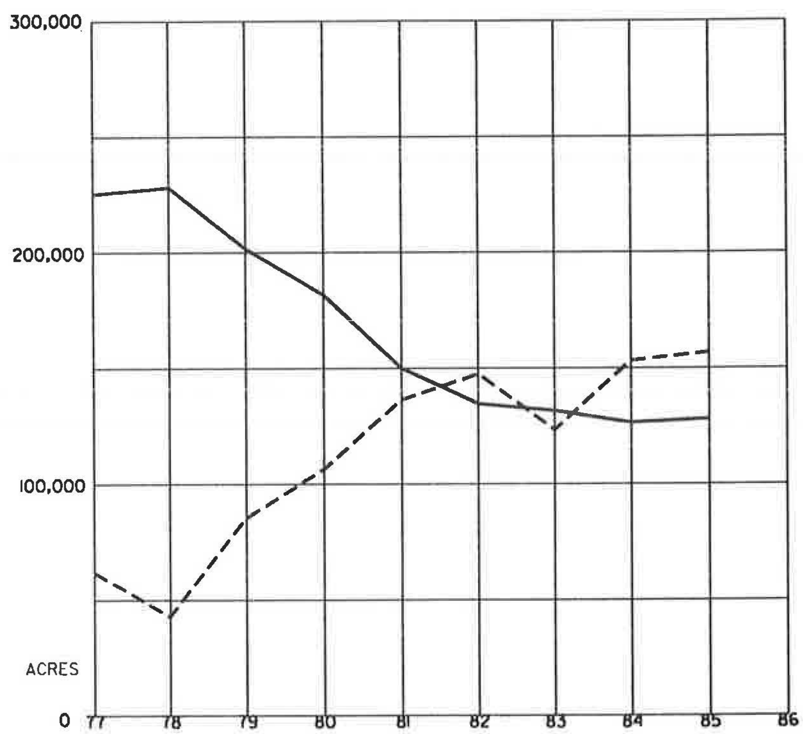

FIGURE 2 A comparison of mowing and broadcast herbicide treatment from FY 1976-1977 through FY 1984-1985.

studies as early in the development process as possible has allowed the department to avoid large-scale testing and statewide demonstrations of new products or techniques that have caused embarassing situations in the past. This policy of using only well-researched procedures and products in the vegetation management program has been of great help in developing public confidence in the department's ability to manage roadside vegetation in an economical and environmentally safe manner.

ECONOMICS AND PROGRAM EVALUATION

The overall accomplishment of integrating mowing and chemical treatments into vegetation management can be seen from Figure 2 and Table 1.

A breakdown of fiscal year 1983-1984 roadside maintenance activities shows a savings of $6.48 per acre by using a broadcast herbicide treatment (see Tables 2 and 3). Comparing the cost for spraying the 153,227 acres with the cost for mowing, an immediate saving of $992,910.95 is realized. Furthermore, if an additional mowing was assumed to be eliminated (it can be reasonably assumed), the overall savings would be $1,647,390.96. The inclusion of the winter weed control program has stabilized mowing costs somewhat, and even more savings could be extrapolated from that factor. In addition, by comparing Figures 1 and 3, a definite trend toward reallocation of workload distribution can be seen, which has had a positive effect and influence over other routine maintenance activities in that the labor force is not overwhelmed at what has historically been a very busy time of year for mechanical and chemical vegetation management.

TABLE 1 Mowing and Herbicide Costs and Accomplishment By Acre from Fiscal Year 1975-1976 Through Fiscal Year 1984-1985

	Mowing		Spraying	
	Acres	Cost/Acre ($)	Acres	Cost/Acre ($)
1984-1985	128,075	17.72	156,750	9.89
1983-1984	126,475	16.84	153,228	10.46
1982-1983	131,688	12.37	123,311	11.24
1981-1982	134,707	16.87	147,490	12.09
1980-1981	150,005	17.96	136,420	14.82
1979-1980	181,693	13.43	106,472	12.78
1978-1979	201,747	13.48	85,403	9.72
1977-1978	228,061	12.11	42,796	22.05
1976-1977	225,328	11.42	61,831	11.63
1975-1976	251,992	10.60	48,000 (estimated)	18.00 (estimated)

Note: Inventory = 103,493 acres.

TABLE 2 Alabama Highway Department Roadside Maintenance Activities, 1983-1984

Activity	Accomplishment	Unit Cost ($)
All roads combined		
625 mowing	126,475 acres	16.84
626 herbicide (broadcast)	153,227 acres	10.46
627 brush and tree cutting	90,542 man-hours	9.70
629 spot litter pick up	51,266 man-hours	10.81
630 full litter pick up	3,615 passenger miles	46.98
631 spot herbicide	799,624 gal	0.51
634 other roadside maintenance	35,560 man-hours	17.53
Interstate		
625 mowing	40,315 acres	15.97
626 herbicide (broadcast)	21,344 acres	8.33
627 brush and tree cutting	22,089 man-hours	18.89
629 spot litter pick up	16,622 man-hours	10.04
630 full litter pick up	1,998 passenger miles	38.84
631 spot herbicide	183,206 gal	0.55
634 other roadside maintenance	10,568 man-hours	18.77
Other state roads		
625 mowing	86,160 acres	17.24
626 herbicide (broadcast)	131,883 acres	10.80
627 brush and tree cutting	68,453 man-hours	10.12
629 spot litter pick up	34,644 man-hours	11.18
630 full litter pick up	1,617 passenger miles	57.05
631 spot herbicide	616,417 gal	0.49
634 other roadside maintenance	24,992 man-hours	17.01

TABLE 3 Alabama Highway Department Roadside Maintenance Activities for 1983-1984, Breakdown by Percent

Activity	Labor (%)	Equipment (%)	Material (%)	Miscellaneous (%)	Total Cost ($)
625 mowing	38.75	60	1	0.25	2,130,119
626 herbicide	12.60	15	72	0.40	2,603,980

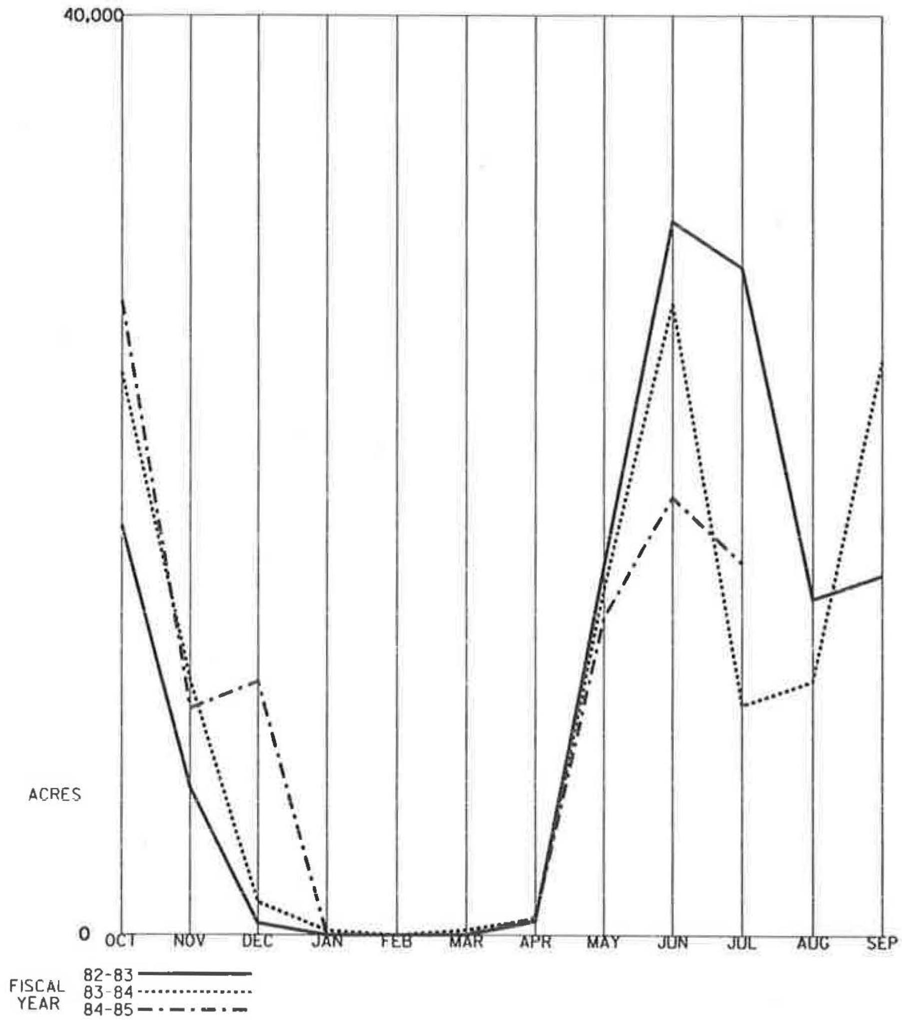

FIGURE 3 Comparison of mowing from FY 1982-1983 to FY 1984-1985.

CONCLUSION

The integration of properly timed and well-planned mowing and herbicide application as elements of an overall vegetation management plan has provided the following tangible benefits to Alabama highway roadsides:

1. Release of bermudagrass, a desirable low-growing turf species that is functionally safer, aesthetically pleasing, and economical to maintain;
2. A lower total dollar expenditure for roadside maintenance at a higher level of service;
3. Workload reallocation, making for more balanced activity accomplishment;
4. More lasting elimination or control of undesirable species;
5. Ultimately a safer and more pleasant highway system owing to the elimination of certain weed pests while maintaining an environmentally and economically sound vegetation management program; and
6. Development of noncritical roadside maintenance, allowing for selective clearing, natural succession, and scenic woodland areas.

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Publication of this paper sponsored by Committee on Roadside Maintenance.

Roadside Vegetation Management in Idaho

J. E. RINARD

ABSTRACT

The objective of roadside vegetation maintenance on Idaho's highways is to provide "a low-growing grass on the shoulder-foreslope areas and a mix of taller grasses, forbs, flowers, shrubs or trees beyond the shoulder to the right-of-way boundary." To accomplish this, vegetation establishment work is classified as landscape or functional. Landscape projects are classified as high, medium, or low level with regard to maintenance costs and are planned and maintained accordingly. Functional revegetation projects, which make up the major roadside effort in Idaho, are planned according to four climatic zones, using eight different grasses and three legumes, plus natives and additional grass varieties for problem areas. Maintenance of the functional projects is carried out through five phases from early spring to late fall and involves the coordination of spraying, blading, mowing, brush clearing, reseeding-planting, and fertilization. This program, intended to hold maintenance costs at the lowest possible level and comply with state weed laws, has resulted in an overall cost reduction in functional roadside maintenance of nearly 21 percent during the last 3 years.

Vegetation on roadsides is beneficial in controlling erosion, dust, and sedimentation. It limits the spread of undesirable weeds, while providing valuable cover for wildlife. It also creates a visual experience that tends to reduce accidents caused by driver fatigue. The policy of the Idaho Division of Highways is to promote the growth and control of as much native and other adaptable vegetation on roadsides as is compatible with safe highway use, attractive appearance, and minimum maintenance.

The objective of Idaho's roadside vegetation program is to have vegetation growing on all roadside areas where its presence is suitable. This is provided by "a low-growing grass on the shoulder-foreslope areas and a mix of taller grasses, forbs, flowers, shrubs, or trees beyond the shoulder to the right-of-way boundary." The intent is to remove undesirable vegetation (noxious weeds and excessive growers) in such a manner that there is no regrowth and at the same time assist desirable vegetation to become established and to remain vigorous. When undesirable vegetation is removed, either mechanically or chemically, the ground will not remain bare, but will reestablish with whatever species is at hand, whether good or bad. Because of this, the job is not complete until desirable vegetation is established.

The achievement of the roadside vegetation objective requires control and coordination of such activities as spraying, blading, mowing, brush clearing, reseeding-planting, and fertilization. This program is intended to hold maintenance costs at the lowest possible level and provide compliance with Idaho noxious-weed laws.

CLASSIFICATIONS

Seeding and planting can be classified into two types: landscape and functional. Landscape is primarily for beautification; however, it has some aspects of functional. Although functional is primarily for the stability and integrity of the roadway, it has some aspects of landscape. With this in mind, Idaho has developed a multifaceted system that has proven beneficial in the planning, design, construction, and maintenance of the vegetation phases of highway projects.

In Idaho seeding and planting programs generally include only two alternatives: use of the standard dry-land seed mix or use of lawn grass seed and fully irrigate. Often the dry-land seedings are not successful and result in a poor quality turf with related undesirable weeds. Lawn grass turf seedings, although of good quality, are costly to establish and require a high degree of costly maintenance. The two primary grasses used in Idaho are sodar wheatgrass and durar hard fescue, which, if properly used, provide additional levels of turf quality to consider.

These two grasses, if planted on the proper sites as shown in the seeding guide, will do an excellent job. They will respond to irrigation water and will provide a more dense cover as the amount of water is increased. Care should be taken to avoid over-irrigation because this will cause bluegrass to invade the sodar and fescue. Proper use of these grasses provides a desirable flexibility.

It should be recognized that the extent to which cities or other agencies will, or can, go in providing proper care and maintenance of roadside areas is not always known; however, use of this plan allows the Idaho Division of Highways to determine a safe level and allows some flexibility, either up or down, should desires or capabilities change in future years. It is important that the agencies concerned determine the level of turf quality that is suitable and that they have good prospects for proper maintenance. This requires thorough discussion with the city, county, or others who may have responsibility for maintenance so that they will fully understand the alternatives and agree on the proposal.

Landscape

The landscape classification is subdivided into high, medium, and low levels with regard to maintenance costs. The use of native plants becomes more important in designing the lower landscape levels and

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functional revegetation projects. Listed in the order of decreasing cost, the following levels, if understood and used, allow the division to satisfy most needs as required based on desires and construction and maintenance resources.

High-Level Maintenance

High-level maintenance normally involves the seeding of a good lawn grass (usually bluegrass); installing a complete, permanent irrigation system (irrigation interval 1 to 2 weeks); frequent mowing (1- to 2-week intervals); and planting suitable flowers, shrubs, ground cover, and trees as desired. This level provides the designer the greatest flexibility in formal planning and choice of planting materials; however, construction costs are much higher and maintenance costs remain high with little flexibility over the years. At this level, cumulative maintenance costs should be expected to equal construction costs in 6 to 10 years (1).

Medium-Level Maintenance

Medium-level maintenance is based on the seeding of the proper primary grass; installing a permanent, minimal irrigation system (irrigation interval 2 weeks to 1 month); more frequent mowing (2-week to 1-month intervals); and native dry-land shrubs and trees as desired. This level provides the widest range of flexibility in maintenance costs. Irrigation could vary from as little as once per month to a maximum of every 2 weeks and still maintain a reasonable condition. A fairly wide selection of flowers, shrubs or trees is permitted and mowing requirements would be related to irrigation. Should the irrigation water become unavailable, the turf will not be lost, but will survive and respond when water becomes available again. Should overirrigation of the primary grass turf occur more often than 2-week intervals, blue grass would be expected to invade. At this level the cumulative maintenance costs should be expected to equal the construction costs in 10 to 15 years (1).

SOUTHERN IDAHO TYPE SITES

Mix No. 1 8-12 in. Mean Annual Precipitation (MAP)	Bulk Seed Per Acre, lb
Grasses	
Sodar streambank W.G. (AGRI)	9
Siberian W.G. (AGSI)	3
Fairway crested (AGCR)	2
Legume	
Madrid clover (MEOF)	1
Natives	
To be determined	3
Total	18
Mix No. 2 10-17 in. MAP	
Grasses	
Sodar streambank W.G. (AGRI)	9
Topar pubescent W.G. (AGTR2)	6
Fairway crested (AGCR)	2
Legume	
Ladak alfalfa (MESAL)	1
Natives	
To be determined	3
Total	21

NORTHERN IDAHO TYPE SITES

Mix No. 1 15-22 in. MAP	
Grasses	
Durar hard fescue (FEOVD)	7
Tegmar dwarf intermediate W.G. (AGINI)	6
Manchar smooth brome (BRIN)	3
Legume	
Ladak alfalfa (MESAL)	1
Natives	
To be determined	3
Total	20
Mix No. 2 20-in. MAP	
Grasses	
Durar hard fescue (FEOVD)	7
Meadow foxtail (ALPR)	4
Manchar smooth brome (BRIN)	3
Legume	
White dutch clover (TRRE)	1
Natives	
To be determined	3
Total	18

Note: Symbols for identification taken from U.S.F.S. "Intermountain Range Plant Symbols," 1977 and S.C.S. "Idaho Plant List," 1976.

FIGURE 1 Seeding guide.

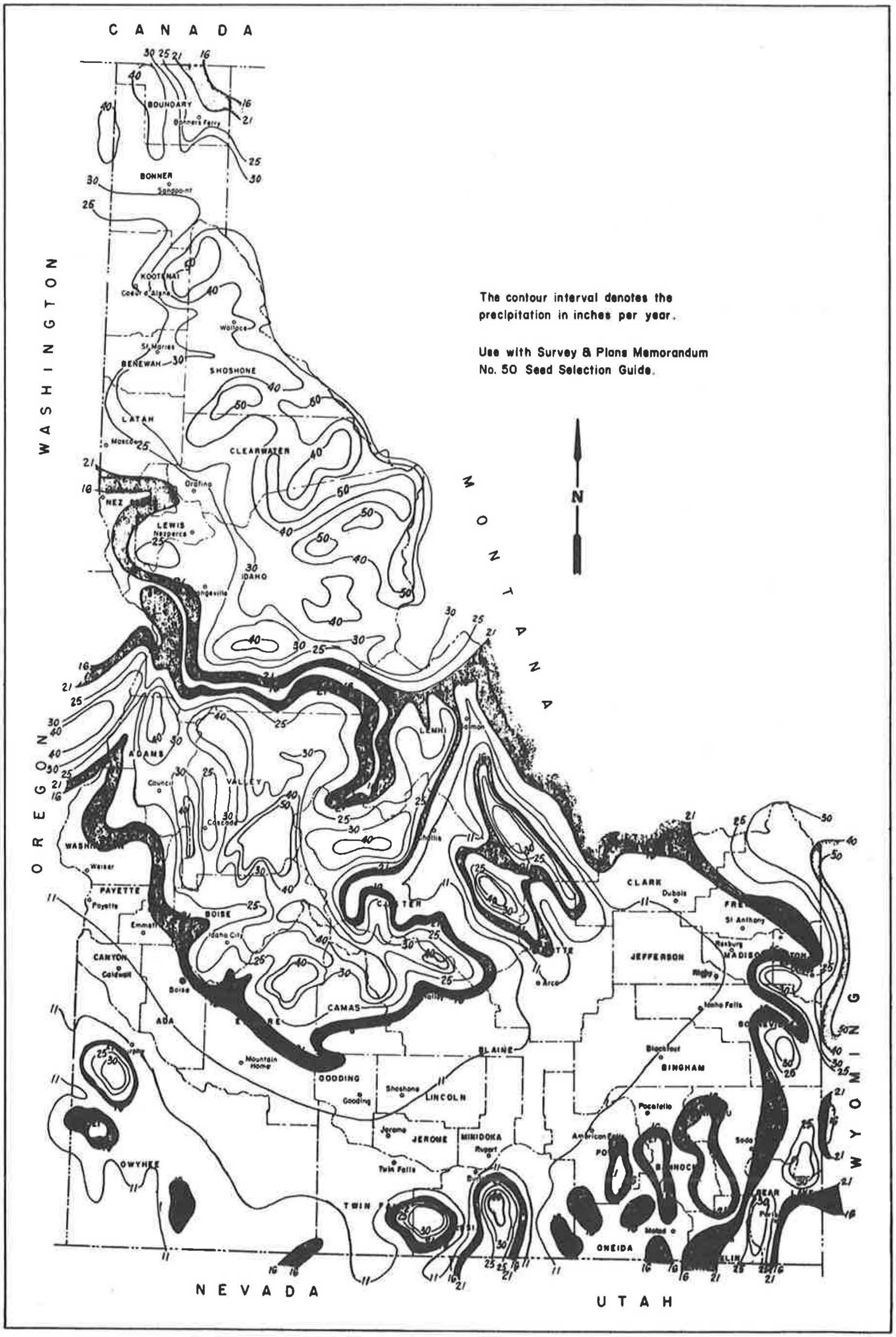

FIGURE 2 Seeding site map.

Low-Level Maintenance

The lowest level of maintenance is based on seeding the proper primary grass, along with the optional use of suitable amounts and combinations of establishment water; native (dry-land) flower, shrub, and tree seed; native flower, shrub, and tree plants; and mowing.

Seeding with normal dry-land seeding methods is, of course, the lowest cost method; however, several years are usually required for a satisfactory level of growth to be developed. In view of this, it is desirable to use establishment irrigation water wherever feasible to obtain a thicker turf in a much shorter time.

Native flower, shrub, or tree seed may be included and is particularly desirable on steep slopes. This may be followed 2 or 3 years later by planting native seedlings to supplement the direct seeding. Should mowing be desired, there would be no need for the natives. In some locations, mowing could be planned for only part of the area, ideally the flatter portions. At this level of beautification, one mowing fairly late in the summer should be sufficient. Early or more frequent mowing would tend to weaken the turf.

With low-level maintenance, the cumulative maintenance costs should be expected to equal the construction costs in 20 to 35 years (1).

A variation that might be used on the two lower levels is installation of a partial irrigation system that would provide water to selected shrubs or trees. This gives a much wider choice of shrubs or trees, or both, and yet leaves maintenance of the larger turf area on the lower cost level.

Functional

Next to low-level landscaping is functional seeding and planting. This area of functional seeding and planting is where the greatest effort is expended in Idaho.

Idaho has 64,000 linear miles of roads that service an area of 83,557 square miles, and the state highway system includes 5,000 miles of the total. State highways are found at elevations ranging from 738 to 8,701 ft above sea level, in moisture zones that range from less than 8 in. of precipitation annually to more than 50 in. The climatic diversity of the state by itself makes functional vegetation management on roadsides a challenging task. In addition, the Idaho Division of Highways has to deal with problems related to steep, rocky, disturbed areas, usually a result of highway construction.

For the functional seedlings, the state has been divided into four zones, and the seed mixes are matched with the moisture and conditions of each zone (see Figures 1 and 2). Eight different grasses and three legumes are used, and native seeds of trees, shrubs, and forbs are included where the opportunity exists for success and where their presence is suit- able. Additional grass varieties are available for use in problem areas of sand or alkali soils.

In the drier areas (southern Idaho) sodar streambank wheatgrass is the primary grass, whereas durar hard fescue is the primary grass in northern Idaho or areas that have more than 15 in. of annual precipitation. Shoulder-foreslope grass mixes are still being developed with particular interest in short-stemmed, low-growing fire-resistance traits, and grasses that are sod formers as opposed to bunch grasses.

The primary goal is to plant the "right grasses in the right places" along roadsides. When right-of-way seedings were first seriously considered in about 1952, the author was working for the Soil Conservation Service (SCS), and part of the work was to assist the state highways with seedings. At that time, the soil conservation districts furnished seeding equipment; the SCS provided a substantial amount of seed and went right out on the roadsides and did the job. Looking back at the old letters and records concerning these efforts, it is easy to see that little was known then about selecting the right grass for the right place on the right-of-way. The objective was to get something to grow, anything, anywhere. Today a good roadside professional knows his grasses like an artist knows his paints, and he can use them in somewhat the same manner. A stage of knowledge in the use of native flower and shrub seeds has now been reached, similar to that in the use of grasses 30 years ago.

THE IDAHO PROGRAM

The Idaho Roadside Vegetation Maintenance Program involves five phases through the season, beginning immediately following snow melt in March and April and carrying through to freeze-up in November and December. The five phases are early spring, late spring, summer, early fall, and late fall. These phases are rotated over a 3-year cycle so that the roadsides are completely treated once every 3 years. One-third of the roadsides are fully treated each year. All are partially treated each year. Herbicides are heavily relied on but the job is considered only half done when the spraying is completed.

During early spring, roadsides are seeded, planted, and fertilized. Late spring is the first spray phase with herbicides, primarily Tordon® 101, with solid spraying of the shoulder foreslopes. The summer phase involves primarily the use of 2,4-D, and in the late fall phase Tordon® 22K is used. Limited sterilizing is, as suitable, done during either spring or fall. In the late fall phase, seeding, planting, and fertilizing is again done in those areas suitable for fall operations.

Another treatment introduced during the last 3 years in the early spring phase is the use of herbicides, such as Oust® and Telar®, and growth retardants, primarily Embark®. Of course, if all the right grass were in the right places there would be no need for concern about this, but that goal will not be reached for many years. Too many roadsides are already seeded with the wrong grass in the wrong places.

During the past 3 years this maintenance program has reduced mowing costs and shoulder pulling costs by 50 percent. Elimination of excess shoulder sterilization has also reduced costs. At the same time the costs of the herbicide treatment has increased, however. An overall reduction of nearly 21 percent has occurred in roadside maintenance costs (2).

REFERENCES

1. Idaho Surveys and Plans Manual, Section 14-760. Idaho Department of Transportation, Boise (undated).
2. Idaho Transportation Resource Management Systems (TRMS) Reports. Idaho Department of Transportation, Boise, 1982, 1983, 1984.

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Chemical Mowing in Indiana: Three Years Of Success

JOHN P. BURKHARDT and D. JAMES MORRÉ

ABSTRACT

Currently the Indiana Department of Highways is responsible for vegetation management on about 100,000 acres of roadside that receives at least one full cycle of mowing and includes other areas, such as medians and corridors adjacent to traffic lanes, that are mowed twice or three times. Both force-account and contract means are used at a total cost of $3,250,000/year. As an alternative to mechanical mowing, a program of chemical mowing was implemented for the state of Indiana in 1983 with 3 consecutive years of success with use on Interstate and dual-lane roads. Using a combination of primary growth retardant, cost-reducing additive, surfactant (detergent) to enhance penetration and primary broadleaf herbicide, a single spray application in the spring controls weeds, prevents seedhead formation, and retards growth of grass blades so that no further spraying or mechanical mowing is required for full-season vegetation management. By employing cost-saving combinations of material, costs are equal to or slightly higher than the per acre cost of a single mowing cycle. This program was designed primarily for use on tall fescue-bluegrass mixed turf and resulted in both seedhead suppression and weed control in excess of 90 percent. Those few seedheads that do form are short and do not appear unsightly. Weeds that remain are largely resistant perennials (common milkweed, Canada thistle, and horse nettle) and late-germinating annuals (black medic, upright spurge, common ragweed, wild lettuce, and various foxtails). Grass heights at the end of the growing season remain well within the standards (12 to 18 in.) of the state of Indiana to eliminate any need for mechanical mowing.

Current safety and esthetic standards require that roadsides be mowed. In Indiana, costs are between $20 and $25/acre for one mowing cycle; one to three cycles are required per growing season to establish and maintain adequate sight distances and visual appearances of tall fescue-bluegrass mixed stands.

On the basis of research initiated in 1977 at Purdue University (1), a program of chemical mowing was initiated in the state of Indiana in 1983 as an alternative to mechanical mowing (2-3). The requirements were for a single spray application, effective in preventing growth and seedhead formation in bluegrass and fescue. There should be no damage to roots or weakening of turf and no carryover that would limit repeated use on an annual basis. The treatment should be environmentally safe and should control the majority of turf weed species. In addition, the treatment must be cost effective. These various criteria have been met by employing a combination of materials that, when applied together, yield cost effective, full-season vegetation management.

PROGRAM DESCRIPTION

The general guidelines for Indiana's current program of chemical mowing are discussed in the following sections. The components of the spray mixture are given in Table 1. No component should be eliminated or changed in rate of application without anticipation of a reduction in treatment effectiveness.

Spray Mixture

The rates for the mixture (as product) are as follows: 1 pt of Embark 2S plant growth regulator (as mefluidide) + 1/4 oz Telar (as chlorsulfuron) + 1/2 gal 2,4-D amine (4 lb acid equivalent per gal) + 0.1 gal X-77 nonionic surfactant (detergent) equivalent to 0.25 percent of the final solution + 40 gal of water. This mixture is applied to one acre.

Time of Application

Dates of application are generally between April 1 and May 10 shortly after spring green-up and before seedhead emergence. The mefluidide and chlorsulfuron combination is fast acting, and generally grass growth can be expected to be stopped at the time of application. Blade growth may resume at a later time but seed stalk growth will not.

Area of Treatment

Application may be fence-to-fence including interchanges or corner cuts, or both, at public road intersections. Variability in results may be expected if applied by off-road equipment because of differences in speed of equipment in traveling rolling terrain. Satisfactory results may be expected with truck-mounted sprayers operated on pavement or shoulders. Full median and 18-ft wide shoulder sections may be treated in this manner because of uniform operating speeds of the spray trucks. This spray area conforms to the standards for limited-width mowing in Indiana.

Application Methods

Although the rate for application can be varied by a factor of two without total loss of effectiveness or permanent injury to the turf, it is essential that the mixture be applied as evenly as possible to

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TABLE 1 Component of Treatment Mixture

Component	Generic Name	Trade Name	Application Rate/Acre (ai)	Amount Per 40-gal Spray Solution	Function in Mixture
Primary retardant	Mefluidide	Embark	1/4 lb	1 pt	Prevents seedhead formation in fescue and slows blade growth of grasses
Additive	Chlorsulfuron	Telar	0.1875 oz	1/4 oz	Reduces mefluidide requirements by 50 percent through synergistic interaction; enhances weed control on 2,4-D resistant species, that is, wild carrot
Surfactant	X-77 (or equivalent)			0.1 gal	Enhances penetration of primary retardant and herbicide
Primary herbicide	2,4-D		2 lb	0.5 gal	Wide spectrum control of broad leaf weeds

TABLE 2 Results of 1983 Application

Date of Application	Amount/Acre (ai) Embark (lb)	Surfactant[a] (%)	Telar (oz)	2,4-D (lb)	Fescue Seedheads Number per ft^2	Height (in.)	Weeds per 100 ft^{2}[b]	Cost per Acre[c] ($)
March 18	-	-	-	-	12	47	160	-
	0.50	0.25	-	2	3	31	25	21.70
	0.25	0.25	0.1875	2	2	29	25	16.70
May 3	-	-	-	-	17	46	124	
May 4	0.50	0.25	-	2	5	5	10	
	0.25	0.25	0.1875	2	1	22	10	
May 9	-	-	-	-	17	46	64	
	0.50	0.25	-	2	7	24	2	
	0.25	0.25	0.1875	2	0	14	0	

Note: Detailed is the effect of mefluidide in combination with surfactant and 2,4-D as influenced by addition of chlorsulfuron at early and late dates of application.

[a]In 1983 several different surfactants were evaluated and X-77 was selected for continued use in the program.

[b]Exclusive of common milkweed.

[c]Based on Embark $32/lb; surfactant $10/gal; Telar $12/oz; 2,4-D $1.60/lb.

achieve uniform seedhead suppression and to obtain the desired control of weeds. Excellent results have been obtained in Indiana using the basic Swinglok® sprayer with computer-controlled injection system.

Treatment effectiveness may be diminished by rainfall within the first 8 hr of application, but results are generally satisfactory under a wide range of weather conditions. To be effective, the material must be delivered to the target area at the prescribed rate of application.

Application Cost

In the 1985 application on the 700-acre test area west of Indianapolis on I-70, costs averaged $27.14/acre; the total cost for application was $19,000. Of this total, $7,000 was for chemicals and $12,000 was for application. It should be noted that the major part of the application cost, with the exception of two 500-gal Swinglok® sprayers and operators, was for dump trucks with trailer-mounted arrow boards and operators that followed the spray trucks for safety. On outside shoulders one truck and arrow board followed, and on median shoulders two trucks with arrow boards followed each unit. These safety precautions are standard for four-lane divided highways in Indiana. Other states may have standards that may increase or decrease application costs.

Even with these safety precautions, and considering the relatively low traffic volume in April, there were several near misses involving commerical trucks running side by side, with both the trailing Indiana Department of Highways (IDOH) employee or a commercial driver using the median to avoid collision.

OBSERVATIONS

The first practical growth retardant mixture that was both effective and equivalent in cost to one-cycle mowing was one in which the herbicide Telar (chlorsulfuron) was included to reduce the amount of the primary retardant Embark (mefluidide) to an affordable application rate (Table 2). Results in 1983 demonstrated that the less expensive mixture of 0.25 lb/acre active ingredient (ai) mefluidide + 0.1875 oz/acre ai chlorsulfuron was as effective as 0.5 lb/acre ai of mefluidide alone in the mixture with 2,4-D and surfactant.

The early application on March 28 was not as effective as later applications. Both seedhead and weed control were near 90 percent with mid-season and late applications (see Figure 1). In 1984 the mixture was applied to a 67-mi, 700-acre segment of Interstate with satisfactory results (Figure 2). Seedhead control in both fescue and bluegrass was excellent (Table 3), and weed control also was

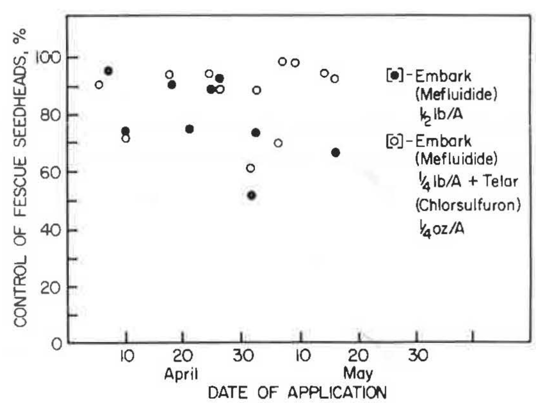

FIGURE 1 Percent control of fescue seedheads as a function of application date for Embark (·) and Embark + Telar (○) in combination with 2,4-D and surfactant. Tall fescue seedheads emerge from about May 15 to May 25 in central Indiana.

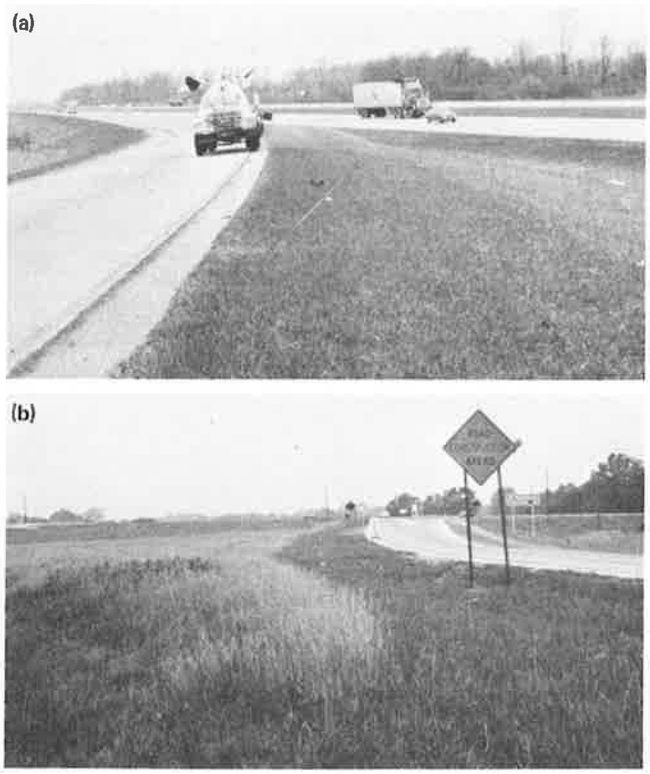

FIGURE (a) April 1984 application adjacent to an Interstate ramp section using Swinglok® sprayer. (b) Results on June 15, 1984, showing seedhead control in the strip next to the ramp using the standard chemical mowing mixture. The interior area of the interchange is untreated.

satisfactory (Table 4). A similar implementation trial was conducted in 1985 in comparison with lowered rates of mefluidide and chlorsulfuron (Table 5). As in 1983 and 1984 the mixture of 0.25 lb/acre ai mefluidide + 0.1875 oz/acre ai of chlorsulfuron provided excellent control of grass seedhead and weeds. The lower rate of application, 0.125 lb/acre ai mefluidide + 0.0937 oz/acre ai chlorsulfuron in combination with 2,4-D and detergent, also provided satisfactory results although suppression of seedhead formation under these conditions was incomplete.

The treatment of 0.25 lb/acre ai mefluidide + 0.1895 oz/acre ai chlorsulfuron in combination with detergent and 2 lb/acre ai 2,4-d did not significantly reduce root development in turf species and has shown no deleterious effects with annual applications to the same area (7 years with mefluidide alone, 3 years with mefluidide and chlorsulfuron). Some slight discoloration of grass blade may occur early but it soon disappears. In mid-summer and fall, the treated areas appear lush and green with a visual appearance equal or superior to comparable areas mowed once.

On secondary highways, where smooth brome is a dominant species, or where roadside infestations of tall, late-germinating annual weeds (giant foxtail, ragweed, and wild lettuce) are a problem, the mefluidide + chlorsulfuron + 2,4-D + surfactant mixture is not satisfactory. The treatment does not suppress formation of seedheads with smooth brome, and the tall, late-germinating annuals become unsightly late in the growing season. New combinations of materials are under development in the research phase of the project to overcome these problems to permit extension of chemical mowing to all secondary highways.

DISCUSSION OF IDOH PROGRAM

The main objective of any roadside maintenance supervisor must be to provide a zone of safety adjacent to the traveled way. This may involve good sight distance, a clear zone free of obstructions, and a clear path for water to follow in draining off of the pavement. Traditionally this was accomplished through mowing. The advent of improved herbicides has permitted the manager to reduce the amount of expensive mechanical mowing by reduction or elimination of weeds and brush (3). The more recent development of plant growth retardants adds another tool for the roadside manager to permit choices not previously available.

Perhaps the key words here are tool and choice. In the management of roadsides the roadside maintenance supervisor should never lose sight of the objectives noted earlier and therefore should not permit programs to be all mechanical mowing or all chemicals, or now all plant growth regulators. Each manager must assess the needs, budgets, abilities, and competencies of the parent organization and then apply the proper method of control to the determined need.

Obviously needs vary state by state and by other governmental agencies. Size of budget, adjacent land

TABLE 3 Evaluation of a Spring Application

	Fescue[a]			Bluegrass[a]		
	Seedheads			Seedheads		
	Number per ft^2	Height (in.)	Blade Height (in.)	Number per ft^2	Height (in.)	Blade Height (in.)
Median						
Unsprayed	17 ± 1	39 ± 2	15 ± 4	12 ± 4	21 ± 1	13 ± 2
Sprayed	2 ± 3	20 ± 5	14 ± 3	2 ± 1	13 ± 3	10 ± 2
Control, %	90			83		
Pavement to ditch						
Unsprayed	15 ± 3	37 ± 2	18 ± 3	7 ± 2	21 ± 1	14 ± 2
Sprayed	1.6 ± 1	24 ± 2	14 ± 2	0.7 ± 0.6	14 ± 2	11 ± 1
Control, %	90			90		

Note: Application consisted of 1/4 lb/A mefluidide + 1/4 oz/A chlorsulfuron + 2 lb/A 2,4-D amine + 0.25 percent X-77 surfactant (by volume of total spray mixture) (25 gpa Swinglok Sprayer®), Indiana Department of Highways on I-70 east of US 231. Application was on April 18, 1984. Evaluations were on August 24, 1984, 4 months after application.

[a]Based on measurements from four different locations selected at random. Heights are average maximum heights in inches from 10 to 20 plants per location ± standard deviation among different locations. Rates are of active ingredients. Initial height of bluegrass is 3.5-4 in. Initial height of fescue 6 to 7 in. Blade height is measured in inches for fully extended leaf blades.

TABLE 4 Control of Weeds by a Spring Application

	Weed/1,000 ft^2											
	Ragweed	White Top	Wild Carrot	Lespedeza	Common Spurge	Milkweed	Wild Lettuce	Clover Sweet	Red	Black Medic	Aster	Total[a]
Median												
Unsprayed	43	67	0	204	30	18	0	27	0	0	2	391
Sprayed	11	0	0	12	0	1	0	0	5	1	0	30
Control, %												92
Pavement to ditch												
Unsprayed	63	9	0	182	54	87[b]	4	57	0	0	12	468
Sprayed	21	0	2	18	11	0	1	3	0	6	0	62
Control, %												87

Note: Application consisted of 1/4 lb/A mefluidide + 1/4 oz/A chlorsulfuron + 2 lb/A 2,4-D amine + 0.25 percent X-77 surfactant (by volume of total spray mixture) (25 gpa Swinglok Sprayer®), Indiana Department of Highways on I-70 east of US 231. Applied April 18, 1984. Evaluations were on August 24, 1984.

[a]Sum of all weeds counted in three different locations. The area was not especially weedy, averaging 18,600 weeds per acre. The treatment reduced the weed population to about 2,000 weeds per acre equivalent to 90 percent control of all species.

[b]Includes 85 whorled milkweed.

TABLE 5 Evaluation of a Spring Application

	Fescue[a]			Bluegrass[a]		
	Seedheads			Seedheads		
	Number per ft^2	Height (in.)	Blade Height (in.)	Number per ft^2	Height (in.)	Blade Height (in.)
Median						
Unsprayed	13 ± 1	33 ± 3	13 ± 1	10 ± 4	14 ± 2	9 ± 2
Sprayed						
Schedule B	1 ± 1	10 ± 5	11 ± 2	1 ± 1	8 ± 3	10 ± 1
Control, %	92			90		
Schedule C	1 ± 1	11 ± 1	11 ± 2	4 ± 3	7 ± 2	11 ± 2
Control, %	92			60		
Pavement to dtich						
Unsprayed	11 ± 2	35 ± 2	18 ± 2	12 ± 3	18 ± 3	15 ± 1
Sprayed						
Schedule B	1 ± 1	10 ± 2	10 ± 2	1 ± 1	8 ± 2	10 ± 2
Control, %	91			92		
Schedule C	1 ± 0	11 ± 1	10 ± 2	3 ± 2	6 ± 2	10 ± 1
Control, %	91			75		

Note: Application consisted of 1/4 lb/A mefluidide + 1/4 oz/A chlorsulfuron + 2 lb/A 2,4-D amine + 0.25 percent (by volume of total spray mixture) = Schedule B with 1/8 lb/A mefluidide + 1/8 oz/A chlorsulfuron + 2 lb/A 2,4-D amine + 0.25 percent X-77 surfactant (by volume of total spray mixture) = Schedule C. Application was in late April 1985, evaluation was on July 26, 1985.

[a]Method of measurement same as in Table 3. Heights are average maximum heights in inches ± standard deviation among different locations. Rates are of active ingredient. Weed control was estimated at 93 percent based on actual counts.

uses, and environmental regulations all have an effect in the determination of a program. The program of the Indiana Department of Highways should apply to any roadside vegetation management program so long as the predominant roadside grasses are tall fescue and bluegrass.

The application of this information may be from full elimination of mowing to spot treatment in order to eliminate expensive hand trimming of sign-posts and guardrails. Perhaps the most promising use, from the standpoint of safety, may be the elimination of seedheads in areas where sight distance is critical such as at-grade intersections, crossovers, and gore areas at interchanges.

The reader is invited to find new ways of applying the methods and procedures presented here to provide yet another effective tool, to help solve the many complex maintenance problems found on roadsides.

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Use of Roadside Plantings by Songbirds for Nesting

EDWIN D. MICHAEL

ABSTRACT

Nesting frequency by songbirds in various tree species was studied along I-79 in West Virginia. A total of 554 trees, 278 coniferous (4 species) and 276 deciduous (13 species), were examined for bird nests. Trees were planted in 1973 and were examined for nests during 7 years from 1974 to 1983. A total of 237 nests were located, 196 in coniferous trees and 41 in deciduous trees. The number generally increased from 16 in 1974 to 54 in 1983. The most preferred tree species were cedar (Juniperus spp.) of which 19 percent contained nests, and Austrian pine (Pinus nigra) of which 16 percent contained nests. The most preferred deciduous species were red maple (Acer rubrum) (8.7 percent with nests), pin oak (Quercus palustris) (8.1 percent with nests), and amur maple (Acer ginnala) (7.1 percent with nests). The bird species that most commonly nested in right-of-way trees were robins (Turdus migratorius) and chipping sparrows (Spizella passerina).

Most limited-access, high-speed highways have a variety of trees planted in their rights-of-way. The main purpose of these plantings is to improve the aesthetics for persons traveling the highways. A secondary benefit involves their use by wildlife.

The purpose of this paper is to compare the nesting frequency of songbirds (one aspect of wildlife usage of roadside trees) in various species of trees and shrubs. The study discussed in this paper was conducted along I-79 (90 percent rural and 10 percent suburban) in northern West Virginia. A total of 554 trees representing 17 species were examined along a 24-mi segment of highway in Marion and Monongalia counties (Table 1). Of the 554 trees examined, 278 were coniferous (4 species) and 276 were deciduous (13 species). Trees and shrubs were 1 to 2 m high when planted in 1973 as part of the landscaping contract let by the West Virginia Department of Highways. Some trees were located in interchanges but most were adjacent to the Interstate. Areas around most trees were mowed annually. Thus, the vegetation was usually less than 0.5 m high. Several trees that were originally selected for the survey died during the course of the study. When this occurred, nest data relating to those trees were discarded.

Trees were searched for nests in November. When nests were located, data were recorded for tree species, tree height, nest height, and nest construction. Nests were removed after appropriate data were collected. Two hundred thirty seven nests were located during the 7 years that trees were surveyed (Table 1). The number of nests generally increased from 16 in 1974 to 54 in 1983 (Table 2). This increase corresponded to an increase in tree size. Mean tree height increased from 1.79 m to 6.76 m,

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TABLE 1 Relative Use of Trees Planted Along an Interstate Highway by Songbirds for Nesting

Species	No. Surveyed	No. of Nests Found	Percent[a] with Nests
Coniferous			
Norway spruce *(Picea abies)*	166	92	7.9
White pine *(Pinus strobus)*	39	15	5.5
Cedar *(Juniperus spp.)*	37	49	18.9
Austrian pine *(Pinus nigra)*	36	40	15.9
Subtotal	278	196	10.1
Deciduous			
Redbud *(Cercis canadensis)*	43	0	0
Bradford pear *(Pyrus calleryana)*	40	0	0
Hawthorne *(Crataegus spp.)*	35	1	0.4
Poplar *(Tilia spp.)*	28	2	1.0
Crabapple *(Malus spp.)*	21	2	1.4
Elaeagnus *(Elaeagnus spp.)*	20	4	2.9
Viburnum *(Viburnum spp.)*	18	1	0.8
Red maple *(Acer rubrum)*	18	11	8.7
Dogwood *(Cornus florida)*	16	4	3.6
Amur maple *(Acer ginnala)*	12	6	7.1
Sugar maple *(Acer saccharum)*	12	4	4.8
Pine oak *(Quercus palustris)*	7	4	8.1
White oak *(Quercus alba)*	6	2	6.1
Subtotal	319	41	2.1
Total	597	237	6.1

[a]Based on total years.

TABLE 2 Location and Height of Songbird Nests Found in Trees Planted Along I-79

Year	Number of Nests Located: Coniferous	Deciduous	Total	x̄ Nest Height (m)	x̄ Tree Height (m)
1974	16	0	16	0.70	1.79
1975	16	1	17	1.26	2.28
1977	25	2	27	1.33	3.10
1978	22	4	26	2.82	3.53
1980	46	11	57	2.08	4.05
1981	32	8	40	2.18	4.58
1983	39	15	54	3.54	6.76
Total	196	41	237	-	-

Note: Tree height refers only to those trees having nests.

and size and number of branches also increased. Mean nest height increased from 0.70 m in 1974 to 3.54 in 1983.

One hundred ninety six nests were located in coniferous trees and 41 nests were located in deciduous trees (Table 1). A mean of 10.1 percent of all coniferous trees contained nests, compared with only 2.1 percent of all deciduous trees. The most preferred tree species was cedar, of which 18.9 percent contained nests. Austrian pine was the second most preferred tree species; 15.9 percent contained nests. The most preferred deciduous trees were red maple (8.7 percent), pin oak (8.1 percent), and amur maple (7.1 percent). Redbud and Bradford pear were the most abundant deciduous trees, but no nests were found in either species.

The species of birds that constructed the nests could not always be determined. A tentative identification was made for many nests, but the only ones positively identified were those for robins (Turdus migratorius) and chipping sparrows (Spizella passerina). Observations during summer months indicated that the trees were also used for nesting by cardinals (Richmondena cardinalis), song sparrows (Melospiza melodia), bluejays (Cyanocitta cristata), and catbirds (Dumatella carolinensis). Robin nests were the most abundant; 96 (40.5 percent of total) were positively identified. These were almost equally divided between coniferous (51) and deciduous trees (45). Forty-eight chipping sparrow nests were identified, 29 (60 percent) in conifers and 19 (40 percent) in deciduous trees.

One criterion that should be used by highway departments in selecting roadside plantings is their value to songbirds. These birds present no danger to passing motorists and few birds are killed by vehicles. Preferred trees, based on songbird use, include cedar, Austrian pine, red maple, pin oak, amur maple, and Norway spruce. When considering year-round benefits, such species as hawthorne, crabapple, viburnum, dogwood, and elaeagnus may also be beneficial because of the fruit they produce.

These data represent only the first 10 years following planting. As trees grow, nesting will increase, and the relative attractiveness of different species may change. Landscaping with trees along Interstate highways and interchanges should continue, especially around rest areas where the public can enjoy the sights and sounds of songbirds building their nests and feeding their young.

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Fish Passage Through Poplar Grove Creek Culvert, Alaska

MICHAEL D. TRAVIS and TIMOTHY TILSWORTH

ABSTRACT

An experimental procedure was developed to analyze the ability of a highway culvert to pass fish. By using a visual technique, the swimming performance of Arctic grayling (Thymallus arcticus) was monitored in Poplar Grove Creek, Alaska. The highway culvert is 110 ft long and 5 ft in diameter, and is inadequate for fish passage if the Alaska Department of Fish and Game criteria are applied. The drainage area experienced a 20-year flood (Q_{20}) during spring 1985. Excessive pipe velocities prevented the fish from passing the culvert for 8 days. A large portion of the fish in the downstream scour pool were removed by sport fishermen during the period of high flow. Approximately 78 percent of the fish attempting to swim through the culvert were successful when the outlet velocity dropped to 7.3 ft/sec (fps) and about 95 percent swam through when the velocity receded to 6.9 fps. A request for information on fish passage was sent to U.S. and Canadian highway departments and fishery agencies. Forty-four states and all Canadian provinces responded. Twenty states reported that they generally do not have problems with fish passage through highway culverts. Eighteen highway departments reported having a good working relationship with resource agencies when addressing fish passage problems. These 18 states commonly suggested that (a) early coordination should occur between highway and resource agencies during the design phase, (b) culvert inverts should be depressed approximately 1 to 2 ft below the natural stream bed, (c) culverts having slopes greater than 1 percent should have a baffling system, and (d) the remaining culvert volume should be able to handle approximately a Q_{50} discharge.

Fish populations are widely distributed throughout Alaska and must often pass through highway stream crossings. These crossings can be crucial to the seasonal migration of fish populations because modifications to the natural stream flow conditions may impede access to feeding, spawning, or overwintering habitats. The proper design of highway culverts is essential to facilitate the passage of fish. Design criteria for culverts should be well defined to ensure fish passage but should still consider the hydrological conditions of the stream site, difficulty of installation, and economics of design and construction.

The Alaska Department of Transportation and Public Facilities (DOT&PF) is the primary agency responsible for design and construction of roads in Alaska. The Alaska Department of Fish and Game (ADF&G) has enforcement authority, as provided by the Alaska Legislature, to ensure efficient fish passage through highway stream crossings (A.S. 16.05.840 and 870). Many road projects are federally funded and require compliance with the National Environmental Policy Act (NEPA). For these cases, the U.S. Fish and Wildlife Service coordinates with ADF&G to maintain fish passage.

In order to facilitate fish passage, the ADF&G has set maximum water velocities for varying culvert lengths that can be attained during a mean annual flood discharge ($Q_{2.33}$) (Figure 1). These criteria were derived from a study performed by MacPhee and Watts in 1976 (1). They analyzed the swimming performance of Arctic grayling through various outlet velocities and 2-ft diameter culvert lengths during controlled conditions. No additional studies have been conducted that investigated the applicability of the extrapolated criteria in natural conditions or using culverts of larger diameter.

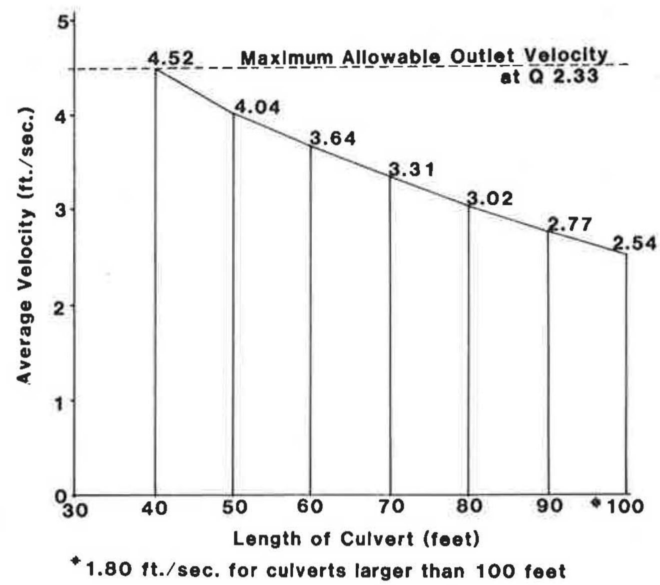

FIGURE 1 Alaska Department of Fish and Game fish passage criteria.

To meet these strict fish passage requirements, the Alaska DOT&PF must often design and install expensive drainage structures such as large-diameter culverts or bridges. Even after these structures have been provided, their general effectiveness for

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fish passage is greatly debated. Often hydrological factors inhibit designing structures that will meet the fish passage requirements. As a result, some engineers believe that ADF&G's requirements are too restrictive and add an unjustified expense to highway projects.

The Alaska DOT&PF and the University of Alaska, Fairbanks initiated a study in 1985 to investigate a highway culvert that is inadequate for fish passage according to the ADF&G criteria, yet a significant number of fish pass through it. The project evaluated the swimming performance of Arctic grayling (Thymallus arcticus) attempting to swim through the culvert.

The objectives of the study were to

1. Develop a procedure for analyzing a culvert's ability to pass fish;
2. Determine the success rate of Arctic grayling passing through a highway culvert that is inadequate for fish passage according to ADF&G criteria;
3. Determine if additional, more comprehensive studies need to be conducted to verify or modify ADF&G's criteria; and
4. Investigate the steps that other state highway departments and resource agencies are taking to address fish passage problems.

METHODOLOGY

This study took place along Poplar Grove Creek near Glennallen, Alaska. The creek's width varies from 5 to 15 ft along its 5-mi length. It flows through a culvert on the Richardson Highway at Milepost 138.1 and then discharges into the Gulkana River, which is about 1.8 mi below the crossing.

Poplar Grove Creek was selected for this project because of previous studies conducted by MacPhee and Watts (1) and Tack and Fisher (2). They compiled extensive information on the stream's fisheries and hydrology. The highway culvert at this stream crossing is inadequate according to the ADF&G criteria. Nevertheless, many Arctic grayling pass through it during the upstream spawning migration following spring breakup (personal communication, Williams and Potterville, Alaska Department of Fish and Game).

The Poplar Grove Creek culvert is 110 ft long (skewed to the road crossing at about 45 degrees), 5 ft in diameter, and is constructed of corrugated metal. It has been in place since 1953. The outlet is perched approximately 1 ft above the streambed. In the middle of the culvert, subsiding road material and traffic load have depressed the top of the pipe (Figure 2). The culvert is positioned on about a 0.5 percent slope, and no streambed material is present along the culvert's bottom. A 60- by 120-ft scour pool exists at the culvert outlet. The pool depth ranges from about 2 to 5 ft and is a popular fishing spot for local residents. The ADG&G fish passage criteria requires a maximum average outlet velocity of 1.8 ft/sec (fps) during a $Q_{2.33}$ for this culvert (Figure 1). According to ADF&G, this maximum outlet velocity will ensure that at 2.8°C, 75 percent of 9.5-in. fish will successfully negotiate the culvert.

This project included the capturing of Arctic grayling downstream of the culvert, tagging the fish according to length, and observing the grayling swimming through the culvert at various water velocities and water quality parameters. A creel census was performed at the scour pool. In addition, an inquiry for fish passage information was sent to American and Canadian highway departments and resource agencies. Arctic grayling were captured near the mouth of Poplar Grove Creek at the beginning of their spawning migration between May 20 and 22, 1985.

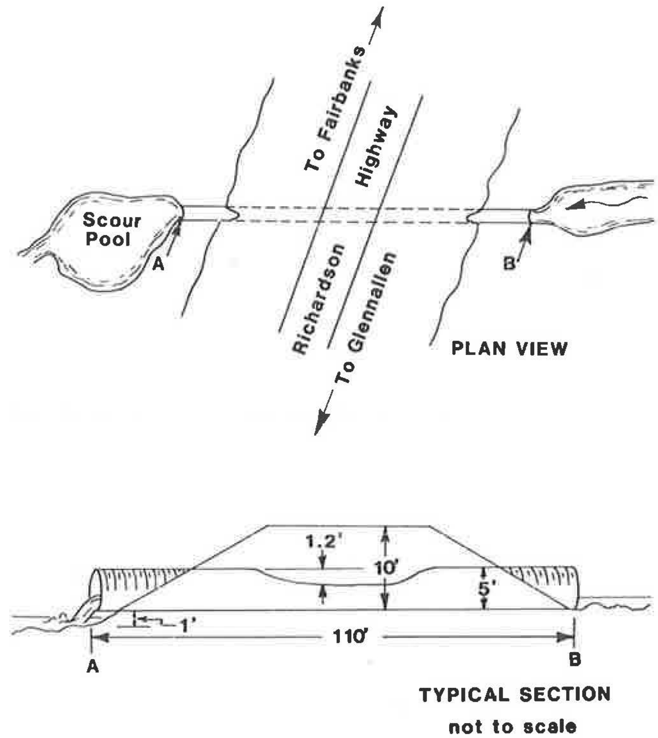

FIGURE 2 Plan view and typical section Poplar Grove Creek.

Fish were captured by dip netting. Previous studies estimated a total migrating population of about 5,000 fish. Fish were netted between 10:00 a.m. and 6:00 p.m. and immediately transferred to holding pens in a side channel of the creek. The holding pens were two 30-gal trash cans perforated with 3/8-in. holes. These "live boxes" were weighted to the stream bottom with rocks and sandbags, and only a few fish were maintained in the pens so as to minimize mortality.

Fish were individually transferred from the pens, using wool gloves, to a measuring cradle that consisted of a 2-ft plywood box lined with foam rubber and a measuring stick along its bottom. Fork length was quickly measured to the nearest quarter of an inch. The fish were then tagged through the base of the dorsal fin and released. To prevent the downstream movement of tagged fish, a temporary weir was constructed from sandbags and wire mesh, approximately 20 ft downstream of the sampling area.

The tags for this study were three 3/4-in. plastic streamers approximately 1/8 in. wide (Floy Tag and Manufacturing, Inc., Model FTSL-73). Although originally designed for use on shrimp, the tag was selected because of its configuration and light weight. It was believed to be suitable for use in this study. Tags were colored to differentiate group sizes: orange, 6 to 9 in.; yellow and blue, greater than 9 in. Tag colors were selected to enhance visibility in colored, turbid water.

Fish smaller than 6 in. were not tagged because their swimming abilities were hampered in swift water. The tag was inserted into the base of the dorsal fin via a needle that detached from the tag once it was in place. Instructions were imprinted onto the tag requesting anglers to return the recovered tags to the Glennallen Sport Fish Division. Because of the substantial distance between the tagging area and the culvert (1.8 mi), it was assumed that the fish had recovered adequately from handling and tagging to become acclimated to swimming with the tag before reaching the highway crossing. Observations of grayling attempting to swim through the culvert were facilitated by using "flashboards" positioned on the stream bottom at the inlet and outlet of the culvert. The flashboards were 8 by 4 ft and were constructed from 5/8-in., all-weather plywood that was painted light grey. Fish swimming over the boards into and out of the culvert were more easily observed against the light background.

Fish were counted as they swam over the flashboard into the culvert. Fish that swam into the culvert were recorded as attempts. Fish that swam back out of the culvert were recorded as failures. Counts were made from 2:00 to 8:00 p.m. from May 31 to June 1.

Individual-tagged fish entering the culvert were recorded swimming through the pipe by observers located at each end of the pipe via two-way radios and a stop watch. This procedure permitted timing of the fish as they negotiated the culvert.

Water quality parameters were monitored daily from the scour pool. Dissolved oxygen and apparent color were determined with a Hach DR=EL/4 water testing kit. Turbidity was monitored with a Hach Model 16800 portable turbidity kit. Temperature in degrees Celsius was measured using a pocket thermometer.

A stream gauge was installed about 20 ft upstream of the inlet and was read daily. Water velocity profiles were taken at least once daily, depending on the fluctuating water levels on the stream gauge at the culvert outlet. Velocities were measured with a Gurley meter attached to a wading rod. Poplar Grove Creek's hydrograph was calculated using Lamke's linear regression method (3).

A creel census was performed by the investigating team to determine the number of fish removed from the scour pool by local fishermen. Anglers were given an information pamphlet that explained the project and requested their cooperation.

Highway department and natural resource agencies from the United States and Canada were contacted to determine how they address fish passage problems. Their methods and approaches were then summarized.

RESULTS

Arctic grayling began entering the mouth of Poplar Grove Creek on May 20 when the water temperature had risen to approximately 1°C. Table 1 gives daily totals of fish that were tagged. A total of 1,252 fish were tagged during the 3 days of sampling. The migration began with grayling generally larger than 9 in. and was followed gradually by smaller fish. The daily migration peaked about 4:00 p.m.

TABLE 1 Daily Tagged Fish

Date	Blue >9 in.	Yellow >9 in.	Orange 9 in. > x > 6 in.	Daily
5/20/85	140	0	51	191
5/21/85	283	0	115	398
5/22/85	75	293	294	662
Total	498	293	460	1,251

Figure 3 shows the daily discharge rates through the culvert. The flow peaked at 139.1 ft^3/sec (cfs) on May 21. Grayling first were observed at the highway culvert on May 23 but were held in the scour pool for 8 days because of excessive culvert outlet velocities. Fish arrival at the culvert corresponded to the decreasing side of the hydrograph.

Figure 4 shows the calculated magnitude and frequency of peak discharges for Poplar Grove Creek. By comparing the peak discharge that occurred during the study period with the graph, 139.1 cfs should occur about every 20 years (Q_{20}). Therefore, the study took place during an unusually high peak discharge.

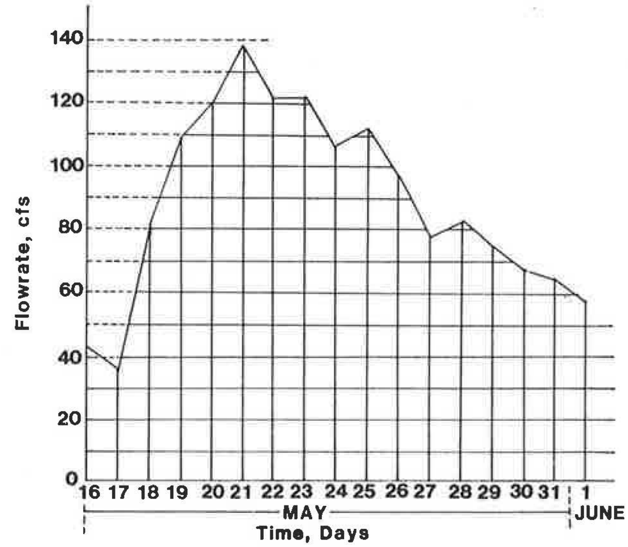

FIGURE 3 Daily discharge rates for 1985 (cfs).

Figure 5 shows the water quality in the scour pool during the study. The maximum daily water temperatures ranged from 6.6°C to 12.0°C, and apparent color fluctuated from 40 to 320 units. Turbidity ranged from 3.1 Nephelometric Turbidity Units (NTU) to 32 NTU. Dissolved oxygen varied from 9.0 mg/l to 11.2 mg/l.

Daily average culvert outlet velocities ranged from 6.9 to 10.3 fps (Figure 6). At 1:35 p.m. on May 26, one ± 9-in. grayling was observed exiting the upstream end of the culvert. The water temperature was approximately 10.3°C, and the outlet velocity was 9.2 fps. Because of abnormally high flows, the investigating crew was unable to determine how many fish negotiated the culvert during these high-flow and high-velocity conditions.

Two fish with yellow tags were observed swimming above the culvert inlet on May 27 at 5:20 p.m. The water temperature was approximately 12.0°C, and the average outlet velocity was 8.4 fps. One of the fish approximately 15 in. long was caught with fly fishing gear. At 10:00 p.m., three 16- to 19-in. longnose suckers (Catostomus catostomus) were observed swimming upstream of the culvert.

At approximately 3:20 p.m. on May 31, the first significant number of fish began migrating through the culvert. Eighty-two attempts were recorded with only 18 failures. This represents a 78 percent success rate. The water temperature was approximately 7.7°C, and the average outlet velocity was about 7.3 fps. No tagged fish were observed swimming through the culvert. All the fish whose attempts were successful were observed swimming very close to the bottom of the culvert.

On June 1, the fish began migrating about 4:00 p.m. Some 1,090 attempts were counted with 52 failures. This was a 95 percent success rate. The water temperature was approximately 9.5°C, and the average outlet velocity was 6.9 fps. Again, successful fish were observed swimming at the bottom of the culvert. Table 2 gives the time required by tagged fish to swim through the culvert. Larger fish took an average of 20.2 min to swim through the culvert, whereas

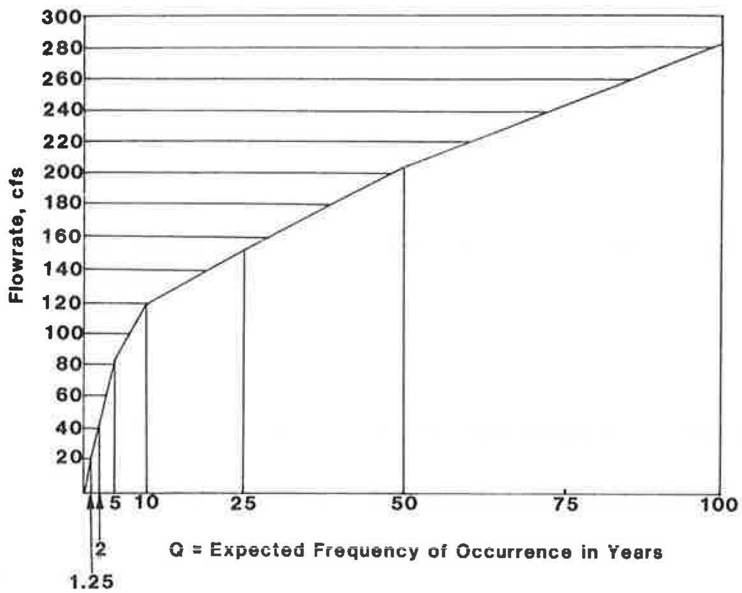

FIGURE 4 Calculated magnitude and frequency of peak discharge.

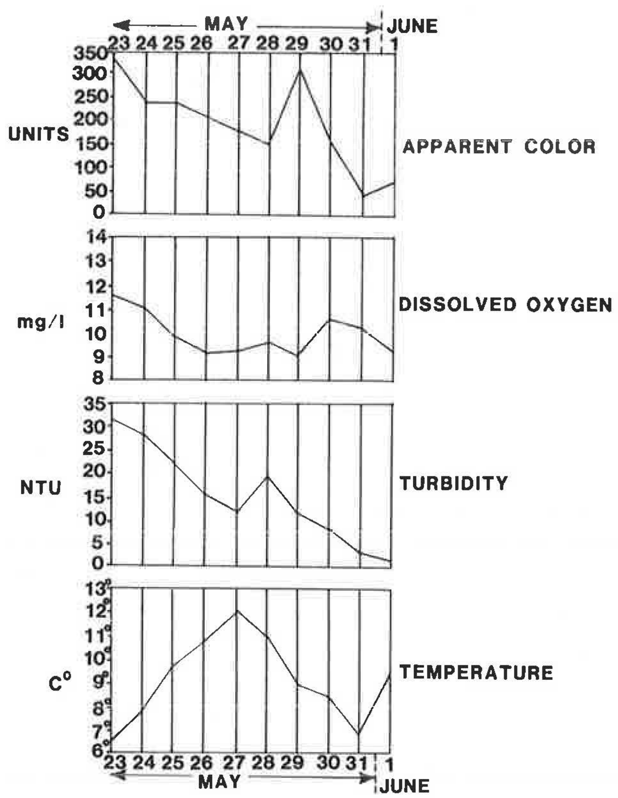

FIGURE 5 Daily water quality parameters.

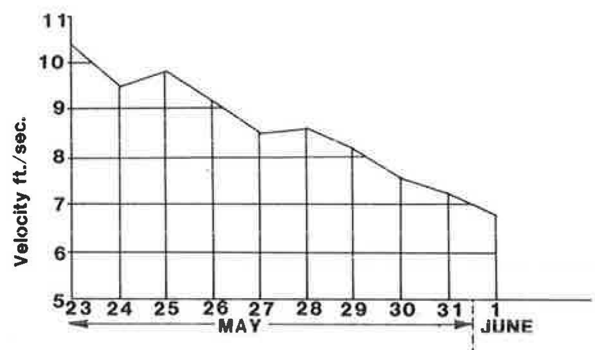

FIGURE 6 Daily outlet velocities.

TABLE 2 Time Durations of Fish Swimming Through Culvert

Tag Color	Number Timed	Mean Time (min)	Range (min)
Yellow	4	20.5	11.9-27.7
Blue	3	19.9	11.5-27.5
Orange	11	28.8	10.75-43.03

smaller fish took 28.8 min. The time range for fish to successfully negotiate the culvert ranged from 10.8 to 43.0 min.

The creel census was performed from May 23 to 29 (Table 3). On several occasions anglers continued fishing in the scour pool late in the evening (beyond midnight) after the investigative team left the project site. Therefore the total number of fish removed from the pool is estimated to be 10 percent more than what is given in Table 3, or approximately 2,600 fish. About 4,180 fish were hooked and landed; some 1,580 were released. Rough handling of fish was observed on numerous occasions. By May 26, most fish larger than 8 in. were dropping eggs or milt when they were lifted from the water by anglers.

Forty-four states and all Canadian provinces responded to the letter of inquiry for fish passage information. Twenty states reported that they usually had no problems with fish passage through highway culverts. Eighteen highway departments reported having a good working relationship with resource agencies when addressing fish passage problems. These 18 departments commonly suggested that (a) early coordination should occur between highway and resource agencies during the design phase, (b) culvert inverts should be depressed approximately 1 to 2 ft below the natural streambed, (c) culverts having slopes greater than 1 percent should have a baffling

TABLE 3 Creel Census

Date	No. of Anglers[a]	Angler Hours[b]	Fish Caught	Fish Kept	Tagged Fish Caught			Tagged Fish Kept		
					Yellow	Blue	Orange	Yellow	Blue	Orange
5/23/85	12	18	103	95	0	0	0	0	0	0
5/24/85	30	37	225	221	1	6	0	1	6	0
5/25/85	65	92.5	726	557	17	35	0	9	17	0
5/26/85	83	149.5	1,370	711	53	32	6	32	28	2
5/27/85	86	143	1,534	620	11	22	4	10	12	2
5/28/85	6	10	104	33	7	13	3	7	11	2
5/29/85	11	13	118	114	2	3	4	2	2	4
Total	293	463	4,180	2,341	91	111	17	67	76	10

[a]Number of anglers = number of anglers interviewed only.
[b]Anglers hours = number of anglers x hours fished.

system, and (d) the remaining culvert volume should be able to handle approximately a Q_{50} discharge.

Several highway departments have a policy of establishing either a formal or an informal fish passage task force. The teams are composed of personnel from various disciplines, including design and hydraulic engineers, environmental specialists, and personnel from resource agencies.

Early in the development of a project, the highway departments contact pertinent resource agencies to determine (a) whether an important fishery utilizes the stream in question; (b) whether there is currently a fish passage problem; and (c) whether there is sufficient spawning and rearing habitat above the culvert to warrant the costs involved in establishing, maintaining, or reestablishing fish passage. On the basis of these determinations, fish passage either becomes a design criteria for the project or is deleted from further consideration. The final fish passage design is coordinated with the resource agencies and is finally approved by the district hydraulics engineer.

Most culverts are positioned parallel along the natural stream gradient. The culverts are depressed approximately 1 to 2 ft below the streambed to prevent perching and are allowed to fill in naturally. If the culvert's slope is greater than 1 percent, either riprap or a baffling system is employed. Baffling consists of a simple concrete weir, removable plates on hangers for simplified maintenance operations, or a variety of complex channeling techniques. Regardless of which system is used, the culvert is usually somewhat oversized to retain its hydraulic capacity for a Q_{50} discharge.

Two state resource agencies reported that they request highway departments to create blocks to fish migration. This is done to prevent the destruction of prime upstream fisheries from the invasion of undesirable fish species (i.e., carp, lamprey, etc.).

DISCUSSION OF RESULTS

Comparison of ADF&G's criteria for a 110-ft culvert (maximum outlet velocity = 1.8 fps) with the observed outlet velocity necessary to pass 78 percent of all fish (7.3 fps) results in a large discrepancy. However, there may be several possible reasons why fish were able to negotiate such a high velocity.

ADF&G fish passage criteria has fixed, maximum values for average cross-sectional outlet velocities for given culvert lengths. The study team observed the fish swimming very close to the culvert bottom and not utilizing the entire water column. Morsell et al. (4) developed a hydrologic model that describes the velocity of a zone close to the culvert bottom, which is called V-occupied. In general, V-occupied equals 0.625 of the average cross-sectional velocity. If this model is valid, then when the average cross-sectional velocity was 7.3 fps, the V-occupied would have been about 4.6 fps. The extrapolated maximum outlet velocities for the ADF&G criteria were generated from studies of Arctic grayling swimming through 2-ft diameter culverts. These smaller pipes possess a much smaller wetted perimeter than the Poplar Grove Creek culvert and thus would generate a smaller V-occupied zone that the fish may not have been able to utilize.

Temperature and spawning motivation may have influenced the fishes' swimming ability. MacPhee and Watts (1) noted that during warmer temperatures and during the upstream spawning runs, grayling were able to swim longer and negotiate higher velocities. ADF&G criteria are based on passing 75 percent of 9.5-in. fish at 2.8°C but does not consider spawning motivation. The fish studied passed through the culvert at about 7.7°C and were migrating upstream to spawn.

The long transient times exhibited by the tagged fish swimming through the culvert suggest that resting areas were available along the bottom. However, this appears unlikely because so much water was flowing through the pipe (64 cfs) when 78 percent of the fish passed. Upstream flow conditions indicated a hydraulic jump near the culvert inlet that would have resulted in an elevated velocity for a short section of the pipe. Further, the center section of the culvert was constricted (Figure 2), which, under selected flow conditions, caused surcharging in the pipe and slower velocities within the constricted section of the culvert. This indicates nonuniform flow conditions in the pipe (constant discharge but varying velocities). It is apparent that the fish were swimming at the extreme limits of their swimming abilities with a slow, net forward speed but with a darting action as they encountered variations in velocities through the pipe.

The final question to be addressed is whether the existing Poplar Grove Creek culvert is inadequate for fish passage. Based on the ADF&G's specification that 75 percent of 9.5-in. fish pass at a $Q_{2.33}$ discharge, then the Poplar Grove Creek culvert is acceptable because 78 percent of the fish population passed through it at approximately 65 cfs, which is about a $Q_{3.3}$ discharge. However, the existing culvert has structural flaws that can only be corrected by replacing it with a new pipe and properly positioning the culvert along the streambed.

During the 8 days that the fish were downstream of the culvert, about 50 percent of the spawning population was removed by sport fishermen. Of the remainder, almost all had been hooked at least once. Because of this, it is recommended that ADF&G consider emergency closures to sport fishing in areas such as Poplar Grove Creek during unusually high flow.

Dryden and Stein (5) suggest that upstream migrating fish should not be held below a culvert for more than 3 days. However, this project did not entirely support this conclusion. The fish studied appeared viable and energetic for the entire 8 days of delay despite the rough handling they endured from sport fishermen. The effects on spawning are unknown.

The study techniques tentatively appear to be simple and effective for analyzing the ability of a particular drainage structure to pass fish. However, two changes are recommended if this procedure is used in the future. First, a smaller, slimmer tag should be used to mark fish that are less than 6 in. Second, during high turbid flows, a small, portable side-scanning sonar counter should be used at the culvert inlet to augment the use of flashboards to count fish and confirm passage.

The highway crossing at Poplar Grove Creek is scheduled to be realigned approximately 100 ft upstream during the 1986 construction season. To meet ADF&G fish passage criteria, a 50-ft long, 10-ft diameter reinforced culvert with reinforced headwalls has been designed. The anticipated cost for this structure is approximately $160,000 (DOT&PF 1986 estimated cost). An 80-ft long, 5-ft diameter culvert similar to the original crossing would cost about $8,000. Such examples suggest the need for ongoing coordination between transportation and fisheries agencies. Obviously, this is a case in which better technical data on the relationship between the behavior of the "design" fish species and the hydraulic operation of highway structures can produce significant cost savings.

Fish passage criteria and techniques that will be cost effective and protect the fisheries resources are in the developmental stages in the state of Alaska. Alaska can learn from other states how they address fish passage issues. The underlying foundation for any criterion is adequate communication between fishery biologists and engineers. Alaska has recently developed a Fish Passage Task Force that is composed of representatives from ADF&G and DOT&PF. Its primary purpose is to bridge the communication gap between the two agencies and to begin working together to solve the problems of fish passage.

SUMMARY AND CONCLUSIONS

Experimental techniques were used to observe fish passage through a highway culvert. Although there were some difficulties with the visual technique, it provided a cost-effective method that did not require sophisticated, expensive monitoring equipment. Observations were hampered by unusually high flows. The population of upstream migrants appeared higher than in previous years.

Some Arctic grayling were able to negotiate a 110-ft long, 5-ft diameter culvert when flows exceeded 9.0 fps. A large portion of the population was unable to pass the culvert during these conditions, and because of this, became highly vulnerable to sport fishing. Most of the remaining fish were able to pass through the drainage structure when the velocity decreased to about 7.0 fps. Some disagreements exist between the study investigators and some individuals of ADF&G about the definition of an attempt and the definition of a failure of a fish in the culvert. ADF&G believes that fish residing in the scour pool should have been included in determining the percent of fish passing through the culvert. An accurate count of fish in the scour pool was not possible because the investigative team was not permitted to recapture fish in the pool.

The experimental procedures used need further evaluation on other streams, culverts, and fish species. The data gathered by this study suggest that the existing ADF&G fish passage criteria may be restrictive and follow-up studies are recommended. Additional studies may provide information leading to criteria that allow for more conservative pipe sizing and cost-effective use of public funds while providing a high degree of protection to fish resources. One final area of study needing a great deal of attention are design criteria at low-flow conditions that might create stream migration blockage.

ACKNOWLEDGMENTS

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Right-of-Way Forestry for a 6.7-Mile Section of I-95 in Maine

HAROLD E. YOUNG and DAVID T. EDSON

ABSTRACT

As a prelude to trial harvest operations, a detailed study of forestry potential was conducted on 6.7 mi of the right-of-way (ROW) median strip of I-95 in Maine, between Routes 143 and 69. Color infrared photography was used to classify forest stands into immature and mature composition classes. Three maps were digitized and plotted (1:2400) to show all forest stands and nonforest areas and to estimate the area in acres for each. The first field session was conducted to verify photo interpretation and to assess open areas for tree plantations. A second session was used to measure 24 temporary sample points. Total volume, total weight, and harvestable volume and weight were estimated for all mature stands. It was concluded that only the median strip would be harvested in the trials; harvested stands could be left windfirm without serious erosion problems; planned harvests can reduce individual tree cleanup by the Maine Department of Transportation; maps and inventory of the ROW can be used to plan and record landscape and forestry treatments; a stumpage value in excess of $1,000 per mile was assessed in the 6.7-mi study area.

In May 1983 a detailed study of a 6.7-mi segment of I-95 between Routes 143 and 69 was commissioned by the Maine Department of Transportation (MDOT). The inventory and mapping phases of the study were performed by James W. Sewall Company.

Woody fiber farming (1) was an early suggestion in the study followed by more conventional forestry (2-3). The latter was based on a study of the forest management possibilities of a 23-mi section of I-95 (4).

The primary objective of this study was to develop a procedure for assessing both stocked and nonstocked areas of the median strip and sidestrips of the right-of-way (ROW) for forestry potential. Implicit in this objective was the assumption that safe and economic harvesting could be accomplished without impairing traffic flow; a separate study was envisioned that would explore traffic and contractual problems with logging contractors during a bonafide harvest of stands within this same 6.7-mi segment of I-95.

A secondary objective was to determine, within the nonstocked areas, whether trees could be planted, which would thereby reduce mowing costs. As highway budgets have been reduced in recent years, there has been less mowing, less spraying, and less planting on the ROW. Alternatives such as slower-growing shrubs and grasses must be compared with establishing small plantations that can produce income and offset some ROW maintenance costs.

A third objective was to get foresters and highway engineers involved in a dialogue. Engineers have problems and opportunities presented by the presence of forest land within the ROW. Foresters are familiar with the sequence of forest stand development. A dialogue between the two professions can help to identify forest stands that may present shading problems, windfall hazard, or income-producing opportunity. A method for chronicling natural and manmade change within the ROW was developed through the mapping process.

James W. Sewall Company, 147 Center St., Old Town, Maine 04468.

METHODS

Aerial Photography

On May 19, 1983, a series of 28 color infrared vertical aerial photographs was taken extending over the study area. A Zeiss 6-in focal length camera with a 9-in. film format was used. The nominal scale was 1:6000 (1 in. equals 500 ft).

The roll of film was processed to positive transparency form and cut into individual exposures. Each exposure was mounted and taped in an acetate envelope. Fiducial marks were traced on the acetate envelope to ensure permanent registration.

Photo Interpretation

Photo interpretation of all forest stands was performed using a Bausch & Lomb Zoom 95 stereoscope with light table. All vegetation was segregated into one of the following categories: (a) open areas, (b) immature stands with a predominance of small premerchantable stems, (c) mature stands with a predominance of merchantable stems, (d) swamp (SW), or (e) rocky (RY). The immature and mature stands were further defined as softwood (more than two-thirds softwood), hardwood (more than two-thirds hardwood), or mixedwood (having less than two-thirds softwood or hardwood). Paved areas and adjacent grassy slopes were not described. Open areas in the sidestrips and median were delimited from the grassy slopes at the bottom edge of the fill line.

Blueprints furnished by the Maine DOT were used to mark the ROW boundaries on the transparencies. Mile markers were noted on the transparencies to facilitate mapping.

First Ground Reconnaissance

After preliminary photo interpretation was completed, the entire 6.7-mi segment was walked to verify photo interpretation and to conduct an assessment of all areas that had been designated as open.

Open areas were evaluated for potential plantation sites, and all recommendations were noted by stand number. Only sites with good or moderate drainage were recommended. This evaluation was performed with a check sheet that had boxes for the following items:

Location:
1. Mile number
2. Stand number
3. Acreage

Size class:
1. Mature
2. Immature

Crown closure:
1. 0 to 33 percent
2. 34 to 66 percent (Over)
3. 67 to 100 percent (Understory)

Composition class:
1. Softwood
2. Hardwood
3. Mixedwood

Removals:
1. Biomass chips
2. Firewood
3. Pulpwood
4. Sawlogs/veneer

Operating condition:
1. Wet
2. Steep
3. Rocky
4. Normal

Regeneration:
1. Species
2. Spacing

Necessary changes in photo interpretation were noted directly on the transparencies. These field observations permitted the following decisions to be made: (a) the forest area within the sidestrips of the ROW is so narrow that it was excluded from the mapping and first forestry operations; (b) no treatment was recommended for the immature stands until harvesting trials had been conducted on mature stands in the median.

Mapping

Lines and designation codes were marked on the acetate envelopes covering the transparencies and transferred onto a base map that was built on the Maine State Plane Coordinate System. Starting with U.S. Geological Survey (USGS) topographic quadrangle sheets, control points and planimetric features were identified and digitized using a computer mapping complex that consists of an AED color graphics terminal, a Talos digitizing tablet, a DEC 11/23 computer, and a Houston CP-15 drum plotter. Enough control points and planimetric features were selected to cover the 6.7-mi segment.

After all lines and designations had been transferred onto the base map, the lines were digitized and the designations were encoded on a separate tabular file. The computer mapping complex was used to compute area in acres for each designated area, and a map was produced (1:2400) with the two-letter designation code and the area number. On a separate listing, the area number was sequenced and each area was further described by this two-letter code and area in acres.

Three maps (1:2400) were plotted to cover the entire 6.7-mi segment. Note that these maps contained information only on the median strip.

Forest Inventory

The second visit to the 6.7-mi segment involved a forest inventory of only the mature forest stands. Eight sample points were established in each of the three composition classes (e.g., mixedwood, softwood, and hardwood). These points were established as temporary with a 10-basal area factor wedge prism. All trees selected by this process were recorded if they had a diameter at breast height (dbh) greater than 4.6 in. All trees and woody shrubs within the range of 0.6 to 4.5 in. dbh were measured on a 1/300-acre fixed-radius subplot (radius equals 6.8 ft).

Trees larger than 4.5 in. dbh were measured at dbh using tree calipers and were graded as pulpwood, undersized, boltwood, sawlog, or cull. These products correspond with local market conditions. Defect codes were used to describe missing tops, rot, insect damage, and so forth.

In coincidence with the grading of each tree for product, a subjective rating was applied to indicate the probability of harvest for each tree sampled. Although this rating did not encompass all stands and trees, it did provide a useful estimate of the percentage of trees that could be harvested within each mature composition class.

Following field tally, all data were encoded and processed by computer. For each mature area, an estimate of volume and weight per acre was computed; this per-acre estimate was multiplied by the number of acres within each mature composition class to produce a total estimate of standing volume, possible harvestable volume, and weight for the entire 6.7-mi segment. One of the points selected for the mature mixedwood was so heavily wooded that it was treated as a separate stand.

The computer report details volume per acre for each product and species by diameter class. A weight estimate in fresh tons per acre was computed using the tally of submerchantable (0.6 to 4.5 in.) and merchantable trees. The weight estimate was reported by species and diameter breast height with subtotals for (a) stump and roots, (b) bole, (c) limbs and top, and (d) total.

A statistical report for the volume and weight estimates was produced that lists the mean, the allowable error as a percent for 2:1, 9:1, and 19.1 confidence limits, standard deviation, coefficient of variation, and standard error of the mean as a percent.

RESULTS

Maps

Three paper maps (1:2400) were plotted with the two-letter designation code and area number. Area boundaries were plotted in black. Both north and south lanes of I-95 were plotted in red; a red dash was marked at each mile marker. Water bodies were plotted in blue.

Acreage Reports

A total of 93.0 acres was mapped, exclusive of the paved area and grassy slopes in the median strip. An acreage summary of the median strip is given in Table 1.

TABLE 1 Summary of Median Strip Acreage

Designation	Acres
SW-swamp	4.4
O-open	19.6
RY-rock	1.6
IM-immature mixedwood	15.6
IS-immature softwood	3.4
IH-immature hardwood	3.0
MM-mature mixedwood	15.5
MS-mature softwood	8.4
MH-mature hardwood	21.5
Total	93.0

TABLE 2 Summary of Inventory in All Mature Stands

Diameter Class (dbh)	No. of Trees Per Acre	No. of Trees to be Harvested Per Acre	Percentage Harvested Per Acre
1-4	1,603	0	0
5-9	181	74	41
10-11	22	18	82
12 and up	14	14	100
Subtotal			
5 and up	217	106	49
Total	1,820	106	6

Forest Inventory

A concise summary of the inventory work is given in Table 2. Reference should be made to the statistical table in the separate computer report to interpret the reliability of these numbers.

The species that comprise the three mature composition classes are listed in Table 3 by volume per acre in cords for all products and as a percentage of total volume per acre. A summary of fresh weight per acre for softwood, hardwood, noncommercial species, and all species combined is given in Table 4.

The primary purpose of the harvest would be to remove mature trees that will provide income and reduce the risk for windfall and insect damage within mature stands. All trees in the sample 12 in. dbh and larger were recommended for harvest. In the 5- to 11-in. dbh classes only 45 percent of those tallied in the sample were recommended for harvest.

TABLE 3 Species Volume Per Acre for All Mature Stands

Species	Volume Per Acre (cords)	Percent of Total
Red spruce	0.1	1
White spruce	0.1	1
Balsam fir	2.2	14
Hemlock	2.4	15
White cedar	0.0	0
White pine	0.8	5
Tamarack	0.1	1
All softwood	5.8	37
White birch	1.0	6
Sugar maple	1.4	9
Red maple	3.4	22
American beech	1.0	6
Poplar	1.3	8
Basswood	0.1	1
White ash	0.6	4
Red oak	0.4	3
Black cherry	0.2	1
Gray birch	0.1	1
Other hardwoods	0.4	2
All hardwoods	9.9	63
All species	15.7	100

TABLE 4 Summary of Fresh Biomass

Species Group	Component	Tons Per Acre
Softwood	Stump and roots	8.0
	Bole	22.0
	Limbs and top	10.0
	Total	40.0
Hardwood	Stump and roots	12.0
	Bole	32.9
	Limbs and top	15.0
	Total	59.9
Noncommercial	Stump and roots	0.1
	Bole	0.2
	Limbs and top	0.1
	Total	0.4
All species	Stump and roots	20.0
	Bole	55.0
	Limbs and top	25.0
	Total	100.0

Tree Plantations

In conjunction with the ground reconnaissance, open areas with good or moderate drainage were evaluated for establishment of tree plantations. Of the 25 stands classified as open, only 12 were considered suitable for plantations. These stands are enumerated in Table 5 and the species and spacing recommendations are listed.

TABLE 5 Summary of Stands Recommended for Planting

Stand No.	Acreage	Species to Plant	Spacing, ft	Total No. to Plant
7	0.5	Larch	6x8	454
13	0.9	Larch	6x8	817
15	0.4	Red pine	8x10	218
19	0.2	Larch	8x8	181
21	0.3	Red pine	8x10	163
23	1.7	White pine	6x8	926
49 and 50	3.5	White spruce	6x8	3,176
56 and 57	2.0	White spruce	6x8	1,815
70	0.9	Larch	6x8	817
74	0.6	Larch	5x8	544
Total	11.0			9,111

DISCUSSION OF RESULTS

Risk Assessment/Harvest Planning

The most significant product of an inventory and mapping process is the visitation of forest stands and the recording of observations in tabular and map form. Forest stands can be rated as immature, mature, prone to windfall, defoliated, or any number of other conditions. Highway maintenance crews clean up fallen trees one at a time; risk assessment could alleviate much of this work by targeting for harvest stands that contain trees that have obvious windfall risk. A forester can review the map and inventory information to predict changes in stand structure (diameter, class, height) and species composition over a period of many decades. Such changes will dramatically affect shading problems, light mitigation, fire hazard, and aesthetics.

The map and tabular information also provide a method for chronicling forest treatments or landscape activities.

Timber Marking

Marking of each harvest tree will provide department personnel proper control. If each tree selected for harvest is marked with a paint spot on the stump below the cut level and on the bole, supervisory personnel can monitor harvest operations. Paint spots directed toward the center of the median would shield such markings from passing motorists.

It is anticipated that when forest management is extended to other sections of the Interstate system, timber marking and field records will be the principal basis for estimating the amount to be advertised for future harvesting.

Harvesting

Maine Department of Transportation personnel could be trained to conduct the harvest, and the necessary harvesting equipment could be rented or purchased; however, this is not recommended. Training time, safety requirements, and brokering wood to local markets are complicating factors. A better arrangement would be to announce the estimated amount of wood available and request stumpage bids with skidding and trucking routes from established contractors. This approach is used in Mississippi where logging on the ROW is earning the state Mississippi Department of Transportation about $1,000 per mile of highway. The contractor marks the wood and the department personnel supervises the harvest operation.

The inventory data collected in this study indicate that about 532 cord equivalents of pulpwood, boltwood, and sawlogs plus 500 fresh tons of biomass are available within the 6.7-mi study area. Valuing this wood at $10 per cord for the roundwood products and $16 per ton for the biomass, the total value is approximately $13,320 or $1,988 per mile average.

Safety

Highway safety is a major concern of the Maine DOT and the Maine State Police. It would be well to visit the operations in Mississippi and learn from the Mississippi Department of Transportation's experience. If exit and entry to the median strip is carefully situated and timed, the first harvest trials will help to determine whether additional measures, such as caution lights or police traffic monitors, are required.

Performance bonds can be posted by the local contractor to ensure that safety requirements are enforced.

Aesthetics

Few motorists are unhappy with the appearance of the I-95 median. The landscape architects have successfully seeded and planted where construction left bare soil, fill or burrow pits, and access ramps. Harvesting operations will elicit response from motorists regardless of the quality of the operation. Clearly, harvests should be planned to foster public support without undue economic penalty to the logging contractor. Harvesting is recommended in this paper only in some stands on the median strip with most of the harvesting confined to the center of the median strip. After the harvest, few motorists will detect cutting because of the dense advanced softwood regeneration that faces the roadway. Clearcuts should be avoided where possible, and it is anticipated that openings created by removal of mature trees will seed in rapidly.

SUMMARY AND CONCLUSIONS

As a prelude to trial harvest operations, a detailed study of forestry potential was conducted on 6.7-mi of the ROW median strip of I-95 in Maine, between Routes 143 and 69. Color infrared transparencies (1:6000) were produced on which forest stands and nonforest areas were delineated. Three maps were digitized and plotted (1:2400) to show all forest stands and to estimate the area in acres for each.

Two field sessions were conducted to (a) verify photo interpretation and assess open areas for tree plantations, and (b) to measure a total of 24 temporary sample points for volume and weight estimates within mature forest stands. An estimate of harvestable volume and weight were also made.

Analysis of the maps and inventory information leads to the following conclusions:

1. Trial harvest operations should be limited to the median strip and to mature stands excluding the sidestrips.
2. Harvested stands should be aesthetically appealing and windfirm without serious erosion problems.
3. Safety and legal problems can be avoided through discussions, contracts, and performance bonds.
4. Harvests can be scheduled to reduce the cleanup of individual trees by the Maine Department of Transportation.
5. Inventory and map information can be used by the department to chronicle landscape activity and to plan harvest operations that will alleviate maintenance as forest stand structure changes over a span of decades.
6. Within the 6.7-mi study area, the stumpage value of roundwood and biomass should range between $1,000 and $2,000 per mile.

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Aerial Seeding

HAROLD D. DOLLING

ABSTRACT

Spring seeding of permanent grasses in a temperate zone can be subjected to many delays. Waiting for the soil to firm after frost and waiting for it to dry after spring rains can consume much of the available and valuable time needed for spring seeding. When complete seedbed preparation is required, along with the application of fertilizer and seed and the application of mulch, a contractor will find it difficult to complete 30 acres per day. Applying seed by aerial means when the ground is loose and friable from frost action, usually during the month of March, is cost effective. Seeding proceeds at the rate of 50 acres per hour. Average annual savings for a 15-year period of use is in excess of $0.5 million per year. Excellent results have been achieved in the establishment of turf because this method permits the seed to start to grow as soon as soil conditions are favorable in the spring. As a part of the grading operation, the roadsides are fertilized and seeded with a stabilizing crop seed. This crop residue then becomes the mulch to be used the following year for the permanent seed. This preparation is necessary for aerial seeding to be successful.

Aerial seeding is one way of applying seed by the overseeding method. Other equipment that will qualify for use in overseeding are (a) broadcast seeder, (b) field cyclone seeder, (c) hand cyclone seeder, and (d) hydraulic seeder. Since 1971, erosion control contractors have chosen to use aerial seeding equipment as a means of overseeding on more than 32,749 acres of highway right-of-way.

Seeding by air is not a new technique. Iowa's first attempt at aerial seeding of highway right-of-way was made in the spring of 1962 using a fixed-wing aircraft.

Two major factors make overseeding a practical method for permanent seeding of highway rights-of-way: (a) major savings in permanent seeding cost, and (b) excellent results in the establishment of turf because this method permits the seed to start to grow as soon as soil conditions are favorable in the spring.

Overseeding should be done when the soil is loose and friable from frost action. This practice allows a growing season approximately 6 to 8 weeks longer than when complete preparation of seedbed is performed.

Total estimated savings achieved from overseeding 32,749 acres has been $8,458,075 for the 15-year period. Table 1 gives the number of miles, acres of overseeding and fertilizing for 1971 through 1985, and includes other bid items relating to permanent seeding.

Table 2 gives the estimated savings achieved from performing aerial seeding. The savings resulting from the elimination of seedbed preparation is the difference between overseeding and fertilizing and seeding and fertilizing, which requires complete seedbed preparation. The estimated savings resulting from the existing drop residue serving as mulch is based on the bid item for mulching when it is done by normal seeding methods. In studying Table 2, it can be seen that extensive savings are achieved by using the aerial seeding method. Aerial seeding includes the application of the seed into existing stabilizing crop residue in early spring without additional soil preparation or mulching and when soil conditions are subject to frost action. The following table gives the estimated savings from 1971 through 1985.

Year	Savings ($)	Year	Savings ($)
1971	230,184	1979	943,400
1972	403,200	1980	433,596
1973	816,060	1981	329,474
1974	465,840	1982	117,521
1975	852,048	1983	365,862
1976	1,119,581	1984	400,140
1977	707,728	1985	703,171
1978	569,910		

Figure 1 shows Plate 1, which provides an analysis of all projects. Significant advances have been made in the seeding operation for the application of the permanent seed for erosion control on Iowa highways. There is, of course, a certain amount of each project that cannot be seeded or is not practical to be seeded, by overseeding methods. Because of the construction scheduling in paving contracts and the shouldering and shaping of the final foreslope, it may be necessary to prepare the seedbed in a normal manner. For both divided and dual-lane highways, the top 12 to 15 ft of the upper portion of the foreslope, as well as the entire median area for divided highways, may require seedbed preparation, seeding, fertilizing, and mulching.

Overseeding is not a new practice. It was used many years in Iowa before the practice of aerial seeding primarily for the seeding of legumes on projects in which the permanent grasses were seeded in the fall. Usually this seeding is done with a hand cyclone seeder or regular field equipment if the ground is dry enough to permit this type of operation.

SOIL CONDITIONING

The stabilizing crop seeding and fertilizing included in the grading contracts provide the general condi-

Office of Road Design, Highway Division, Iowa Department of Transportation, Ames, Iowa 50010.

TABLE 1 Average Bid Price for Permanent Seeding and Erosion Control, 1971-1983

Year	Activity	No. of Miles	No. of Acres	Average Bid Price ($)
1971[a]	Overseeding and fertilizing	59	1,656	74.00
	Seeding and fertilizing		1,474	103.00
	Seeding, fertilizing, and mulching		1,503	217.00
	Mulching		1,462	110.00
	Mowing (3)		8,304	5.00
1972[a]	Overseeding and fertilizing	103	3,200	85.00
	Seeding and fertilizing		1,900	116.00
	Seeding, fertilizing, and mulching		662	229.00
	Mulching		1,812	95.00
	Mowing (3)		14,667	6.00
1973[a]	Overseeding and fertilizing	108	2,814	120.00
	Seeding and fertilizing		1,013	245.00
	Seeding, fertilizing, and mulching		629	332.00
	Mulching		1,346	165.00
	Mowing (3)		9,322	11.00
1974[a]	Overseeding and fertilizing	82	1,941	175.00
	Seeding and fertilizing		60	250.00
	Seeding, fertilizing, and mulching		187	391.00
	Mulching		29	170.00
	Mowing (3)		6,329	12.50
1975[a]	Overseeding and fertilizing	87	2,928	179.00
	Seeding and fertilizing		436	317.00
	Seeding, fertilizing, and mulching		212	470.00
	Mulching		1,023	229.00
	Mowing (3)		10,487	12.00
1976[a]	Overseeding and fertilizing	206	4,889	179.00
	Seeding and fertilizing		993	275.00
	Seeding, fertilizing, and mulching		144	408.00
	Mulching		1,218	232.00
	Mowing (3)		14,749	12.00
1977[a]	Overseeding and fertilizing	82.5	2,492	168.00
	Seeding and fertilizing		948	282.00
	Seeding, fertilizing, and mulching		115	452.00
	Mulching		1,051	192.00
	Mowing (3)		7,956	10.00
1978[a]	Overseeding and fertilizing	70.2	1,727	190.00
	Seeding and fertilizing		721	287.00
	Seeding, fertilizing, and mulching		58	707.00
	Mulching		734	233.00
	Mowing (3)		5,321	10.00
1979[a]	Overseeding and fertilizing	93	2,650	205.00
	Seeding and fertilizing		894	286.00
	Seeding, fertilizing, and mulching		119	663.00
	Mulching		727	275.00
	Mowing (3)		7,986	12.00
1980[a]	Overseeding and fertilizing	68	1,682	225.00
	Seeding and fertilizing		426	248.00
	Seeding, fertilizing, and mulching		240	514.00
	Mulching		661	235.00
	Mowing (3)		5,082	13.00
1981	Overseeding and fertilizing	77	1,282	216.00
	Seeding and fertilizing		809	234.00
	Seeding, fertilizing, and mulching		2,128	550.00
	Mulching		491	239.00
	Mowing (3)		3,861	12.00
1982	Overseeding and fertilizing	24	527	262.00
	Seeding and fertilizing		306	268.00
	Seeding, fertilizing, and mulching		168	595.00
	Mulching		715	217.00
	Mowing (3)		2,039	16.00
1983	Overseeding and fertilizing	36	1,302	253.00
	Seeding and fertilizing		370	287.00
	Seeding, fertilizing, and mulching		64	585.00
	Mulching		723	247.00
	Mowing (3)		4,737	16.00
1984	Overseeding and fertilizing	45	1,482	227.00
	Seeding and fertilizing		103	247.00
	Seeding, fertilizing, and mulching		206	497.00
	Mulching		103	250.00
	Mowing (3)		4,514	14.00
1985	Overseeding and fertilizing	72	2,177	228.00
	Seeding and fertilizing		177	283.00
	Mulching		171	268.00
	Mowing (3)		6,531	15.00

[a]Based on summary of awarded contracts for the calendar year.

TABLE 2 Overseeding (Aerial Seeding), Estimated Savings for Permanent Seeding and Erosion Control, 1971-1985

Year	Miles Seeded	Acres Seeded	Averaged Bid Overseeding and Fertilizing Per Acre ($)	Additional Cost for Seedbed Preparation Per Acre ($)	Additional Cost for Mulching Per Acre ($)	Estimated Savings, No Seedbed Preparation Required ($)	Estimated Savings, No Mulch Required ($)	Total Savings by Overseeding ($)
1971[a]	59	1,656	74	29	110	48,024	182,160	230,184
1972[a]	103	3,200	85	31	95	99,200	304,000	403,200
1973[a]	108	2,814	120	125	165	351,750	464,310	816,060
1974[a]	82	1,941	175	70	170	135,870	329,970	465,840
1975[a]	87	2,928	179	138	153	404,064	447,984	852,048
1976[a]	206	4,889	179	96	133	469,344	650,237	1,119,581
1977[a]	82	2,492	168	114	170	284,088	423,640	707,728
1978[a]		1,727	190	97	233	167,519	402,391	569,910
1979[a]		2,650	205	81	275	214,650	728,750	943,400
1980[a]		1,682	225	23	235	38,686	395,270	433,956
1981	77	1,282	216	18	239	23,076	306,398	329,474
1982	24	527	262	6	217	3,162	114,359	117,521
1983	37	1,302	253	34	247	44,268	321,594	365,862
1984	45	1,482	227	20	250	29,640	370,500	400,140
1985	72	2,177	228	55	268	119,735	583,436	703,171

[a]Based on summary of awarded contracts for the calendar year.

PLATE No. 1
Permanent Seeding Fiscal 1985
Low Bid Costs

Projects: 17
Acres: 2,177.0

Total Miles: 72.1
Total Contract Cost: $1,387,720

Project	Miles	Acres	Bid Price (per acre)	Total Overseeding and Fertilizing	Seedbed Preparation, Seeding and Fertilizing (per acre)	Mulch (per acre)	Wildflower Seeding (lb)	Native Grass (acres)	Total Project Cost
Black Hawk (11) 520	1.0	70	$230	$ 16,790	$260	$250	68		$ 47,184
Black Hawk (29) 380	3.1	151	230	34,730	260	250	20.6		78,801
Black Hawk (27) 380	3.0	302	240	72,480	280	250	7		132,490
Black Hawk (63) 380	1.6	60	240	14,400	280	250	11		43,258
Wapello 1	5.5	90	200	18,000	325	325	16	3.7	51,605
Poweshiek 146	2.4	22	325	7,280	350	350	4		27,764
Muscatine (34) 61	3.5	67	196	20,171	222	200	12	67.2	61,594
Muscatine (42) 61	4.3	106	196	20,776	222	200	24	126	73,566
Chickasaw (10) 63	4.4	50	240	12,000	300	300	6.2		22,524
Chickasaw (26) 63	4.9	47	240	11,280	300	300	5.8		20,192
Bremer 63	13.0	141	240	33,840	300	300	17		68,334
Polk 35	4.0	130	237	30,755	282	282	27.5		221,192
Benton 380	4.0	280	205	57,400	280	300	23.6		160,918
Linn (72) 380	4.9	239	230	55,085	280	250	23.6		128,536
Linn (75) 380	6.9	268	230	61,755	280	300	23.6		135,340
Linn (78) 380	2.3	100	205	20,500	280	300	11.8		59,788
Scott 61	3.3	51	340	17,340	520	340			54,635
Total	72.1	2,177	Ave. 228	$497,582	Ave. 283	Ave. 268	301.7	196.9	$1,387,720

Average cost overseeding and fertilizing	$228/acre
Average cost seedbed preparation, seeding, fertilizing and mulching	$551/acre
Savings (no seedbed preparation or mulch)	$323/acre
Total savings 2177 acres x $323	$703,171

*Total project includes all seeding, sodding, special ditch control, mowing, water for ditch control, traffic control, and mobilization.

FIGURE 1 Analysis of all seeding projects.

tioning of the soil. The abundant vegetation cover, basically weed-free, together with the root structure to bind the soil particles, minimizes erosion.

The seed mixture consists of the following: winter rye, sudangrass (piper) fescue, Ky. 31, and alfalfa (ranger or vernal) for early spring; sudangrass (piper), fescue Ky. 31, and alfalfa (ranger or vernal) during the summer; and winter rye, fescue Ky. 31, and alfalfa (ranger or vernal) for the fall schedule. All areas that are not seeded by September 30 are to be rough-finished. The more critical areas may be scarified, fertilized, and mulched with the mulch to be anchored with the mulch tiller. This practice provided a natural environment to use the overseeding technique by aerial or other adaptable equipment.

PERFORMANCE

The first two projects in 1971 consisted of more than 600 acres. The seeding was done between the first of March and the first of April. The standard specifications require that the seed be applied when the ground is loose and friable from frost action. Overseeding techniques are used only in the early spring and are not practical for fall seeding when complete seedbed preparation is required. In all cases, establishment of the vegetation has been considered excellent when compared with seeding done by the standard procedures, which are usually carried out during the end of the spring seeding period.

By using a helicopter, enough seed can be carried to seed 8 acres. A small airplane can carry enough seed for 8 acres whereas a larger airplane can carry enough seed for 12 to 24 acres. It is necessary for the pilot to use a good deal of judgment in order to get the seed applied at the proper rate.

In order to calibrate the seeding equipment, one or two test plots are staked out based on the capacity of the equipment. It is the contractor's obligation to see that the seed is applied at a uniform rate. It then becomes the pilot's obligation to secure a uniform distribution of seed. To achieve this, a minimum of two passes are made over a given area. By seeding at one-half rate, a uniform distribution of seed is achieved.

The contractor makes his own arrangements with an aerial seeding firm. The aerial seeding firm may furnish all related equipment, the pilots as well as necessary ground personnel, which usually consists of one man and two-way radios so there can be ground-to-air communication in order to monitor and control the seed application.

The rate of seed application varies from 30 to 50 acres per hour with wind conditions calm or less than 10 mph. Gusty wind causes poor seed distribution and an unsafe condition for the control of the aerial seeding equipment. Uniform application of seed has been obtained with the air speed of 40 to 45 mph for the helicopter at an altitude of 30 to 45 ft. The width of the swath being seeded varies from 40 to 45 ft.

SUMMARY

The helicopter, which has the side-mounted seed hoppers and all seeding apparatus within the confines of the helicopter, makes a compact unit that is easy to maneuver. The unit with the suspended seed hopper has the advantage of being able to reach into tight corners; however, it has the disadvantage of being more unwieldly to handle. The airplane does an excellent job during low-wind conditions and when few obstacles exist on the highway right-of-way and the right of way is of uniform width.

The following data and dimensions are provided for aircraft used for overseeding.

	Helicopter with Suspended Bucket	Helicopter with Side Mounts	Airplane
Size of batch, acres	8	8	8-20
Air speed, mph	40-45	40-45	90
Altitude, height	40-45	25-30	50-60
Swath spread, width	45-50	40-45	45-55

In the operations in Iowa, the erosion-control contractor furnishes the seed, the fungicide, the inoculant, and sufficient ground personnel to handle processing of the seed. Because a large volume of seed can be used in a very short period of time and because of the effectiveness of this type of seeding, efficiency is one of the keys for economy. The contractors have streamlined their own operation in order to provide fast service with a minimum of unproductive time for the helicopter. Probably the most satisfactory service has been obtained when a large-capacity mixing unit, such as that used in the livestock industry, was used for mixing the seed. The appropriate proportions are put in the mixing unit. After it is thoroughly mixed, the seed can be augered into containers and weighed on a platform scale to determine proper quantity of seed to use for the project. While the pilot is applying a load of seed, ground personnel are preparing for the next load. For an 8-acre load, four containers of seed are prepared to empty into the hopper when the pilot returns for seed. This results in a minimum of downtime.

Under most conditions, the fertilizer is applied at a later date when the ground is firm and can support normal field spreaders with flotation tires. On some projects the helicopter has been used to spread the fertilizer. This method of application may be used because of extremely unstable and wet soil conditions. During fiscal year 1985, some contractors used the helicopter for the second or fall application of fertilizer.

In 1971 aerial seeding firms charged the contractor $1.50 to $2.00 an acre for the application of seed. This varied somewhat, depending on the size of the job. For fiscal year 1985, the average cost was approximately $8.00 per acre for applying seed and $14.00 per acre for applying fertilizer. This type of work is attractive to the aerial applicators because it is required during the last part of February and the month of March. This time of year is extremely slack for other aerial application work.

This brief description of aerial seeding is intended to provide information about a practical, proven, and economical method of permanent seeding for highway use.

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Do White-Tailed Deer Avoid Red? An Evaluation of the Premise Underlying the Design of Swareflex Wildlife Reflectors

JAMES L. ZACKS

ABSTRACT

The increase in deer-vehicle accidents has created a demand for preventive measures. A red reflector system (Swareflex wildlife reflectors) that reflects vehicle headlights to the side of the road has been claimed to frighten deer from the highways because red is instinctively frightening to the deer. Using penned deer, this research examined the premise that red is instinctively frightening to the white-tailed deer by measuring the effectiveness of red reflectors in keeping deer from crossing a line defined by the reflectors. No evidence was found that the deer avoid the area marked by the reflectors, or that they exhibit any other behavior that suggests that red is instinctively frightening to them. The results are considered in the light of other reports that vary in the degree to which they suggest that the reflectors are effective on the highway. It is argued that, where they are effective, the reflectors may have influenced the behavior of the drivers rather than the behavior of the deer.

Because of the steady increase in deer-vehicle accidents in recent years, it has become desirable to find a means to keep the white-tailed deer off of the highways when vehicles are present. In 1971 a red reflector system was introduced that reflects vehicle headlights to the side of the road to frighten the deer away from the roadway until the vehicle has passed. The basis for the reflector system is the assumption that

> red light exerts a warning effect on deer. . . . The headlights of approaching vehicles strike the wildlife reflectors which are installed on both sides of the road. Unnoticeable to the driver, these reflect red lights into the adjoining terrain and an optical warning fence is produced. Any approaching wildlife is alerted and stops or returns to the safety of the countryside. (Unpublished data on Swareflex wildlife warning reflectors, manufactured by D. Swarovski and Company, Rock Island, Illinois.)

Although the Swareflex reflector system has been in use for a number of years, its effectiveness is still in question (1). Thus far, most of the attempts to evaluate the reflectors have involved installing them along a roadway and comparing the rate of vehicle-deer collisions with the collision rate when the reflectors are not in place. The present research focuses instead on the manufacturer's claim that the white-tailed deer are afraid of the illuminated red reflectors to the extent that they either stop or run away when the reflectors are illuminated. Although it has been shown previously that the white-tailed deer has sufficient color vision to discriminate a band of long wavelengths (which looks red to humans with normal color vision) from white, there have been no data to support the claim that red frightens the deer (2).

In this report an experiment is described that attempts to test the claim that the red reflectors are inherently frightening to the deer. This was accomplished by arranging several red reflectors in a line and illuminating them in a manner similar to that in which they would be illuminated on the highway. The behavior of the deer was then monitored to determine whether the presence of the red reflectors deterred the deer from crossing the line marked by the reflectors. It is shown in this paper that the results of the experiment provide no evidence that the white-tailed deer responds any differently to the presence of red Swareflex reflectors in a headlight beam than it does to white reflectors of the same geometry, or to the headlight beam with no reflectors. Other attempts to evaluate the effectiveness of the reflector system in the face of the research results are also discussed. The reported reduction in the number of deer killed in what appears to be the best highway study to date, is more likely a result of an increase in driver attentiveness than an effect of the reflectors on the behavior of deer.

The present experiment was specifically designed to evaluate the claim that an optical barrier of red reflectors would, when illuminated, frighten deer from crossing the barrier. The claim was evaluated under conditions that in some ways approximated those in which the reflectors might actually be used. A group of 10 white-tailed deer was housed in a large pen. They were encouraged to move about in the area where the reflector barrier was set up by providing

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Through no fault of the author's the publication of this paper was inadvertently delayed from its original publication date of 1985.

the primary sources of water for the animals in that area.

Movement of the deer across a line defined by five sign posts was monitored under three different conditions. Red Swareflex reflectors, identical white Swareflex reflectors, or no reflectors at all were installed on the posts and illuminated by vehicle headlamps at night. If red Swareflex reflectors were frightening to the deer because of their color, then the deer would have been less likely to cross the illuminated reflector barrier than when no reflectors were present. White reflectors were used as a control condition to evaluate further the claim that an inherent fear of red is what makes the reflectors effective.

METHODS

Following is a description of the methods used in conducting the experiment.

Animals and the Site

Ten white-tailed deer (*Odocoileus virginianus*) were housed in a 3.5-acre pen (Figure 1). Three yearling bucks and seven yearling does were chosen to approximate the ratio of males to females in the Michigan deer herd during the fall before hunting season. All of the deer were bred at the facility. The does had previously participated in experiments in which the effects of trace elements in their diet were investigated.

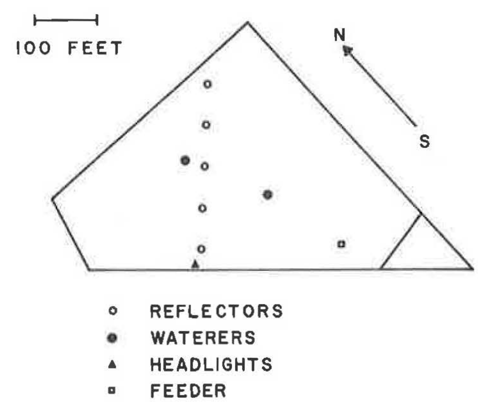

FIGURE 1 A map of the pen.

The deer were released into the pen on July 11, 1984 and final data collection occurred between August 20 and October 6, 1984. The deer were fed a commercially prepared exotic game feed that was continuously available from a hog feeder, which was refilled as needed. Water was available from two waterers separated by about 150 ft. Each waterer consisted of a covered reservoir from which water could be dropped into an aluminum pan. A toilet flush valve was used to release about 3 L of water with considerable splashing noise. A toilet float valve was used to control the refilling of the reservoir and the quantity of water per flush. The flush valve of each waterer was operated remotely by a radio-controlled servomotor.

To encourage a rapid response to the operation of a waterer, small holes were made in the bottoms of the aluminum watering pans. The water that was flushed into the pans drained out in about 1.5 min if it was not consumed by the deer. It was absorbed into the sandy soil very rapidly. During the period when data were being collected, the deer received most or all of their water during the course of the experiment, as described in the following paragraphs.

Experimental Procedure

Five sign posts were installed in a straight row across the pen and between the two waterers. They were spaced at intervals of 66 ft as recommended by the manufacturers of the reflectors. A bolt was installed on each post 42 in. above the ground. A reflector could be quickly installed or removed from the bolt. The terrain that was crossed by the reflector row was nearly flat, the difference between the heights of the highest and lowest posts being only 14 in. At one end of the line of reflectors, a pair of automobile headlamps was mounted in a position that simulated their location if they were actually installed in a vehicle that was driving down a road; the nearest headlamp was about 6 ft to the side of the reflector line. The headlamps were powered at 12 volts AC through a transformer.

From the west end of the reflector line, just outside of the pen and just behind the location of the headlights, the experimenter could view the deer, record data, and operate the waterers. Operation of a switch by the experimenter recorded the time and direction of each passage of a deer on a chart recorder. The definition of when a deer had crossed the line was arbitrary, but consistent across conditions. A crossing was recorded at the time that more than one-half of the animal's body was judged to have crossed the line. Because the animals often grazed in the area along the posts, they sometimes grazed right up the line, meandering onto it, and then back off it again. They similarly tended to walk up to the posts and lick them, sticking their heads up to or across the line, but often not crossing with the rest of their bodies. The most important fact is that the criterion for crossing the line was applied consistently and the behavior of the animals across the conditions did not differ in any way that would lead to a differential effect of the criterion under different conditions.

The author and two other people trained by the author served as the experimenter on separate occasions. A session was begun after sunset, when it was sufficiently dark so that automobiles that were driving under those conditions would have their headlights on. The passage of cars and trucks on a road that passed the pen was monitored to determine whether the passing vehicles had their headlights on. A session was never begun until a number of vehicles had passed, all having their headlights on.

On each night, each of the three conditions (no reflectors, white reflectors, and red reflectors) was tried. The order in which the conditions were run was varied according to a predetermined, counterbalanced order so that each possible order was run equally often. With three conditions, there are six different possible orders. Each order was repeated three times, for a total of 18 different sessions.

The basic procedure began with setting up the reflector condition. Then the headlights were turned on. For the next 15 min, every time that a deer crossed the line, the crossing and its direction were recorded. At the end of the first 5-min period, the waterer to the north of the line was operated once, loudly spilling about 3 L of water into the pan. At the end of the second 5-min period the waterer to the south of the line was operated. At the end of the next 5-min period (total of 15 min) the headlights were turned off. The experimenter then changed the reflectors to the next condition, using a flashlight if it was too dark to see without it. It usually took between 2-1/2 and 3-1/2 min to make the change. Five minutes after the headlights had been turned off, they were turned back on with the new reflector condition installed, and the procedure was then repeated. The deer were observed for 15 min, with each waterer operated once during this interval as in the first interval. Then the lights were turned off and the reflectors were changed again. After the third reflector condition was installed, a final 15-min observation interval was repeated. (See Figure 2.)

Early in the experiment, several cycles were run

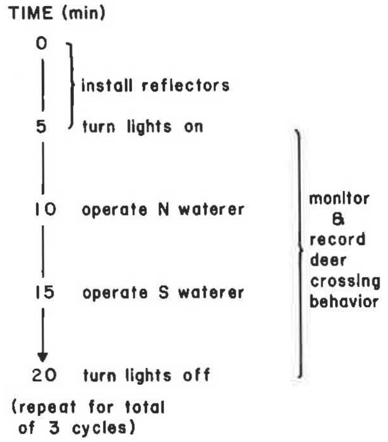

FIGURE 2 Diagram of the time course of a session.

each night, repeating the same pattern of alternation among the three reflector conditions two or three times. However, it was observed that the deer tended to be much more active during the first hour after the start of the session than later, when they often bedded down, so this practice was eliminated and each reflector condition was used only once per evening. The final data analysis is based only on the data from the first cycle through the three reflector conditions on any evening. Sessions in which the total number of crossings was less than 13 were repeated at a later time. Three sessions had to be repeated for this reason.

The data thus gathered consisted of the times and directions of each crossing of the signpost line by an animal. In addition, a log was kept in which were noted the crossings and type of movement, such as whether the animals were running, walking, grazing, and so on. (Any other salient events were also noted.) The experimenters were particularly careful to note the responses of the animals when the lights were first turned on, especially early in the experiment. The purpose of this was to determine whether there was any behavioral evidence that the animals were or were not especially responsive to the red reflectors (or the other two conditions) in a way that might not have been captured by the crossing data. (Note: on one evening, because the deer were exceptionally active, two different sequences were run.)

RESULTS

The principal question is whether the deer cross the reflector barrier less often when red reflectors are installed than when there are either white reflectors or no reflectors at all. Following is a discussion of the experiment results.

The Main Effect of Varying the Reflectors

Of the 720 crossings that were observed in 18 sessions, the deer crossed the barrier line 264 times when no reflectors were installed, 256 times when red reflectors were installed, and 200 times when white reflectors were installed. (See Figure 3.) An analysis of variance found no statistically significant effect of the reflector condition ($F[2, 34] = 1.62$, $p > .10$). The only trend in the data, which did not approach statistical significance, was in the direction of the white reflectors; this reduced the crossing rate relative to both the red-reflector and no-reflector conditions.

In addition to the quantitative measures of barrier crossings, the experimenters wrote verbal descriptions of the animals' behavior. No systematic method was used to describe these other aspects of

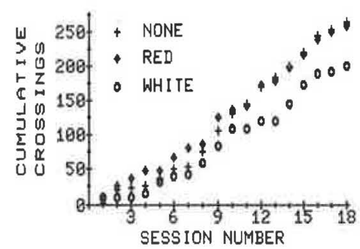

FIGURE 3 Total crossings in each session for each reflector condition.

the deer's behavior, but the experimenters were especially alert for any other behavioral indications of whether the animals reacted to the reflectors. There were none. From the very first time, the deer appeared not to respond in any observable way to the presence of the reflectors. Each of the three experimenters concurred that they would not be able to tell, from observing the behavior of the deer, which reflectors were installed. It was common to observe animals browsing in the area illuminated by the headlamps, and to see them browse slowly past the reflectors as though the reflectors were not present, even when they were oriented in the direction of the reflectors. Thus the informal behavior descriptions of the deer concur with the quantitative measure of their behavior in failing to reflect any effect of the presence of the illuminated red reflectors.

The reflectors were set up as though they were marking one side of a roadway. Because they are designed to reflect the headlights to only one side of the road, it would be expected that, even if deer are frightened by the reflected light, only those deer that approach from the side to which the light was reflected would be deterred from crossing. In effect, the reflectors were not set up as a bidirectional barrier, but rather as a one-way gate. For this reason, the effects of the barrier on crossings in each direction were analyzed separately. The analysis yielded the same result as was obtained from the analysis of the combined data.

There was no significant difference between the reflector conditions for movement south to north, where the deer would be facing the reflected light, or north to south, the case in which the manufacturers claim that the reflectors would not be visible. Figure 4 shows the data separated on the basis of the direction of movement through the barrier.

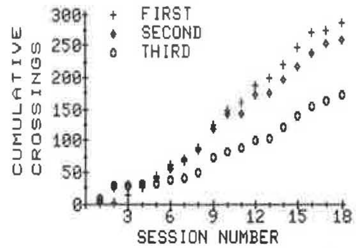

FIGURE 4 Total crossings in each session plotted separately for north-to-south and south-to-north with red reflectors.

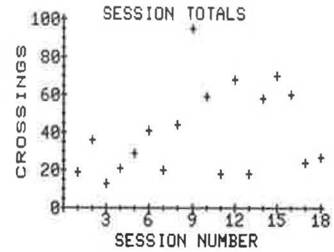

FIGURE 6 Total crossings in each session across reflector conditions.

Order Effects on Trials Within a Session

There are several additional aspects of the data that were examined. It was clear from observing the deer that they tended to become quite active somewhat before sundown and gradually to diminish their activity over the next 1 to 3 hr. For this reason an analysis of variance was performed on the effects of the order in which different reflectors were tried in a session. It can be seen in Figure 5, which summarizes the results, that there is a distinct tendency for the number of crossings to decrease over trials in a session. This decline was significant ($F[2, 34] = 5.84$, $p<.01$). Because the order in which the reflector conditions were run in different sessions was counterbalanced, with each of the six possible orders being replicated three times, this order effect was not the cause of the failure to find any differential effect of the reflector condition.

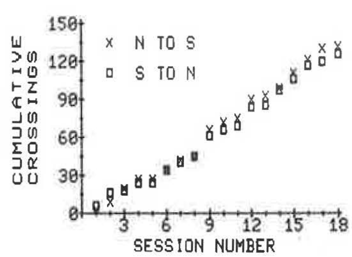

FIGURE 5 Total crossings in each session arranged in the order in which they were run.

Variations in the Number of Crossings Per Session

There was considerable variation in the number of crossings observed per session. Data from 3 out of 21 sessions were discarded because of a failure to observe a minimum of 13 crossings in each. Of the 18 sessions on which the main data analysis is based, a mean of 40 crossings was observed per session. However, the standard deviation was about 23, with a minimum of 13 crossings and a maximum of 95 crossings observed in different sessions. There was a slight increase in the number of crossings per session but the effect was small compared with the overall day-to-day variability. The session-to-session variability in overall responding is shown in Figure 6.

DISCUSSION OF RESULTS

The present study was designed to evaluate the assumption that red is an inherently frightening color to the white-tailed deer. Although the conditions for testing this assumption were chosen to be similar to the conditions under which the reflectors were designed to be used, there are admittedly several differences between the test situation and conditions along a real highway. For example, the headlights in the study were stationary rather than moving, the noise of a moving vehicle was lacking, and the deer became familiar with the testing situation. Although these differences might weaken the ability to generalize the results of the test to the general effectiveness of the reflectors in a highway situation, they bear less directly on the determination of whether red is inherently frightening to the deer, the question that the present research was designed to address.

The claim that red is an innately frightening color receives no support from the results of this research. The present study failed to reveal any effect of red Swareflex reflectors in keeping the deer from crossing a boundary that they defined. The study also failed to reveal any other gross changes in their behavior in the presence of the red reflectors. Because the assumption that red was inherently frightening to the deer was the basis for using the reflectors, it appears unlikely that they will affect the behavior of deer under highway conditions.

Although under highway conditions other factors are present, research with those factors that are present but with different reflectors showed no demonstrable effect of the reflectors (1). Thus, there is no basis for expecting wildlife reflectors to keep deer off the highways.

In view of these findings, the recent study by Schafer et al. (3) would appear to be problematic. They have installed red Swareflex reflectors on several stretches totaling 2.3 mi along SR 395 in Washington state and have alternately covered and uncovered the reflectors for successive time intervals (1-week intervals initially, and 2-week intervals subsequently). From a total of 58 deer killed at night in the test section since the beginning of the test in 1981, 52 were killed when the reflectors were covered and 6 were killed when the reflectors were uncovered. These results appear to provide a direct answer to the question this experiment attempted to address indirectly, and to have supported the opposite conclusion. There is, however, an alternative interpretation that eliminates the apparent inconsistency.

In the study by Schafer et al., Swareflex reflectors were installed on both sides of a highway at intervals of 66 ft on the straight sections and 33 ft on curves, as specified by the manufacturer. The reflectors were mounted as recommended by the manufacturer (and as mounted in the present study) so that the reflective surfaces were approximately at a 45-degree angle to the side of the road, thereby diverting the headlight beam away from the road along a line almost perpendicular to the edge of the road. The combination of a series of concave depressions in the highly reflective surface (which lies behind the red lens of the reflector) and the molded lenslets on the back of the red reflector lens causes the beam to be dispersed so that it can be viewed over a range of angles.

In the advertising literature the manufacturer suggests that the reflectors are "unnoticeable to the driver," and the illustrations show that all of the light is diverted to the side of the road. However, in the course of the current pen study, it became obvious to each of the experimenters that the color of the reflectors that had been installed was readily apparent from a vantage point behind the headlights that corresponded to the position from which the driver of a vehicle would view the scene. Thus a driver who enters a stretch of highway on which the reflector system is installed views a corridor of red reflectors that recede into the distance. In the study by Schafer et al. (3), this meant that as they covered and uncovered the reflectors, they were not only changing the conditions that the deer faced, they were also changing the conditions that the drivers faced. Because signing of a roadway with red markers on both sides of the road is unusual, and reserved for areas of extreme danger (such as proceeding the wrong way on a divided highway), it would appear plausible that the drivers would respond with increased alertness. Conventional signing for areas with high rates of automobile-deer accidents usually involves placing a small number of signs (often only one) warning of a deer crossing area. In the study by Schafer et al. (3), the warning signs are repeated every 66 ft (33 ft on curves) in the area that they protect. For this reason, it is ambiguous whether the behavior of the deer or the behavior of the drivers has been manipulated when the reflectors were covered and uncovered.

Another study, similar to that of Schafer et al., is under way in Colorado (personal communication with Dale Reed, wildlife biologist at the Colorado Department of Natural Resources). Although only 31 vehicle-deer accidents have been recorded of the 95 needed to have the desired statistical power, the number of deer killed when the reflectors were uncovered is thus far not statistically lower than when they were covered (12 killed when uncovered, 19 killed when covered), whereas Schafer et al. (3) observed a ratio of more than 8 to 1 in the number of accidents when the reflectors were covered compared with that when the reflectors were exposed. Although it is possible that there is a difference in the behavior of the deer populations in these two locales, it appears as likely that there may be significant differences in the drivers in the two studies. It would be important to determine whether there are differences such as the extent to which drivers on each of these stretches of road are local drivers who travel the roads frequently (and hence may have adapted to the presence of the reflectors) or whether they are drivers who tend to be on these stretches of roads infrequently and are confronting a novel highway signing condition. Such differences might explain differential effects of the reflectors on the behavior of the drivers in the two studies.

In summary, a plausible reconciliation of the data from the two highway studies and from this pen study is that the Swareflex reflectors do not deter the deer from moving onto the roadway, but that they cause drivers to be more alert. Further research to distinguish between these possibilities is important in determining whether it is more profitable to work toward changing the behavior of the deer or that of the drivers.

AUTHOR'S NOTE

Because this research has used Swareflex wildlife reflectors as an integral part of the research design, they have been referred to specifically rather than generically. Although the special property of these reflectors is supposed to be the color of the light reflected from them, the geometry of the lens, and so forth, are also salient features of the reflectors and would be virtually impossible to describe generically. In addition, this research was designed specifically to evaluate the Swareflex implementation of this kind of system.

ACKNOWLEDGMENTS

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The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Michigan Department of Transportation or of the Federal Highway Administration.

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Discussion

JOHN R. STRIETER

The Swareflex Wildlife Warning Highway Reflector System has been shown by preponderance of evidence to reduce nighttime deer-vehicle collisions by 50 to 100 percent. Exhaustive tests were conducted in

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Austria beginning in 1971, and testing begun in the United States and Canada in 1979 continues today.

Basically, objections are made to two conclusions in the paper. First, that white-tailed deer do not respond to the presence of red reflectors and second, that reflectors influence the behavior of the driver, rather than the behavior of the deer, in reducing roadkill.

The following aspects of Zacks' investigation and research project are analyzed:

1. Ten pen-raised yearling deer confined to a fenced area were used instead of wild deer in their native state.
2. Stationary headlight beams illuminating a single row of reflectors do not adequately simulate actual nighttime highway conditions of moving vehicles.
3. Drivers are generally unaware of reflectors along the roadways and do not become more alert when passing through a Swareflex reflectorized area.

The investigation does not take into account the designed function of Swareflex reflectors, namely, that as patterns of red optically moving lights progress ahead of vehicles they alarm the deer for a sufficient duration to permit vehicles to pass safely. Eyewitnesses have observed deer running toward, or standing beside, the reflectors suddenly turn and run away from the highway when the reflectors were lit up from a passing vehicle.

The methodology used and the conclusions drawn by James L. Zacks in the published report titled "An Investigation of Swareflex Wildlife Warning Reflectors" (1), and the paper in this Record titled "Do White-Tailed Deer Avoid Red?: An Evaluation of the Premise Underlying the Design of Swareflex Wildlife Reflectors" is the subject of this discussion.

In any test of a product it is reasonable to assume that the conditions used simulate true and actual conditions under which the product is intended to perform. However, the research and conclusions in Zacks' investigation are almost totally out of context with actual conditions under which Swareflex reflectors have been proven effective. For example, 10 white-tailed deer fenced within a 1.4 hectare area were used instead of wild deer in their natural state. Yearling bucks and does were bred at the facility, and the does had participated in other experiments.

For a total of 18 different sessions, two headlights were mounted on stationary posts and lighted for 15-min cycles. Stationary headlights in a fenced environment do not simulate vehicular headlights moving at high speeds with associated sounds and fumes. Nor do they simulate moving headlights striking reflectors along both sides of a highway, causing each reflector to light up progressively ahead of the approaching vehicle, with each reflector peaking in intensity.

Zacks' conclusion that red reflectors influence the behavior of drivers rather than the behavior of the deer is not substantiated. Highway safety personnel state that warning signs and devices lose their effect, if there is any, after drivers have observed them for 10 days. Furthermore, drivers are unaware of the presence or purpose of the red reflectors and therefore have no reason to decrease speed or to become more alert.

The watering device, learned-response methodology for compelling deer to cross the reflector line, may override even the fear mechanisms that alert wild animals to possible dangers. In Zacks' experiment, deer are forced, through desire for water, to drastically alter their normal behavior patterns. It is suggested that a more scientific approach should have been used.

Comparison of data from an incomplete test conducted in Colorado with data from the completed test conducted in Washington state (2) was wholly inconclusive. The Colorado test required a total of 100 accidents, and only 31 vehicle-deer collisions were recorded at that time. Several empirical tests showing effective reflector results were not considered.

In evaluating the Zacks investigation, I sought unbiased appraisals from three biologists: Lee Gladfelter, Wildlife Research Station, Boone, Iowa; Bill Davidson, Idaho Fish and Game, Pocatello; and Erich Klinghammer, Purdue University, West Lafayette, Indiana. All have distinguished themselves in wildlife management and study.

The first objection is to the use of deer in a fenced area. Deer had become adjusted to a pen-reared environment and were conditioned to rapidly responding to a remote-controlled noisy watering device that emptied quickly if they did not rush to it. The reflectors were positioned to entice deer movement through the corridor in alternate cycles of five red and five white lights reflected from two stationary headlights mounted on posts.

Lee Gladfelter, Wildlife Research Biologist, wrote: "These captive animals may be . . . indistinguishable from wild deer in appearance or genetics, but certainly not in behavior, which is the main thrust of this project." (Personal communication, October 16, 1985.)

He stressed the great difference between captive and wild deer, noting that highway danger avoidance is learned from dams in the first year of life. The project tested yearlings, not adults, and none probably had been exposed to highway dangers; therefore, they would not respond in a manner typical of wild deer.

Bill Davidson, Regional Wildlife Biologist, stated: "There is always a danger when you try to anthropomorphize wild animals. Setting up the study on the basis of what a human might do and subjecting animals to the same sort of stimuli must carry some questions of applicability. Equally of concern is the use of yearling animals. Yearlings have a low experience level on survival mechanisms, and in pen-reared systems have rarely, if ever, been faced with life-threatening situations." (Personal communication, November 17, 1985.)

Zacks focused his research on the manufacturer's claim that white-tailed deer is afraid of the illuminated red reflectors.

Erich Klinghammer, Biologist, stated:

> This is not what the manufacturer has claimed. Zacks has taken an empirically tested warning system and formulated a limited, specific hypothesis, which is then tested under controlled conditions using captive deer which are used to humans, in an artificial situation which does not in essential features resemble the real situation along highways where a high number of deer kills are a problem. In my view, Phase I of the experiment is irrelevant to the basic question, 'Will the Swareflex Reflectors reduce roadkills by cars?' (Personal communication, November 29, 1985.)

Klinghammer also criticized segments of Phase II:

1. A relatively small number of deer was used in a familiar setting.
2. Stationary stimuli in a row illuminated by a constant light source do not simulate moving auto lights.
3. Humans that didn't elicit avoidance

response took active roles in the experiments.
4. Thirst motivation enticed deer to cross illuminated lines.
5. Missing is the essential control group: wild deer in the same setting, which would not work because they would not be tractable in this situation, or direct observation of deer in the wild.

Klinghammer indicated that he based his observations on his personal knowledge of white-tailed deer in the wild and of captive deer at Wolf Park, near Battleground, Indiana, where he kept such deer years ago.

For a total of 18 different sessions, the stationary headlights were illuminated for 15-min cycles, during which spilling water was released to entice the deer to cross in front of the lights. Humans entered the pen in the presence of the deer after each cycle to change or remove reflectors.

Gladfelter made these further observations:

> I do not feel that the stationary headlights' beams illuminating a row of five reflectors properly simulates the conditions encountered by deer on a reflectorized stretch of highway. Noise and movement associated with a vehicle moving down a highway at night are missing in the experiments. The changing angle and intensity of light on the reflectorized surface certainly would be more noticeable to an animal near the highway than the reflected light from stationary headlights. I personally feel that this is the single most important concept of reflectors.
>
> The color of the flickering light is not the question here, but how effective the reflector is at reducing highway mortality of deer. The 66-ft spacing of reflectors is designed for a moving vehicle. With this stationary project design, only the first two or three reflectors are obtaining good light intensity with the remaining reflectors too far from the light source to be properly illuminated. In a reflectorized portion of highway, a deer is exposed to danger for just a few seconds, but this test studies behavior during 15 minutes of continuous lighting. It does not, or could not, evaluate that fraction of a second decision a wild deer might make to avoid a highway crossing when confronted by a vehicle moving through a reflectorized section.

The statistically valid results of the 90 percent reduction in nighttime roadkill in the Washington State Department of Transportation report were not considered in this investigation (2). The premise that drivers might see the reflectors and respond with increased alertness is disputed by monitors of actual Swareflex reflectors' tests. Reflectors in four approximately 1/4-mi locations were alternately covered and uncovered at 2-week intervals during the late fall to early spring from 1981 to 1984. Assuming drivers were more cautious when reflectors were uncovered, in the first 2-week period they would have slowed in the area where reflectors were uncovered, then sped up in the second area (no red lights) where they were covered, slowed again in the third uncovered area, and finally accelerated again in the fourth covered area. During the second week, they would have had to reverse driving habits when different areas were covered. However, this type of erratic speed up-slow down driving is not reflected in test results. Nor does it appear likely that any motorists would accept such traffic regimentation.

I believe that the field data collected since 1971, which indicate an average 80 percent reduction of nighttime roadkills by reflectors, is a far better analysis of the effectiveness of the Swareflex reflector system.

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Author's Closure

John R. Strieter, the U.S. distributor of Swareflex Wildlife Warning Reflectors, has raised a number of objections to the arguments advanced in my paper. These objections led him to challenge two of my conclusions:

1. He questioned whether I have demonstrated convincingly that white-tailed deer are, under natural conditions, not afraid of red reflectors, a conclusion that I drew from the results of experiments that I reported.

2. He disagreed with my proposed reinterpretation of the results of Schafer et al. (1). In their experiment they observed a reduction in the number of white-tailed deer killed when red Swareflex reflectors were installed beside a roadway and compared this reduction to the number of deer killed when the reflectors were not visible to the deer. Because in my research white-tailed deer showed no change in their behavior in the presence of illuminated red Swareflex reflectors, I was led to consider alternative explanations of the results reported by Schafer et al. I suggested that their results might have been due to an increase in driver awareness resulting from drivers seeing the red reflectors, rather than the result of any response of the deer to the reflectors.

I will review Strieter's objections and consider the extent to which they cast doubt on my conclusions.

Is there other evidence that suggests that Swareflex reflectors are effective? Strieter began his arguments with the claim, reiterated several times, that there is extensive evidence showing the reflectors to be effective in reducing deer-vehicle collisions. He suggested that my results are anomalous in that context. Although he claimed that there was a significant reduction in vehicle-deer collisions when Swareflex reflectors were used, few published sources of such data exist other than the report by Schafer et al. (1), which is discussed next.

There are two published reviews of the evidence on this issue. The first, by Gilbert (2), concluded that

> There is no statistically valid evidence that either the Van de Ree stainless steel

mirrors or the Swareflex red reflectors reduce vehicle-deer collisions. The only statistically valid test with a minimally sufficient sample size concluded that the Swareflex reflector was ineffective [Woodard, et al. (3) 1973].

More recently Reed and Ward (4) have reached a similar conclusion about the effectiveness of wildlife reflectors, including the Swareflex reflector system. Thus, the published record does not support Strieter's suggestion that there are substantial data that demonstrate the effectiveness of Swareflex wildlife reflectors. In addition to the published research, Strieter alludes to anecdotal reports from customers who have installed the reflectors in varied settings. However, these reports are usually incomplete and involve few, if any, of the appropriate controls necessary to make evaluation of the reflector system's effectiveness possible. For this reason they must be viewed with extreme caution.

Has my research isolated the principles on which design of Swareflex reflectors is based? Strieter's arguments that my research has not took two forms. First, he argued that I failed to capture the key components of the reflector system design. He suggested that it is not simply the color, but rather the movement of the light along the line of reflectors, with each reflector peaking in intensity, that is important. Second, he argued that the research design did not simulate a real highway situation with the other stimuli associated with a moving vehicle (noise, movement, exhaust odors, etc.).

Consider first the criticism that the reflector system was designed to be effective when illuminated by a moving, not stationary, light. An understanding of the basis for the design of the reflectors must be gleaned from the advertising literature distributed by the manufacturer and its representatives. It was my reading of their claims, and the evidence that they offered to support them, that the reflectors were designed to attempt to capitalize on a presumed innate fear of red. I was not alone in this interpretation. In two different reports Schafer et al. (1) and Schafer and Penland (5) came to the same conclusion that I did. They stated that "the manufacturer of the Swareflex reflectors claim that the red color of the reflectors initiates an instinctive 'freezing' behavior in deer. Evidence for this functional response to red color has been given by Backhaus (6) and discussed by Koenig (7) and Weis (8), although Severinghaus and Cheatum (9) stated that deer are colorblind." Similarly, Reed and Ward (4) believed the reflector design to stem from the suggestions by Koenig (7) that predator eyes appear red to deer (although they challenged this "because the eyes of predators do not reflect light except from human sources").

Another reason that the succession of illuminated reflectors was not believed to be crucial was that the previous research with white reflectors, along real highways with moving vehicles, did involve their successive illumination, but the reflectors were judged not to be effective [Gilbert (2)]. Thus the red color was judged to be the significant difference in the Swareflex design.

Strieter's second argument with the design of the experiment was that I did not simulate highway conditions. This argument ignored the fact that the research was designed to isolate and assess the premise on which the design of the reflector system was based. If a response of deer to reflectors is the result of "an instinctive freezing behavior" in the presence of the reflected red light, then the other features of the highway situation would not be relevant. Similarly, I would argue that the use of penned deer rather than wild deer was not as significant as Strieter suggests. It is part of what we mean by calling a behavior innate that it is extremely stereotypical of the species and very resistant to change. Students of animal learning who sought to find species-independent laws of learning found that it was extremely difficult to make major changes in innate behavior even when they brought to bear all that had been learned about animal learning from many years of research [Breland and Breland (10)].

Still another feature of the conditions of my experiment that Strieter challenged was the procedure for attracting the deer to the reflectorized area of the pen. I used remotely controlled waterers to splash water into a metal pan. He suggested that the deer's normal fear responses to the reflectors may have been overridden because of extreme thirst. In the absence of additional information that suggestion is plausible. However, additional data argue against that suggestion. Although they were not reported, observations were made not only of the time and direction of a crossing, but also of the approximate location, and whether the animals were walking or running. If most of the crossings occurred as the deer ran to the waterers, Strieter's suggestion would be plausible. However, only a small number of the crossings were of that type. More typically, animals that may have come into the area initially, at the flush of a waterer, were observed to be remaining in the general vicinity, browsing on vegetation, wandering about, and generally walking slowly rather than running, often moving through the line of reflectors. There was nothing in the behavior we observed that would have suggested that the deer were blindly responding to the water, letting excessive thirst override their normal instinctive reactions.

Do Swareflex reflectors affect the behavior of the deer or the behavior of the drivers? The report of Schafer et al. (1) is the one, apparently well-controlled experiment that suggests that the Swareflex reflectors are effective. Although I do not dispute the statistical significance of these findings, I have suggested that there is an interpretation that is quite different from the one Schafer et al. offered. They suggested that the reflectors were effective because they kept the deer from the roadways during the time that the reflectors were illuminated by the headlamps of a passing vehicle. I have outlined the suggestion that the reflectors may have influenced the behavior of the drivers, rather than that of the deer. Strieter argued that this interpretation is unlikely because the drivers would have been observed to slow down in sections in which the reflectors were exposed, and to speed up in sections in which they were covered. He suggested that "this type of erratic speed up-slow down driving is not reflected in the test results."

Unfortunately, no systematic observations of the drivers were reported in this experiment. In addition, although slowing down in the presence of the signs would indicate a response to the signs, failure to slow down would not necessarily be evidence against an increase in attentiveness. Often, to demonstrate such a response, it is necessary to tax the limits of drivers' attention in order to show that they are paying increased attention. This might be done by observing drivers' responses to an attention-demanding situation. For example, even though the drivers in an area with reflectors might not be observed to slow down when they approach the reflectors, they might still be more attentive so that, when deer are present, they are quicker to notice them and slow down.

Only through additional research will it be possible to determine the correct interpretation of the results by Schafer et al. (1). The thrust of my alternative interpretation of the research of Schafer et al. was to suggest the direction in which additional research might go in order to determine the reason that they found the reflectors to be effective.

Because the problem of vehicle-deer collisions is serious in some areas, it might be argued that it does not matter why the reflectors worked in the experiment by Schafer et al., only that they did work. That argument is unsatisfying. For example, if my suggestion that the reflectors worked because of their effect on drivers is correct, then it raises other serious issues. Highway engineers have traditionally been opposed to using red to mean anything other than Stop. In the installation of the reflectors in my experiment, photographs verified that the reflectors were visible from a vantage point that simulated a driver in a highway situation. For this reason use of the reflectors might be unacceptable. If the reflectors have an effect on driver behavior, then additional evidence will be required to determine whether their effectiveness persists as drivers become more familiar with the reflector installations.

As illustrated in the preceding paragraph, it is important to understand the reasons for any present success in order to guide the direction of future attempts to refine and improve the use of measures to keep wildlife from the highways when vehicles are present.

In conclusion, Strieter's comments notwithstanding, certain points remain clear. First, there is no direct evidence that white-tailed deer are innately afraid of red light. Nor is there direct evidence that the behavior of white-tailed deer is influenced by Swareflex wildlife reflectors, installed beside a real highway, when illuminated by the headlamps of a vehicle moving past. The majority of published research suggests it is not.

Finally, there are plausible alternative interpretations of the one report of an experiment in which the installation of wildlife reflectors led to a reduction in vehicle-deer collisions. For these reasons it would appear prudent to refrain from the expense of installing the reflectors except where they are part of a well-designed experiment that will make evaluation of their effectiveness possible, and will provide insight into the reason for the effectiveness if it is found to exist.

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Pilot Study of Small-Scale Monitoring Methods of Herbicide Residues in Soil and Water

MARTHA T. HSU

ABSTRACT

Because of its concern for the environmental impact of roadside herbicide spraying, the Maine Department of Transportation initiated a preliminary study of small-scale monitoring methods of herbicide residues in soil and water. Samples were collected at certain time intervals after the application of herbicides to target plants. The herbicides were extracted in the department's Materials and Research Division chemistry lab, and the amount of the extracted herbicides was determined by high-performance liquid chromatograph (HPLC) in the Department of Food Science and Technology at the University of Maine, Orono. The phytotoxicity of Banvel 720 on brush was evident. One week after application, the plants started to show the effect of the herbicide, and by one month, all the foliage showed no signs of life. Herbicide residue was not detected in the water samples taken from the nearby streams. The results of soil analysis on the herbicide content were predictably erratic. The reasons for this could be attributed to many factors. For example, varying amounts of off-target spraying occurred; the sampling process was not totally systematic; and there was a long period of delay in analyzing all the samples stored in a freezer throughout the period. Viewing the individual test site separately, it is obvious that the level of herbicide suddenly diminished between 1 day and 1 week after application. In spite of the oversights and drawbacks of this project, it is encouraging that the methods of extraction and HPLC determination of the herbicide are adequate for future use. It is feasible to develop a low-budget monitoring program from local resources, the cost of which could be included in ongoing roadside spray operations.

Roadside vegetation management has long been an integral part of highway maintenance operations. Unwanted brush growth diminishes the driver's viewing range and increases pavement shading, which lowers surface temperatures thus causing ice to form in winter. Therefore public safety is a direct concern, in addition to the obvious aesthetic criteria for highway roadsides.

In order to achieve a safety clear zone between the edge of the pavement and the face of the woods, two methods are usually employed: (a) conventional mowing and hand cutting or the use of selective herbicide spray to control the unwanted brush chemically. The former is both time-consuming and costly. The latter, though effective, has aroused much public concern; the fear is that the residue may enter the groundwater or crops. The most suitable herbicide should be one that has a short, persistent period in the soil (but long enough to control the plant) and low environmental hazards.

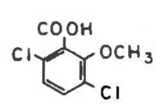
Many factors influence the soil degradation of herbicides (1), among them: the chemical structure of the herbicide, soil surface mobility, vegetative ground cover, organic matter in the soil, soil pH, soil moisture and temperature, presence of other compounds or ions, clay content of the soil, herbicide formulation, and application methods. Therefore, the rate of degradation will vary from one location to another. The only way to know whether or not a certain herbicide has been degraded is to actually sample the soil near the target plants and test for that herbicide. If enough samples were taken in one area for one type of herbicide and soil conditions, it is possible that eventually some correlation could be predicted.

The Maine Department of Transportation has been concerned about the environmental implication of roadside spray for a long time (2). Management strategies have centered on (a) chemical safety and effectiveness, (b) minimal tank-mix dilutions, (c) selective applications, (d) frequency of applications, (e) no-spray buffer zones, (f) personnel training, (g) monitoring, and (h) public information. Great strides have been made in all these areas.

In 1983 a proposal was developed to conduct a preliminary study of a method for monitoring the herbicide residues in soil and water. The main purpose of the study was to learn through experience. The study was a joint effort of the Maine Department of Transportation's Bureau of Maintenance and Operations and the Materials and Research (M&R) Division in spraying and sampling operations. The tests were performed in two parts. Part one, extraction, was carried out by the M&R chemistry lab, and part two, determination of the herbicides in the extracted samples, was accomplished by the Department of Food Science Technology under the supervision of R. Bushway.

One of the herbicides used by the Maine Department of Transportation in 1983 was Banvel 720 (12.82 percent dicamba and 24.5 percent 2,4-D). The following is a summary of the chemistry of these two compounds.

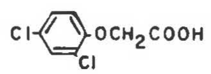
1. Dicamba, 3,6 - dichloro-o-anisic acid (3)



Materials and Research Division, Maine Department of Transportation, Box 1208, Bangor, Maine 04401.

This compound is a white crystalline solid. It is relatively mobile in the soil. Dicamba mobility in soil can be affected by leaching capillary movement or surface evaporation, or both. Metabolism by soil microorganisms is the major pathway of degradation under most conditions (3). The rate of biodegradation generally increases with increasing temperature and soil moisture, and tends to be faster when soil is slightly acidic (3). Study and experience have shown that dicamba can be leached out of the zone of activity in a humid region in a period of 3 to 12 weeks. The acute oral toxicity, LD 50, for rats is 2900 ± 800 mg/kg (3).

2. 2,4-D (2,4-dichlorophenoxy) acetic acid (3)



This compound is also a white crystalline solid, 2,4-D undergoes microbial breakdown in warm, moist soil (3). The average persistence in warm, moist soil is 1 to 4 weeks. The acute oral toxicity, LD 50, ranges from 300 to 1000 mg/kg for rats, guinea pigs, and rabbits (3).

Analysis of 2,4-D and dicamba has been the subject of numerous research publications. The extraction procedures also vary depending on the media analyzed. The Official Methods of Analysis of the Association of Official Analytical Chemists (4) included a method for formulation of the dimethylamine (DMA) salts of dicamba and 2,4-D, which are subsequently precipitated by hydrochloric acid, then extracted with acetone. The test methods include gas liquid chromatograph (GLC) (5), radioactive analysis (6), infrared spectroscopy (4), and high-pressure liquid chromatography (7).

EXPERIMENT

Selection of Application Sites

During project planning, a set of requirements were considered for the selection of an appropriate site. The site selected was close to Bangor, Maine, where the central laboratory is located. The study area included as many soil types as possible, and was to be at least 300 ft away from wells, ponds, lakes, or wetlands. The highway orientation was as close to east-west as possible; variations of slope gradient were also desirable. The population of the test area was to be sparse, and individual target plants had to be present.

Several sites were chosen and ultimately the site in Clifton on Route 9 just south of Peaked Mountain (Figure 1) was selected. The section starts at the Hancock County line running westward into Penobscot County to a point approximately 1,000 ft short of the roadside state picnic area. Target plants, both conifers and deciduous, were available on each side of this section of highway.

Before the spray operation, preliminary tests were carried out on control soil samples taken from these sites 2 days before spraying. Temperature, pH, and water content for each site are given in Table 1. The sieve analyses revealed that the soils at Sites 1 and 3 were silty sandy gravel, Sites 2 and 5 were pebbly silty sand, Site 4 was gravelly sand, and Site 6 was sandy clay silt.

Application of Herbicide

On July 27, 1983, a Maine Department of Transportation spray crew routinely sprayed the experimental section. The herbicide used was Banvel 720 (12.82

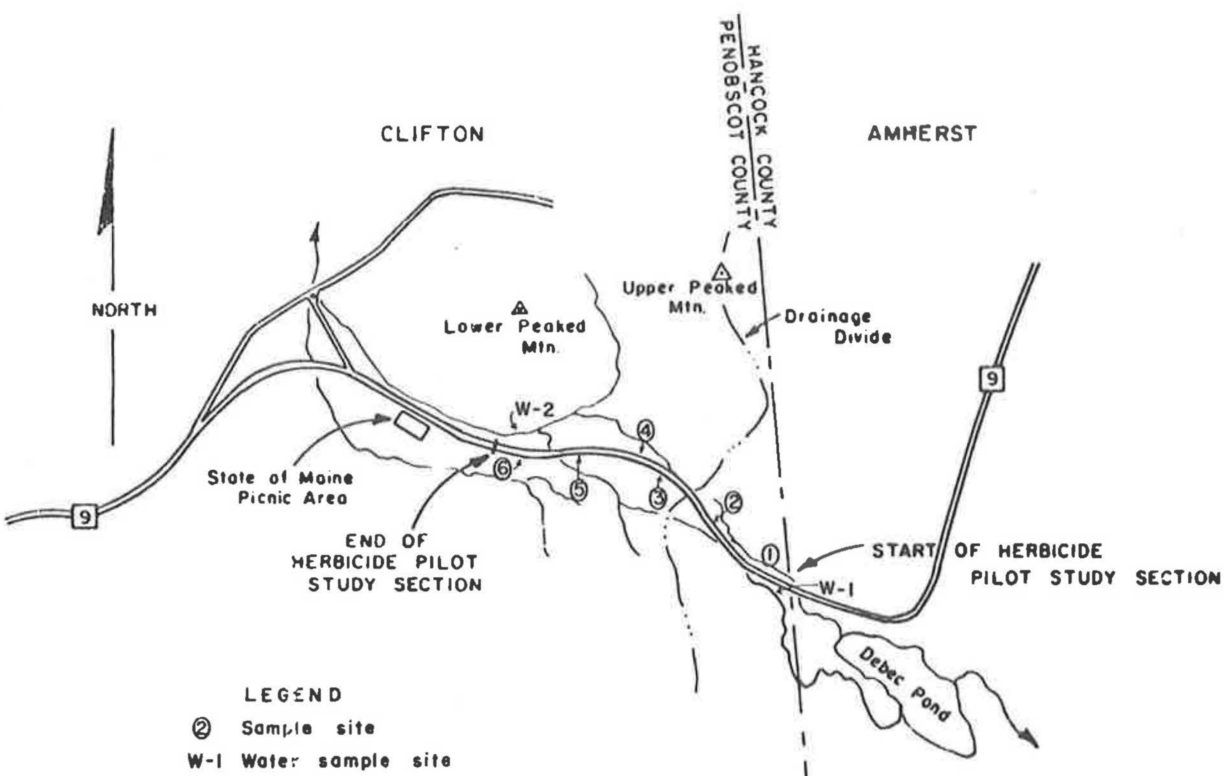


FIGURE 1 Drainage of herbicide pilot study location.

TABLE 1 pH and Temperature of the Soil at Various Spray Sites

Site	pH	Temperature (°F)	Water Content (%)
1	6.1	68	5.7
2	6.5	66	12.1
3	4.7	62	15.4
4	6.6	63	8.3
5	5.5	60	10.6
6	6.2	65	11.0

Note: Target plants are listed in Table 2.

percent dicamba, and 24.5 percent 2,4-D). The mixing rate was 3 qt/100 gal of water, or a 0.75 percent tank-mix solution.

The ambient temperature was 75°F at the time of application (daily high was 85°F, the low was 52°F) and the temperature of the soil was between 60° to 70°F, depending on the location. Sunshine was present throughout the day until around 5:00 p.m. when clouds began to form. By evening, light showers occurred for a short time.

Collection of Soil and Water Samples

Soil and water samples were collected at the following time intervals.

Control, 2 days before application	July 25, 1983
1 hr after application	July 17, 1983
8 hr after application	July 27, 1983
24 hr after application	July 28, 1983
1 week after application	August 3, 1983
1 month after application	August 26, 1983
2 months after application	September 23, 1983
3 months after application	October 25, 1983

The samples were taken with a soil sampler to within 12 in. Soils were immediately collected around the target plant at random distances. After the sample was collected, it was wrapped in a piece of heavy aluminum foil that was stored in a styrofoam ice cooler (with a piece of dry ice inside the cooler). After all the samples were collected, they were immediately transported to the chemistry lab of the M&R division and stored in a freezer. The water samples collected from nearby streams (Figure 1) were also stored in the freezer for eventual analysis by high-performance liquid chromatograph (HPLC) at the University of Maine, Orono. Direct injection was used in the HPLC procedure.

On each sampling trip the appearance of the target plants were investigated and photographic records were kept. A summary of the observation is given in Table 2.

Extraction of the Herbicide From the Soil Samples

The procedure for extracting herbicide from the soil samples was based on the procedure used by Olson et al. (5). The soil was first air-dried and then screened through a 40-mesh screen. One hundred grams of the sample was weighed into a 500 ml Erlenmeyer flask. Seventy-five milliliters of 1 N H_2SO_4 was added to the sample to make a slurry, after which 150 ml of ethyl ether was added and the mixture was shaken for 15 min on a platform shaker at a rate of 150 cpm. This solution was vacuum-filtered through a Buchner funnel, fitted with Whatman No. 1 filter paper, and washed with two portions of 5 ml water. The filtrate was transferred to a 250 ml separatory funnel, shaken for 1 min, and the aqueous layer was discarded. Fifty milliliters of 1 N NaOH were then added, shaken for 1 min, and the organic layer was evaporated. The aqueous solution was then mixed with 50 ml of methylene chloride (CH_2Cl_2) and subsequently the CH_2Cl_2 layer was discarded. The aqueous layer was acidified with 2 ml of concentrate H_2SO_4, after which 50 ml of ethyl ether was added, shaken for 1 min and the aqueous layer was discarded. The ether phase was transferred to a 500 ml suction flask and evaporated to dryness under vacuum at 50°C. The residue was then transported to the Department of Food Science Technology at the University of Maine, Orono for HPLC analysis.

Analysis of Herbicides in the Extracted Samples

For each of the extracted samples, 10 ml of HPLC grade acetonitrile CH_3CN was added, sonicated for 3 to 5 min, and transferred to a scintilation vile that was then frozen until ready to inject on HPLC. The HPLC conditions were as follows:

Solvent: 67 percent 30 mM phosphoric acid, pH = 28
33 percent CH_3CN
Flow rate: 2.9 ml/min
0.04 absorbance unit full scale (AUFS)
λ = 230 nm
Column = μ Bondapak C_{18}
psi = 1900
50 μl volume injected

The stock solution contained 20 mg dicamba (99.9 percent pure) and 23.9 mg 2,4-D (99 percent pure) in a 25-ml volumetric flask and diluted to the mark with HPLC CH_3CN. The standard solutions were prepared by diluting 1/2, 1, and 2 ml of preceding stock solution to 100 ml with HPLC CH_3CN.

The standard solutions, as well as the sample solutions, were injected to Waters High Performance Liquids Chromatograph, Model ALC-220. The amount of sample in each solution was then determined by peak height using the standard curve. If there appeared to be interferences at or around the expected retention time, the sample was then spiked 50:50 with the

TABLE 2 Target Plants and Their Appearance After Certain Time Interval

Site	Name of Plant	Time Period After Application: 1 Day	1 Week	1 Month	2 Months	3 Months
1	White pine	Healthy	1/5 needles brown	95 percent brown	All dark brown	10 percent needles gone
2	Gray birch	Healthy	1/3 leaves brown	All brown	All dark brown	Most leaves gone
3	Silver maple	Healthy	1/2 leaves brown	All brown	Most leaves gone	Leaves all gone
4	Staghorn summac	Healthy	2/3 leaves brown	Most leaves gone	Leaves all gone	Leaves all gone
5	Black spruce	Healthy	5 percent brown	95 percent brown	Needles gone	Needles gone
6	Gray birch	Healthy	1/5 leaves brown	All brown	75 percent leaves gone	Most leaves gone

most concentrated standard solution. If the peak was increased, it would be confirmed as the desired compound. If two separate peaks appeared, the presence of the herbicide in that sample would be ruled out.

RESULTS AND DISCUSSION

The phytotoxicity of Banvel 720 was evident from the results given in Table 2. One week after application, the plants began to show the effect of the herbicide, and by 1 month, all of the target foliage were without signs of life.

The water samples collected from the nearby streams were analyzed by direct injection to the HPLC. Analysis of the water samples showed that the herbicide levels were all under the detectable value.

Known amounts of herbicides were added to the control soil samples collected before the spray operation. These mixtures were extracted and analyzed for both dicamba and 2,4-D. The results are given in Table 3. It is apparent that the extraction process did not result in total recovery at the levels of 1 or 0.1 ppm. However, it can be inferred that none of these types of herbicides existed in the control soil samples.

TABLE 3 Herbicide Contents in Control Soil Samples

Sample No.	Dicamba Added (ppm)	Dicamba Found (ppm)	2,4-D Added (ppm)	2,4-D Found (ppm)
1A	1	0.42	1	0.46
2A	1	0.53	1	0.44
3A	1	0.40	1	0.50
4A	1	0.13	1	0.27
5A	1	0.62	1	0.74
6A	1	0.62	1	0.60
2B	0.1	Not detected	0.1	0.08
3B	0.1	0.08	0.1	0.13
4B	0.1	0.07	0.1	0.12

Note: Known amount of herbicide was added.

The results of soil analysis on the herbicide content given in Table 4 are erratic. The reasons for this could be attributed to many factors, for example, the spray mix coverage on targeted foliage canopies was not easily controlled, and the distances between the spray gun on top of the spray truck and the target plants varied from 10 to 30 ft. Depending on the shape and size of the plant, different volumes of herbicide mix were sprayed in order to properly control plant growth. Moreover, the soil samples, taken at different time periods after application, were collected from around the plants, which varied geometrically at each location.

Viewing the individual test sites separately, it is obvious that the level of herbicide suddenly diminished between 1 day and 1 week after application. The explanation for this phenomenon can only be speculative. One factor involved was the storage period of the sample. There was a long period of delay in analyzing all the samples. The samples from the early collections were analyzed after 10 to 11 months storage in the freezer and the samples from later dates were analyzed after 12 to 14 months.

Another variation was the location of sampling at different time periods. Because the spray application was not uniform, concentration of the herbicide in the vicinity of the plant would not be uniform. Instead of sampling at random as was done during this project, the sample should be collected at one particular station.

Weather conditions also greatly influence herbicide degradation. A summary of the temperature and precipitation records for Bangor and vicinity for the months of July to October 1983 is given in Table 5. Closer examination of the daily temperature between July 27 and August 3, 1983, showed high temperature readings of 85, 90, 83, 88, 82, 72, 84, and 86°F, consecutively. Moderate rainfall occurred during that period. Traces of rainfall occurred on July 27, July 29, August 1, and August 3; 0.37 in. occurred on August 30, and 0.36 in. occurred on August 2. Therefore it is conceivable that the herbicide degraded at a seasonably faster-than-normal rate.

It has been reported that the persistent period of 2,4-D is 1 month and that of dicamba is 2 months (8,9). The rate of degradation depends on the content of organic matter in the soil, pH, clay content, and water content. At this stage of the study, it is difficult to pinpoint the reason (or reasons) for the quick disappearance of the herbicide.

It is unfortunate that samples were not collected between 1 day and 1 week, thus the exact trend during this period was not detected. Improvement of this aspect of the experimental design to include sampling between 1 and 8 hr, 8 and 24 hr, 1 and 7 days, and 1 week to 1 month would reveal more of a trend on the degradation pattern.

Further research should also (a) quantitatively control the spray operation, (b) define clearly the

TABLE 4 Herbicide Contents in Soil Samples at Various Time Periods After Application

Sample No.	1 Hour	8 Hours	24 Hours	1 Week	1 Month	2 Months	3 Months
Dicamba (ppm)							
1	8.61	2.55	8.64	ND	ND	ND	ND
2	0.47	ND	0.81	ND	ND	ND	ND
3	4.62	15.7	15.3	ND	ND	ND	ND
4	5.44	3.49	10.1	ND	ND	ND	ND
5	2.75	5.95	5.98	ND	ND	ND	ND
6	1.61	1.98	3.50	ND	ND	ND	ND
2,4-D (ppm)							
1	13.9	3.74	14.3	ND	ND	ND	ND
2	0.69	ND	1.56	ND	ND	ND	ND
3	6.28	20.5	22.8	ND	ND	ND	ND
4	9.10	4.63	15.9	ND	ND	ND	ND
5	4.04	8.02	8.89	ND	ND	ND	ND
6	2.56	3.23	5.38	ND	ND	ND	ND

Note: ND = none detected at a detection level of 40 ppb.

TABLE 5 Climatological Data for July-October 1983, Bangor and Vicinity

Month	Temperature (°F) Average Maximum	Average Minimum	Average	Total Precipitation (in.)
July	81	60	71	7.25
August	78	58	68	2.65
September	75	50	63	1.57
October	58	38	48	2.13

sampling location, (c) shorten the storage period between sampling and test, and (d) quantitatively determine the efficiency of the extraction procedure.

In spite of the oversights and drawbacks of this project, it is encouraging that, with better experimental design, the methods of extraction and HPLC determination of the herbicide are adequate for future use. Because this was a pilot study, the goal of learning through practice was accomplished.

CONCLUSION

An in-house method of extracting the herbicide Banvel 720 (12.82 percent dicamba and 24.5 percent 2,4-D) was developed. The extracted material was analyzed for dicamba and 2,4-D by means of high-performance liquid chromatograph. The result showed a sudden disappearance of the herbicide between 1 day and 1 week. At present the reasons for this phenomenon are only speculative.

It appears routinely possible to monitor herbicides in soil and water on a small scale suited for maintenance spray program management. Data collected over time may provide a sound statistical base for major management decisions.

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