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Monitoring Wildlife Populations and Activity Along I-95 in Northern Maine Before, During, and After Construction

ROBERT C. BURKE II AND JAMES A. SHERBURNE

From 1975 to 1980 the impact of constructing Interstate 95 in northern Maine on the distribution, abundance, and diversity of birds, rodents, and other mammals was assessed. Populations and activities of breeding birds and mammals were examined before, during, and after construction of I-95 along sections adjacent to various forest habitat types. Movements and densities of birds and mammals adjacent to and away from I-95 did not differ significantly during and after construction. The use and avoidance of newly created edges by some species were examined. Immediate losses of habitats for breeding birds were noted, and the long-term effects on populations of birds and mammals are discussed.

Interstate highway construction is a common and widespread activity that influences wildlife today. Beginning with the alteration and disturbance of habitats, Interstate roads result in the creation of a right-of-way (ROW) and a median strip that represents an edge where contiguous vegetation once existed. When construction takes place in a forest community, the change in that community can be dramatic, sometimes rendering the ROW and adjacent forest habitat unsuitable and/or unavailable for certain species. Other species, however, have adapted to or taken advantage of these new habitats or edges.

The impact of Interstate 95 in northern Maine on wildlife before, during, and after construction was studied from 1975 to 1981. The objectives were to assess the impact of I-95 on the distribution, abundance, and diversity of birds, rodents, and other mammals.

Beginning in 1975, the preconstruction phase of the study was initiated by Ferris (1) and Palman (2), who investigated the status of songbirds, small to medium-sized mammals, and white-tailed deer (Odocoileus virginianus). From 1977 to 1979, the effects of construction were examined by James Buttitta, a graduate student at the University of Maine, Orono (UMO), who studied songbird behavioral responses to construction activities while continuing to monitor mammal populations and activities.

Results of this early work, along with findings of the current postconstruction phase initiated in 1980, are summarized here. Much of the data summarized for the preconstruction phase of the study has been previously published (3,4). In addition, data are presented in annual reports to the Maine Department of Transportation (DOT).

STUDY AREAS

The study was conducted along two 15-km sections of I-95 in Penobscot County, Maine (Figure 1). The southern section, which represents a control, was completed prior to the study while two southbound lanes that constitute the experimental area were completed in the northern section during the study. The distance between north- and south-lane fences (or ROW boundaries) was about 150 m; a 30-m-wide residual median strip separates the northbound and southbound lanes.

Sample plots were established in representative softwood and hardwood cover types that border the highway. All softwood stands were composed of balsam fir (Abies balsamea), red and white spruce (Picea rubens and P. glauca), eastern hemlock (Tsuga canadensis), eastern white pine (Pinus strobus), and northern white cedar (Thuja occidentalis), 40-100 years old. Hardwood plots along the southern section contained aspen (Populus tremuloides and P. grandidentata), gray and paper birch (Betula populifolia and B. papyrifera), American beech (Fagus grandifolia), and red maple (Acer rubrum), 20-40 years old. Hardwood plots adjacent to the northern section were principally American beech, sugar maple (Acer saccharum), and eastern hophornbeam (Ostrya virginiana), 20-120 years old.

Most of the land adjacent to the highway is owned by large lumber and pulpwood companies and is harvested periodically for forest products. There is little other human disturbance in the study area.

SONGBIRDS

Methods

Preconstruction Phase

The status of birds that reside in the forest was determined by examining species abundance and composition of populations at increasing distances from the highway (3). Numbers of breeding birds were censused by spot-mapping (5) on 12 study plots, each 200x400 m (8 hm^2), oriented at right angles to the highway beginning at the ROW edge. Each plot was censused along four 400-m transects spaced 50 m apart. Transects were marked at 50-m intervals, which provided a grid to aid in the location of singing males. Censuses were conducted during early morning hours from late May through early July, 1975-1977. Three replicates in each cover type (hardwood and softwood) were placed adjacent to the highway in both northern and southern sections. Plots were located in patches of uniform habitat to minimize within-plot variation.

During-Construction Phase

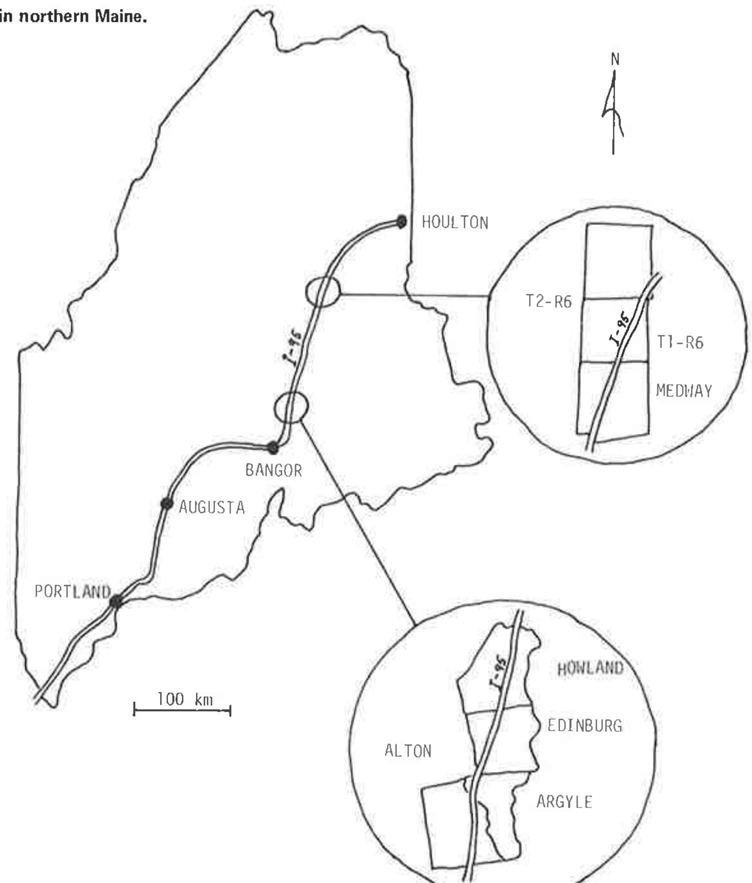
To examine the effects of construction on individual breeding songbirds, an intensive study was designed to investigate behavioral response to daily construction activity. Two sites were chosen. The experimental area was an active gravel pit with trucks hauling fill and rocks crushed on the site. The control area was an unused, 12-year-old gravel pit located 1-2 km away and surrounded by vegetation similar to that at the experimental site.

In each area the singing behavior of five male rose-breasted grosbeaks (Pheucticus cianus) was monitored from dawn until 10:00 a.m., when singing stopped. The relative amount of time individual birds spent singing in each area was recorded between May 23 and July 7. This was done with a metronome (6) for the presence or absence of singing every 5 s during 100-s intervals. The intervals were initiated whenever a male grosbeak was heard that had not been monitored during the previous 5 min. Observers recorded singing of birds in both the experimental and control areas at the same time.

Postconstruction Phase

Four plots examined during the preconstruction phase

Figure 1. Location of study areas along I-95 in northern Maine.



in the northern study area were recensused by using the methods previously described. Breeding-bird populations were examined within successive 100-m intervals by using analysis of variance (ANOVA). Ferris (3) reported that populations in plots 300-400 m distant from I-95 were sufficiently removed to serve as controls. Therefore, we established a 200x100-m control in the fourth 100-m interval of each recensused plot. Plots were censused at least seven times from June 6 to June 26 during the height of the breeding season.

Results

Censuses for all plots for breeding-bird populations before and after construction are summarized in Figure 2 (3). For the first year of the postconstruction phase (1980), overall breeding-pair density averaged 13.0/2 hm^2. During the preconstruction phase, Ferris (1) reported 21.4 breeding pairs/2 hm^2 in 1975, 15.2/2 hm^2 in 1976, and 17.0/2 hm^2 in 1977. He concluded the decline to be attributed to a general trend for bird populations in Maine during those years and not related to highway effects. The total number of species breeding on the four census plots was 38, 37, 35, and 37 for 1975, 1976, 1977, and 1980, respectively. Migration, weather factors, presence of disease, and environmental pollution influence yearly fluctuations in breeding-bird populations but were outside the scope of this study.

Breeding-bird population density did not vary significantly between 0 and 400 m away from the highway either during the preconstruction (3) or postconstruction phase (see Table 1). Although species density was not related to distance from the highway during the postconstruction phase, species composition appeared to change in response to the forest and ROW edge created along the highway. Within the four plots sampled, bird species were categorized into (a) those preferring forest habitats and (b) those preferring edge or open habitats as previously done in the preconstruction phase (3). Work by Sherburne (7) showed that those preferring edge habitats included robins (Turdus migratorius), chestnut-sided warblers (Dendroica pennsylvanica), yellowthroats (Geothlypis trichas), and white-throated sparrows (Zonotrichia albicollis). Populations that breed within 100 m of the highway contained a larger component of these edge species (see Figure 3). [Populations for 1975, 1976, and 1977 are averages for 12 census plots for each year (3). Populations for 1980 are averages for four census plots.] Edge species constituted 18.9 percent of populations within the first 100 m of the forest habitat outside of the ROW, as compared with 0.6 percent of populations from 100 to 400 m. Ferris (3) reported similar results for the preconstruction phase with 16.2 percent within the first 100 m and 2.1-3.5 percent for 100-400 m. Edge species within forest plots were associated with small clearings and openings in the forest canopy.

Presence of edge habitat should increase species diversity along the forest and ROW edge. Species diversity was calculated by using Brillouin's index (H), which is the most appropriate measure for total counts on small areas (8). Diversity during the preconstruction phase was slightly higher within 100 m of the highway than at greater distances, but the difference was significant only during 1976 (3). Michael and others (9) demonstrated that species diversity along an Interstate in West Virginia

Figure 2. Number of species and breeding pairs per 2 hm^2 for four 8-hm^2 plots adjacent to highway during preconstruction and postconstruction.

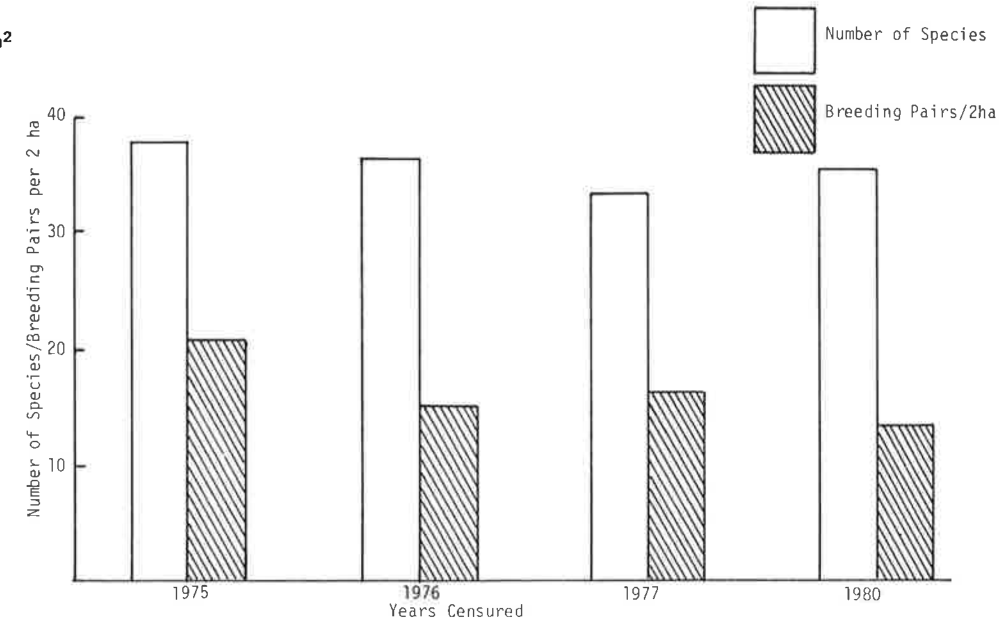


Table 1. Characteristics of forest breeding-bird populations during postconstruction.

Item	Distance from I-95 (m)			
	0-100	100-200	200-300	300-400
Breeding pairs/2 hm^2 [a]				
Plot				
Softwood 1	8	16	20	13
Softwood 2	9	14	10	10
Hardwood 1	19	13	15	15
Hardwood 2	18	5	11	12
1980 mean	13.50	12.50	14.00	12.50
No. of species/2 hm^2 [a]				
Plot				
Softwood 1	6	13	18	9
Softwood 2	9	14	10	10
Hardwood 1	10	9	10	11
Hardwood 2	14	3	7	7
1980 mean	9.75	9.75	11.25	9.25
Species diversity (H), Brillouin's index (base 2)				
Plot				
Softwood 1	1.66	2.48	2.94	2.02
Softwood 2	1.94	2.60	2.18	2.18
Hardwood 1	2.29	2.20	2.29	2.31
Hardwood 2	2.57	0.98	1.88	1.74
1980 mean	2.12	2.07	2.32	2.06

[a] No significant differences at either $P < 0.05$ or $P < 0.01$ levels.

increased in the edge between the ROW edge and adjacent forest. We noted no significant increase in diversity within 0-100 m in the edge during postconstruction.

If the highway affected a particular species either negatively (for example, through traffic disturbance) or positively (by creating suitable habitat along the forest and ROW edge), then the abundance of that species should show some relation to distance from the highway. Ovenbirds (Seiurus aurocapillus), which were abundant and found in all plots, were compared within the four 100-m intervals by using ANOVA (Table 2). Ovenbirds appeared unaffected by the highway in relation to distance from the ROW. However, during the preconstruction phase, Ferris (3) demonstrated that bay-breasted warblers (Dendroica castanea) and blue jays (Cyanocitta cristata) were more abundant 300-400 m from the highway and less numerous or absent adjacent to the highway. Bay-breasted warblers and blue jays are forest-dwelling birds (10), and their response to the forest and ROW edge serves as indicators of such species.

The density of most breeding birds did not vary with distance from the highway either during the preconstruction or postconstruction phase. Rather, species composition changed in relation to the forest and ROW edge habitat created. Diversity increased within 100 m of the highway during the preconstruction phase in 1976. No change was detected for the postconstruction phase. Two forest species, bay-breasted warblers and blue jays, were less numerous or absent adjacent to the highway during the preconstruction phase, but no differences were found for the postconstruction phase.

Although the results between the preconstruction and postconstruction phases demonstrated an insignificant impact of I-95 on breeding-bird populations that exist in the adjacent forest, examination of individual birds' responses to activities in the active gravel pit during construction indicated they were affected by the disturbances and noise. The relative amounts of time grosbeaks were monitored singing differed between the control and experimental areas. Birds in the experimental or active area sang more on days when construction activities occurred than on days after construction activity. These results suggest that construction activity could lead to greater energy expended by birds through singing, thus reducing the time available for foraging and nest tending.

SMALL MAMMALS

Methods

Preconstruction Phase

Populations of small mammals (including Cricetidae, Zapodidae, Soricidae, and Talpidae) were sampled in the northern and southern sections by Palman and Richens (4) during the preconstruction phase on the census plots used for birds as described above (3). Two trappings grids that measure 100x100 m were placed in each study plot sampled for a total of 16 grids: one in the forest adjacent to the ROW boundary and the other 300-400 m distant. Grids close to

Figure 3. Contribution of edge species of breeding populations in forest habitat at 100-m intervals away from I-95 during preconstruction and postconstruction.

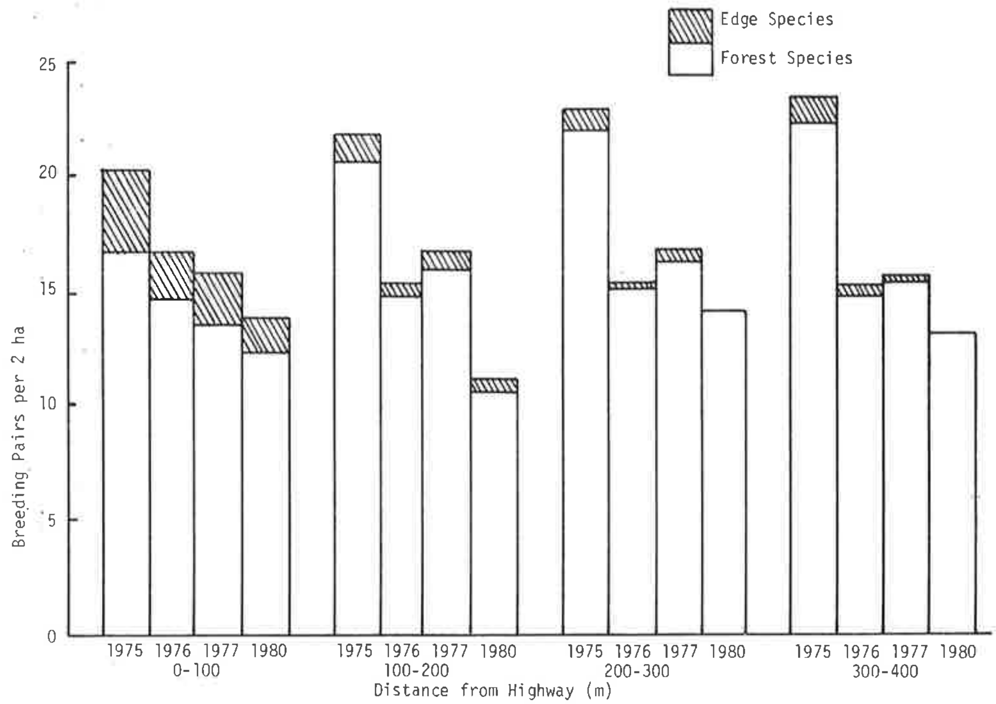


Table 2. Single factor ANOVA in relation to 100-m interval distances away from highway during postconstruction.

Source of Variation	Sum of Squares	df	Mean Square	F[a]
Breeding pairs/2 hm^2				
Total	228.44	15		
Group	8.69	3	2.90	0.16
Error	219.75	12	18.31	
Number of species/2 hm^2				
Total	660.00	15		
Group	9.00	3	3.00	0.06
Error	651.00	12	54.25	
Ovenbird pairs/2 hm^2				
Total	17.75	15		
Group	2.25	3	0.75	0.53
Error	15.50	12	1.29	

Note: $F_{0.05(1)\ 3,\ 12} = 3.49$

[a]No significant differences at either the $P < 0.05$ or $P < 0.01$ levels.

the highway constituted experimental samples while those farthest from the highway represented controls. The assumption was made that conditions at the back of the plot approached those found in undisturbed habitat, since Michael (11), working in West Virginia, concluded that indirect effects of the highway did not extend beyond 161 m and Ferris (3) reported that plots 300-400 m distant from the ROW were not affected.

Each grid contained 121 trap stations spaced 10 m apart in an 11x11 arrangement. Two Victor snap traps baited with peanut butter were placed within 2 m of each station. Every third station had a pitfall trap containing 3- to 5-cm water, since shrews are underestimated by using snap traps alone. Each grid was trapped for three consecutive nights over three periods during the summer.

During-Construction and Postconstruction Phases

Small mammals were sampled during construction in the summers of 1978 and 1979 and during 1980 for the postconstruction phase. Four study plots located in the northern study area were resampled by using 50x50-m trapping grids. Each grid contained 36 trap stations spaced 10 m apart in a 6x6 configuration. Trapping was carried out the same as during the preconstruction phase.

Results of small-mammal trapping were analyzed statistically by using a nested ANOVA. The analysis separated variation due to effects of the highway (grid location in relation to the highway, i.e., experimental or control grid), to effects of the trapping period (June, July, and August), and to effects of plot type (hardwood or softwood). Species of small mammals were analyzed separately if their catch for the entire study exceeded 30; species with less than 30 were included as part of the total catch of all species (4). Diversity indices were calculated for catches on the road and control grids by using the Shannon diversity index (12). Indices were compared by using a t-test, as suggested by Hutcheson (13).

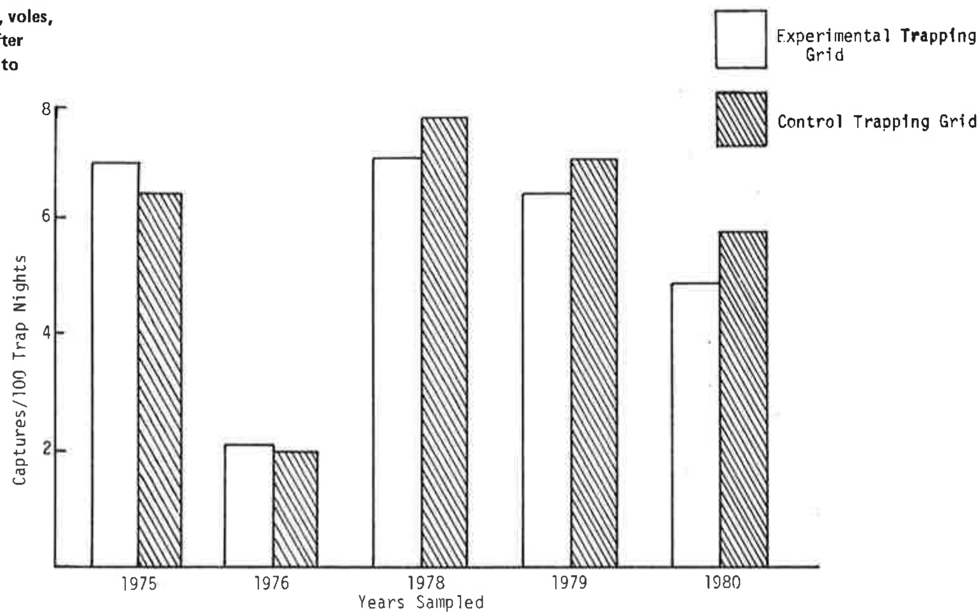
Results

Prior to construction, total catch rates in both the experimental and control plots for small mammals were 6.8 and 1.8/100 trap nights (TN) in 1975 and 1976, respectively [Figure 4 (4)]. During construction, the total catch rates were 7.4 and 6.8/100 TN for 1978 and 1979 (7). In 1980, 5.4/100 TN were caught in all plots. Except during 1976, when a general decrease in small-mammal populations occurred throughout the state, total capture rates were similar for all phases.

Grid Location (Distance from Highway)

Palman and Richens (4) found red-backed voles (Clethrionomys gapperi) to be significantly ($P < 0.05$) more common in the control plots, and more woodland jumping mice (Napeoozapus insignis) were found in the experimental plots before construction. Sherburne (7) reported that during the construction phase, the capture rates did not differ significantly between grid locations for any species

Figure 4. Total captures of mice, voles, and shrews before, during, and after construction by location relative to I-95.



tested except masked shrews (Sorex cinereus) (Table 3). After construction, grid location for all species of small mammals had no significant effect on capture rates (Table 4).

Trapping Period

For those species tested, the trapping period had a significant ($P < 0.05$) effect on numbers caught during the postconstruction phase (Table 4). More captures were made during July [166 (8.23/100 TN)] than June [40 (1.98/100 TN)] and August [119 (5.90/100 TN)], which probably reflects increased recruitment during the height of the midsummer reproductive period. These results agree with Sherburne (7) and Palman and Richens (4) for deer mice, red-backed voles, and all species combined, although the number of masked shrews was not affected by trapping period and plot type.

Habitat Type

Plot type (hardwood or softwood) had no significant effect during postconstruction for deer mice, red-backed voles, masked shrews, and all species combined (Table 4). Hardwood and softwood cover types appeared to have similar communities of small mammals. In contrast, habitat had a significant effect on numbers caught during the preconstruction and construction phases (4,7). However, the effects of plot type and trapping period were not separated, thus confounding the results, as shown in the table below (note, no significant differences at either the $P < 0.05$ or $P < 0.01$ levels):

Designation	Softwood	Hardwood
During construction		
Experimental	0.674	0.587
Control	0.600	0.604
Postconstruction		
Experimental	0.583	0.403
Control	0.508	0.488

Shannon diversity indices for catches from road and control grids by plot type showed no significant differences for the during-construction and postconstruction phases, as shown in the above table. This agrees with the findings of Palman and Richens (4) during the preconstruction phase.

In summary, the during-construction and postconstruction phases had similar catch rates and diversity indices for small mammals that exist in the experimental and control grids, which suggest that the highway's impact was small during this study. During the preconstruction phase, Palman and Richens (4) demonstrated that total numbers of small mammals trapped on the grids adjacent to the highway were similar to those trapped on control grids, but catches of individual species differed.

MEDIUM AND LARGE-SIZED MAMMALS

Methods

Preconstruction Phase

The distribution and relative abundance of medium and large-sized mammals were determined by counting tracks in relation to distance from the highway during the winters of 1975-1976 and 1976-1977 by Palman (2) and Ferris (1). Signs were recorded for mammals common to the study areas. However, insufficient data were accumulated for analyses for moose (Alces alces), black bear (Ursus americanus), bobcat (Lynx rufus), and marten (Martes americana). Data were collected on the 12 plots located in the northern and southern sections used by Ferris (3) for censusing songbirds. Counts were made within 2 to 6 days following snowfall on the two outer 400-m transects within each plot, since most animals walked parallel to the highway that crossed all four transects. At least 7 separate counts were made on each of the 12 plots. All tracks and other animal signs were recorded on maps of the study plots. Transects were marked at 50-m intervals to aid in the location of individual tracks.

The distribution of white-tailed deer in relation to the highway was examined by using pellet group counts. Counts were conducted in early spring soon after snowmelt (spring) and in early autumn (fall) before leaf fall. Pellet groups were counted on the same plots as winter tracks. Pellet groups within 1 m of the transect line were counted and destroyed or removed to prevent recounting later.

During-Construction and Postconstruction Phases

By using the methodology described above, approxi-

Table 3. Nested ANOVA of small-mammal catches for during-construction phase from experimental and control grids.

Species	Source of Variation	df	Mean Square	F
Deer mice	Trapping period and plot type	11	68.20	4.53[a]
(Peromyscus maniculatus)	Grid location	12	15.06	<1
	Residual	24	16.48	
	Total	47		
Red-back voles	Trapping period and plot type	11	86.92	4.45[a]
	Grid location	12	19.54	1.16
	Residual	24	16.88	
	Total	47		
Short-tailed shrews	Trapping period and plot type	11	16.54	66.16[a]
(Blarina brevicauda)	Grid location	12	0.25	<1
	Residual	24	2.71	
	Total	47		
Masked shrews	Trapping period and plot type	11	14.63	2.62
	Grid location	12	5.58	2.63[b]
	Residual	24	2.08	
	Total	47		
Woodland jumping mice	Trapping period and plot type	11	7.77	6.42[a]
	Grid location	12	1.21	<1
	Residual	24	1.92	
	Total	47		
All species	Trapping period and plot type	11	472.20	9.30[a]
	Grid location	12	50.75	<1
	Residual	24	52.17	
	Total	47		

[a]$P < 0.01$ level. [b]$P < 0.05$ level.

Table 4. Nested ANOVA of small-mammal catches during postconstruction phase from experimental and control grids.

Species	Source of Variation	df	Mean Square	F
Deer mice	Plot type	1	210.79	3.05
	Trapping period	4	69.23	8.70[a]
	Grid location	6	7.96	<1
	Residual	12	16.88	
	Total	23		
Red-backed voles	Plot type	1	92.05	2.18
	Trapping period	4	42.33	5.55[a]
	Grid location	6	7.63	1.78
	Residual	12	4.29	
	Total	23		
Masked shrew	Plot type	1	10.67	1.46
	Trapping period	4	7.33	7.97[a]
	Grid location	6	0.92	<1
	Residual	12	4.42	
	Total	23		
All species	Plot type	1	26.04	<1
	Trapping period	4	272.54	14.57[b]
	Grid location	6	18.71	<1
	Residual	12	36.13	
	Total	23		

[a]$P < 0.05$ level. [b]$P < 0.01$ level.

mately four separate snow-track surveys were conducted on the six northern plots during the winters of 1978-1979 and 1979-1980 during construction. The plots were surveyed five times during postconstruction, 1980-1981.

Deer pellet group counts were conducted on the same plots during spring and fall for both phases. Data were analyzed by using a chi-square test (12). Each 400-m transect was divided into eight 50-m sections; the number of tracks or pellet groups in the four sections farthest from the highway was averaged to determine the expected value and compared with the actual value of each section. If the expected chi-square value was less than 5, adjacent sections were lumped and tested as four 100-m sections.

Results

Red Squirrel

The 59 track observations for red squirrels (Tamiaseiurus hudsonicus) for the during-construction phase and 35 for postconstruction showed no significant relation to distance from the highway from either hardwood or softwood cover types. This suggests that the highway had no effect on red squirrels living in the forest beyond the ROW. Palman (2) reported similar results during the preconstruction phase.

Snowshoe Hare

Palman (2) and Sherburne (7) reported that snowshoe hares (Lepus americanus) were distributed in aggregations during preconstruction and during-construction phases, respectively, either because of patches of dense cover favored by hares or the hare's habit of traveling on runways. Their sample size was considerably larger than that used in the postconstruction phase, where 32 snowshoe hare tracks were observed on softwood plots with no significant deviations from a uniform distribution.

Weasel

Weasel (Mustela frenata and M. erminea) tracks were present on three of the six plots with a total of 29 observations for the postconstruction phase. There were no significant differences in the number of tracks near or far from the highway. Similar results were reported during the preconstruction phase. Track numbers were insufficient to test for the during-construction phase.

Fisher

There were insufficient data to statistically test fisher (Martes pennati) distribution with respect to distance from the highway edge for both the during-construction and postconstruction phases. However, observations suggest a trend toward greater numbers away from the highway on the hardwood plots (2). Topography of the area may have influenced the results, since an edge of the hardwood plots was near the top of a ridge.

Red Fox

An insufficient number of red fox (Vulpes vulpes) tracks were found for the during-construction and postconstruction phases for statistical testing. Single fox tracks frequently were found traveling in the ROW parallel to the highway; the animals were apparently hunting for mice and voles. Stanley (14) reported that foxes usually hunted along the edges of fields, behavior similar to that of foxes along the highway. Statistically significant aggregations of fox tracks concentrated near the ROW were reported during the preconstruction phase by Palman (2).

Coyote

During the postconstruction phase, coyote (Canis latrans) tracks were absent on the softwood plots but moderately abundant on hardwood plots. No significant trend near the ROW was found, which contrasts with Palman's (2) results. However, coyote tracks were seen occasionally in the ROW and some tracks did cross the highway. No tracks were recorded for the during-construction phase.

White-Tailed Deer

Track counts during the postconstruction phase indicated significantly greater use of the forest area 100-300 m from the highway rather than 0-100 m. We cannot determine cause and effect due to highway disturbance. Ferris (1), who had similar results during preconstruction, suggested that the forest edge may be exposed to more severe conditions, since wind and snow penetrate some distance.

A total of 19 pellet groups was recorded for the postconstruction phase during summer counts. Eighteen were in softwood and one in hardwood cover types, which indicates that hardwoods were used very little. Pellets appeared to be distributed equally with respect to distance from the highway; however, this could not be tested statistically because of the small sample size. During-construction examination of the distribution of 34 pellet groups suggested that the highway had no effect. Ferris (1) found that the distribution of summer pellet groups was different with respect to distance from the highway. He found fewer pellet groups in the first two 50-m intervals than the number recorded from 100 to 400 m.

During the winter of the postconstruction phase, a total of 85 groups was recorded, 79 in softwoods and 6 in hardwoods. Frequency of groups demonstrated that fewer pellets were recorded than expected within 100 m of the highway than in any other interval from 100 to 400 m ($\chi^2 = 24.48$). Ferris (1) found a similar distribution of pellets for the preconstruction phase. As with winter track counts, this could be due to the weather, since the forest edge is exposed to more severe conditions. During construction, pellets were deposited with equal frequencies at all distances from the highway.

CONCLUSIONS AND FUTURE STUDY

The impact of I-95 on birds and mammals in forest ecosystems in Maine was examined from 1975 to 1981. Baseline data were collected. These data imply that the effect on breeding-bird and small-, medium-, and large-mammal populations has been limited to immediate loss of habitat. The extent of the effect of this habitat loss on populations as a whole in the vicinity of the highway is as yet unknown, but is probably insignificant for those species studied to date. Clearly, the effects of the highway as a physical barrier to movement, particularly of small mammals, are not understood.

Some species have, however, adapted to or taken advantage of habitats created by the construction of I-95. Chipping sparrows, yellowthroats, chestnut-sided warblers, crows, ravens, meadow voles, and red foxes, to name a few, are using the newly created ROW while species adapted to forest habitats, such as bay-breasted warblers, red-backed voles, and fishers, seem to be avoiding it. To what extent the use of the ROW affects populations of species now found there is also unknown but it may be a beneficial influence. Some species--crows and ravens particularly--use the highway itself as available habitat.

Up to now the emphasis of this study has been on the impact of extending I-95 through northern Maine forest ecosystems by examining adjacent forests and edges. For the second year of the third phase (postconstruction), some of the dynamic interrelations within the new habitat (ROW) created by the highway are being examined; also being studied are the wildlife species that reside in or use available food resources from the ROW. In this way, the question of which species are directly benefiting from highway construction may be addressed.

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Mule Deer Behavior in Relation to Fencing and Underpasses on Interstate 80 in Wyoming

A. LORIN WARD

Where Interstate 80 crosses the migration route of approximately 1000 mule deer (Odocoileus hemionus), there were 37-60 vehicle accidents involving deer each year from 1973 to 1976. A 7.8-mile section of the right-of-way fence was replaced with an 8-ft-high big-game fence in October 1978 to force the deer to use three machinery and four box-type underpasses in the area. During four migration periods immediately following installation of the fence, more than 4000 deer went through these underpasses, as recorded by track counts and surveillance cameras. About 70 percent of the deer used the machinery underpasses to move to their winter range; the others passed through the box-type concrete underpasses. During spring migrations, more than 90 percent of the deer used the two machinery underpasses at the east, or higher end, of the migration area. Baiting with alfalfa hay, fresh vegetable trimmings, and apple pulp helped lure deer through the underpasses the first time. There was only one deer-vehicle accident inside the fenced area during the two years after the big-game fence was completed. In addition, two deer were killed above (east of) the end of the fenced section of the highway and a few were killed below (west of) the fenced area in an area where accidents had been common before the deer fence was constructed. The major difficulties associated with the fencing were (a) selection of the proper area for the fence (an additional mile of fence was built to discourage deer from going around the ends), (b) inadequacy of deer guards on ramps of an interchange, and (c) the need for continuous monitoring for holes in the fence.

Interstate 80 is a busy highway for east-west travelers in southern Wyoming, and a 55-mile section of the highway bisects the migration routes of between 1600 and 2000 mule deer (Odocoileus hemionus) that move from their summer range on the Medicine Bow Range west of Laramie to their winter ranges in the lower sagebrush steppe country. Since this section of highway opened in late 1970, about 1000 mule deer have been recorded killed by vehicles. The Wyoming Game and Fish and Highway Departments became concerned and, in 1973, with guidance and funding from the Federal Highway Administration (FHWA), they teamed up with the Rocky Mountain Forest and Range Experiment Station of the Forest Service at Laramie to try to solve the problem. The primary objective of the studies was to determine the effects of highway operation practices and facilities on elk (Cervus canadensis), mule deer, and pronghorn antelope (Antilocarp americana) and to assess the effectiveness and impact of 8-ft-high gameproof fencing on mule deer at a heavy migration crossing along I-80 at Dana Ridge near Walcott, Wyoming (Figure 1). This study area was 7.8 miles along the highway where previous data had shown at least 1000 deer crossed twice a year and between 37 and 60 deer-vehicle accidents had occurred yearly (1,2).

The studies were conducted by the crew from the Rocky Mountain Station. The $240 000 gameproof fencing was funded by FHWA (93 percent) and the Wyoming Game and Fish Department (7 percent). The Wyoming Highway Department furnished the planning design, negotiated the contracts for construction, and monitored the project. The Highway Department also accepted maintenance responsibility after construction was completed and approved.

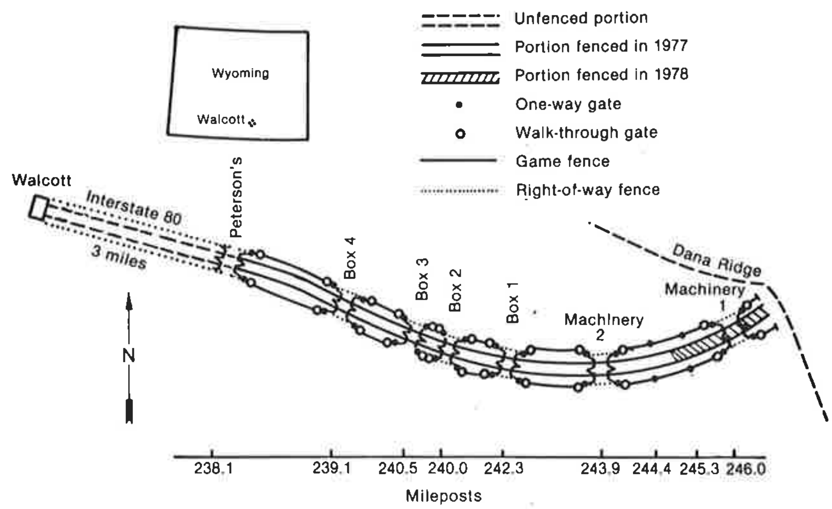
METHODS

Major methods used to collect deer behavior, population, distribution, and movement data were visual observation, track counts, telemetry-radio collars (tracking and monitoring), and automatic day and night movie camera surveillance systems (2). During the fall-to-spring period, regular daily survey trips were made to record animal populations, distribution, and activity in relation to I-80. The track counts were made across raked patches of loose dirt or snow at each end of the underpasses or along the end of the high fence. The telemetry equipment enabled the tracking of individual animals and their associates as they moved throughout their range in both summer and winter. Because track counts become inaccurate when more than about 20 deer are involved, a surveillance camera system was developed and used to photograph deer that use the major underpasses. From these photographs, deer behavior, numbers, and classification (bucks, does, or fawns) could be determined.

BIG-GAME FENCING

The fencing constructed along I-80 at Dana Ridge is

Figure 1. Mule deer winter range and big-game fenced area along I-80.



a modification of elk fence recommended in guidelines adopted by the Wyoming Game and Fish Department (Figure 2). Modifications were made to the existing 46-in-high right-of-way fence by setting 12-ft by 5-in treated line posts at alternate existing fence posts, thus making the taller posts 16.5 ft apart and 8 ft tall. After removing the barbed wire strands from the top of the existing fence, crews added two panels of 32-in eight-strand woven wire (weighing approximately 234 lb/110 yards) above the existing panel. The new panels and existing panels were then laced together with 12-1/2 gauge wire. Brace panels were built as required to support the wire over uneven terrain.

The gameproof fence was constructed for 6.7 miles along both sides of I-80 during the summer of 1977. Because deer made end-runs around the upper (east) end of the fence during the first year, additional fencing was constructed along 1.1 miles of the highway before the fall migration of 1978.

The high fence was constructed to allow deer access to the three machinery and four box-type underpasses. At the Peterson Interchange (milepost 238.1) and at machinery underpass 2 (milepost 243.9), the high fence was constructed all the way through the underpasses by using the pillars for guides (Figure 3). At machinery underpass 1 (milepost 246), the high fence was built to the end of the structure and had sections between the separated lanes of the highway, which allowed more open space under the highway and helped alleviate the possibility of snowdrift build-up in the underpass.

The 46-in right-of-way fence was left in place at all underpasses, with the exception of the south end of box underpass 3 (milepost 240.5), where it was removed. This was done at the request of the landowner and livestock operator. In order to move through the underpasses or boxes, deer were forced to jump the right-of-way fence during the time livestock were on the range (from April until snow covered the ground in December). The gates were left open when cattle were gone. The deer jumped these fences without much difficulty but used the open gates when available.

One-way deer gates, as described by Reed and others (3), were built into the gameproof fence at all four corners of each underpass where the right-of-way line and the underpass entrance wings meet. To allow deer to leave the right-of-way without traveling to the end of the high fence, one-way gates were built on each side of the highway at two places (mileposts 244.4 and 245.3) where right-of-way width changed, thus making construction convenient.

There was a problem with fawns getting into the corners at underpasses between the back side of the one-way gates and the short 46-in right-of-way fence, particularly during the fall migration. A few fawns went through the one-way gates the wrong way until the tines on the one-way gates were closed to within 4 in. This problem could be avoided by locating the one-way gates at least 100 yards away from the underpasses or by removing the short right-of-way fences. It is questionable whether the short fences are necessary, because a low gate at the mouth of the underpasses would keep the livestock out just as well.

Walk-through gates (pipe frame, 5 ft wide by 7 ft high) were installed in the fence lines adjacent to the one-way deer gates at each underpass. These gates are used by highway maintenance crews to get through the high fence without climbing over them. These gates were all chained and locked to prevent public entrance and to ensure that they are kept closed so deer cannot get into the highway right-of-way.

Deer-crossing records on I-80 before the gameproof fence was constructed in 1977 did not justify extending the first fence construction beyond the top of Dana Ridge at milepost 244.9. After a few deer were found inside the right-of-way within the gameproof-fenced area at the upper end in December 1977, tracking patches were monitored at the end of the high fence and the deer tracks showed that deer were moving around the end and coming back inside. Many deer used the one-way gate on the south side of the highway and escaped. Others moved across the highway, and there were 19 deer-vehicle accidents. The same problem developed during the spring migration of 1978, which resulted in six deer-vehicle accidents.

An unsuccessful attempt was made to turn the deer back away from the end of the high fence on the south side of the highway by parking a trailer house between the game fence and a 12-ft snow fence 324 ft long, but deer (tracked in the snow) either walked past the trailer or came around the snow fence.

With the cooperation of federal and state agencies, a 1-mile extension of gameproof fence was constructed in 1978 on both sides of the highway to reach machinery underpass 1 (milepost 246.0). When the deer came back during the fall and winter of 1978-1979, they were forced to use the underpass or move even farther around the end of the high fence. They did not get inside the game-fence right-of-way area, and there were no accidents. During the 1979 spring migration, 85 deer used the upper machinery underpass, and 27 deer tracks were counted going

Figure 2. Big-game fence used to force mule deer to use underpasses along I-80.

Figure 3. Mule deer using machinery underpass 2 on I-80.

around the end and across the highway. Only one accident was reported, about 100 yards beyond the end of the gameproof-fenced area. No consistent track counts have been made for the past two years, but there was only one accident in November 1979. No accidents have been reported in this area by the Wyoming Highway Department during the past year.

There were some problems associated with the gameproof fence that should be recognized. The first and foremost is holes, whether through or under the fence. The only deer killed on the highway inside the fenced area during the migration of 1978-1979 was one that crawled under the fence at a washed-out place. It is essential that all holes more than 6 in deep under the fence be filled with dirt or rocks.

Even though four people inspected the entire fence for signs of weakness and filled all low spots, they missed a gap between the mesh wire panels in an area where the fence passed through very thorny saltbush (Atroplex nutalli), which makes the lower panels difficult to see. The deer found the hole in late January, and 31 deer moved through the hole and onto the right-of-way before the fence was repaired. The deer were herded out through the walk-through gates. Twice holes were found that had been cut by people--one was used to gain entrance to obtain antlers from a large, dead buck mule deer, and the other showed indications that it had been used for access for poaching.

Two truck tires came off moving semitrailer trucks and hit the fence, and one caused a hole. Two deer and nine antelope came through before the hole was found. The animals were again herded out through a walk-through gate.

The possibility of holes developing in the fence makes it imperative that, during deer migrations, highway maintenance crews or Game and Fish Department personnel monitor the fence constantly to find and repair holes. The sooner holes are repaired, the better.

Two heavy snow winters were ideal for evaluating the gameproof fence and underpasses in relation to drifting snow. The snow depths of 14-16 in at the top of Dana Ridge were the heaviest since 1973, and there was enough wind to blow drifts into problem areas. Three areas accumulated enough drifting snow to cause concern that snow bridges would allow deer to cross. Two drifts were on the south side of the highway at mileposts 243.4 and 243.5 and the other was under machinery underpass 2. All problems developed after more than 90 percent of the deer had already moved to their winter range beyond the highway. There were no problems during spring migrations. The snow can be controlled by snow-fence construction. Building short sections of extended woven wire fence on top of the high fence would prevent deer from walking over drifted fences.

When snow depths reached about 12 in at machinery underpass 2 the first year after deer-fence construction, deer started moving down hill along the fence on the south side of the highway. One morning in January 1978 at least 26 deer were tracked around the end of the deer fence and back across the cattleguard at the Peterson Interchange at the lower end. Another herd of 18 deer crossed the cattleguard in February 1978. These deer accounted for 11 deer-vehicle accidents before the remaining deer either went through one-way deer gates or were herded out through walk-through gates or over cattleguards. During the 1978-1979 winter, only 11 deer crossed the cattleguard; 6 of these came back out the same way and the other 5 were herded out without an accident. Because there is no such thing as an effective deer guard at present (4), about the only solution is gates over the cattleguards, which would be an inconvenience for people.

For the past two years, panty hose filled with human hair have been hung under both sides of the cattleguard at the Peterson Interchange. Very few deer crossings have been observed and no accidents reported but, because of light snow cover and few deer seen in the area, it is not possible to evaluate the usefulness of the human hair deterrent.

UNDERPASSES

The inside dimensions of the three machinery underpasses and four box-type underpasses are given in Table 1. Machinery underpasses 1 and 2 are at the upper (east) end of the area and were constructed mainly for animal use and have dirt floors. Machinery underpass 1 has a seldom-used road through it. The underpass at the Peterson Interchange is at the lower (west) end of the fence. A double-lane macadam road goes under I-80 at this interchange, and the area is plowed open during periods of deep and drifting snow. Drifts of snow accumulate across the machinery underpasses, but deer walk over the dense snow.

The box underpasses have concrete walls and floors and only end openings. Box underpasses 1 and 3 have accumulated a few inches of dirt over the concrete on the floor. During periods of blowing snow, drifts accumulate in the boxes, particularly box underpasses 2, 3, and 4. Visibility is good through box underpasses 1 and 4; they are high enough to see the skyline from either end. They are also the shortest. Box underpasses 2 and 3 are low and long and carry the water flow from Coal Bank

Table 1. Location and dimensions of underpasses.

Underpass	Location (milepost)	Length (ft)	Width (ft)	Height (ft)
Machinery 1	246.0	200	30	15
Machinery 2	243.9	110	30	13
Box 1	242.3	153	10	10
Box 2	240.8	280	10	10
Box 3	240.5	393	10	10
Box 4	239.1	282	10	10
Peterson Interchange	238.1	200	50	17

Table 2. Number of deer-vehicle accidents on I-80 in the Dana Ridge area.

	No. of Accidents		
Migration Period	West Deer Fence Area	At Fence Location	East Deer Fence Area
Before deer fence construction			
Spring, 1976	2	7	0
Fall-winter, 1976-1977	4	33	0
Spring, 1977	2	13	0
Deer fence constructed to top of Dana Ridge			
Fall-winter, 1977-1978	5	37	9
Spring, 1978	2	1	5
Deer fence extended to machinery underpass 1			
Fall-winter, 1978-1979	4	0	0
Spring, 1979	0	1	1
Fall-winter, 1979-1980	5	0	1
Spring, 1980	1	0	1
Fall-winter, 1980-1981	4	0	0
Spring, 1981	0	0	0

Draw during periods of snowmelt or seldom-occurring rainstorms. They do not have a skyline view from either end and are cold and dark in the center. Noise at either end of the boxes is echoed throughout them. Traffic noise in the boxes is very low, especially toward the middle. Noise levels under the machinery underpasses are between 64 and 69 dB(A) for cars and 65 to 80 dB(A) for trucks. The faster trucks in the westbound lane going downhill are noisier than those in the uphill, eastbound lane.

RESULTS

Mule deer mortality along the 55 miles of I-80, including the migration area at Dana Ridge, was reported through the period 1967 to 1975 by Goodwin and Ward (5). Over the entire route, 571 deer kills were reported, 70 of which were in the Dana Ridge area. The number of deer-vehicle accidents recorded since 1975 in the Dana Ridge area is shown in Table 2. The 61 deer struck by vehicles during the two spring migrations and one fall-winter migration between April 1976 and June 1977 (before gameproof-fence construction) were killed west of where Dana Ridge crosses the highway. Eight were killed west of the Peterson Interchange, beyond the end of the future deer fence.

The first year after the deer fence was constructed from the Peterson Interchange to the top of Dana Ridge, 59 deer were killed. Most of the problems were associated with deer making end-runs, particularly at the upper end at Dana Ridge. Some deer crossed the cattleguards at the Peterson Interchange and some found holes in the fence. The holes were repaired, but end-runs continued during the spring migration. The number of accidents at the lower end of the high fence did not show as much change as at the top of Dana Ridge. There were some deer crossing in the area west of the Peterson Interchange prior to gameproof-fence construction, but some additional deer moved down the fence and crossed the highway. Deer are reluctant to use the interchange underpass, possibly because of the double-lane macadam road through it and because plowing the road often leaves an icy surface.

After the deer fence was extended to machinery underpass 1 during the late summer of 1978, the major problem of end-runs at the east end of the fence was alleviated. There are still deer-vehicle accidents below the Peterson Interchange, but they are not increasing in number.

The one deer killed inside the deer-fenced area during spring 1979 crawled under the fence where the dirt had washed out. It appears the deer will always be testing the fence, so a good maintenance program is mandatory. A fence is of little use if it has holes through which the deer can pass.

Regular early morning observation trips to the Dana Ridge area were started in mid-October 1977 and continued through the fall, winter, and spring until 1979. During 1980 and 1981, the inspection trips were at irregular intervals but usually made once a week to check the surveillance cameras. Accurate track counts were possible when ground cover was either loose dirt or snow and less than 20 deer were involved. Poor counts resulted during periods of intermittent or blowing snow or when ice or running water were in the underpasses. As a result, counts are considered conservative except those made with surveillance cameras. Cameras were used in box underpass 3 and machinery underpass 2 during daylight hours from October 1978 to March 1979 and during both day and night at box underpass 1 and machinery underpass 2 during the April-June 1979 migration and all migration periods from October 1979 to January 1981, with the exception of the period December 3-9, 1979, when vandals stole the camera and film.

Table 3 shows the number of deer passing under I-80 at machinery underpass 2, box underpass 3, and around the east end of the deer fence for the migration periods from October 1977 to January 1981. In mid-February 1978, a baiting program was initiated to attract deer under the highway at all of the underpasses and boxes except the Peterson Interchange at the lower (west) end. Third-cutting baled alfalfa hay, with a supplement of apple pulp, was used at box underpasses 2 and 3, and vegetable trimmings were used in box underpass 1 and machinery underpass 2. Both baits work well and deer began using the underpasses immediately. The baiting continued for a month, and the deer became familiar with the late afternoon baiting program. The baiting undoubtedly improved the use of the underpasses, especially box underpasses 2 and 3, which are long and dark. After a few days of baiting, deer were commonly found bedded down inside the underpasses during the day. The biggest problem was associated with motorists who stopped above the underpasses and spooked the deer. People are not accustomed to seeing deer as close as 100 ft. The deer paid little attention to the moving traffic but, when vehicles stop and people get out, the deer move away.

About 200 deer never did cross the highway the first year after fence construction but remained on the large sagebrush flats to the south between mileposts 239 and 240.5. The delay of deer going under the highway caused heavy use of the browse, particularly the sagebrush within 440 yards of the highway.

The first year after fence construction the deer were reluctant to cross under the highway, and deer accumulated in large numbers on the south side of the highway through February and into March. The highest count for one day was on February 11 when

Table 3. Number of mule deer passing under I-80 and making end-runs.

Year	Migration Period	Machinery 2		Box 3		Upper End-Runs	
		N	S	N	S	N	S
1977-1978[a]	Fall	877	311	126	12	160	71
	Spring	107	698	0	6	88	105
1978-1979[b]	Fall	712	93	161	10	16	5
	Spring	37	708	1	10	27	0
1979-1980	Fall	656[c]	39	21	6	-[d]	-[d]
	Spring	52	709	0	10	-[d]	-[d]
1980-1981	Fall	512	47	4	0	-[d]	-[d]

Note: N = north-moving migrations and S = south-moving migrations.

[a]Fence construction only completed to milepost 244.9.
[b]Fence constructed to machinery underpass 1 at milepost 246.0.
[c]Camera data missing December 3-19.
[d]No record.

525 deer were seen on the south side of the highway and 86 on the north side. It was obvious from monitoring telemetered deer in the herd that they were concerned about the high fence and underpasses. Their extensive movements up and down the fence for distances of seven miles indicated frustration. In some cases they passed approaches to underpasses and boxes several times. "Collared deer" took from two weeks to three months to decide to move under the highway.

The difference between years in the number of deer seen adjacent to the highway reflects a learning pattern by the deer to use the underpasses. It was first observed during the spring migration of 1978 and has been even more evident in recent years. The telemetered deer have been monitored during movement and are spending only a few days near the highway and in many cases are moving through in one day. The deer activity along the fence and at the entrances to the underpasses also indicated less anxiety and hesitation. Baiting was used only for the one period. No baiting has been necessary recently.

Machinery underpass 2 near the top of Dana Ridge (milepost 243.9) received the most use during all migrations. More than 60 percent of the deer used this underpass during movement to their winter range and about 90 percent during the spring migration. This underpass is near a previously identified heavily used highway crossing site (1). During the first fall and winter there was considerable movement in both directions through this underpass, mainly because of the baiting program. The deer showed less concern for their safety, even though it is open sagebrush habitat. They were often seen feeding and resting under the highway, even during the early morning when traffic, particularly trucks, is heavy (Figure 3). Movement of deer back and forth through the underpass has decreased considerably in recent years, particularly after the first year of baiting. There is no apparent reason for this activity except during the rut when the bucks can be seen on the film making sure they have accounted for all the does and fawns in the group. One buck may make a couple of round trips through the underpass during such an event.

DISCUSSION

Because of the expense involved in patrolling game fences for gaps, planners will generally want to limit such patrols to the times when deer are likely to be migrating across the fenced sections of highway. Observations during the course of this study indicate that migration timing and duration are variable and that detailed knowledge of local conditions is valuable in planning for patrolling fences.

The first deer arrived at I-80 in mid-October during all four years. Activity increased through November and generally reached a peak in December when the heavy snow cover came. Some deer moved regardless of how much snow was on the ground, but most showed a definite movement toward their winter range when snow depths of 6-12 in accumulated. The major migratory triggering device is snow depths (1, 2, 6-8). It is especially evident in deer moving from summer to fall or intermediate ranges. On the intermediate range, deer show variation in tolerance to snow depths less than about 12 in. After each snowfall, different groups of deer move lower and show up at I-80.

The number of days the telemetered deer spent on the spring, summer, fall, or intermediate and winter ranges is summarized in Table 4. There appear to be two herd segments. One arrives at I-80 in October and November and the other in December and January. Good examples are D45 and D20 and their segment that arrives early and D5, D14, D21, D37, and D46 and their segment that arrives late. (Note that the "D" listed before the numbers refers to the deer collar numbers given in Table 4.) Average days spent on the summer range were similar for both herd segments (averages 143 days for early arrivals and 147 days for late arrivals). The major difference was the amount of time spent on the intermediate or fall range. Early migrants spent from 5 to 45 days (average 22 days) on the fall range while the late arrivals spent from 8 to 73 days (average 39 days) in the area. These same differences are also reflected in the amount of time spent on the winter range. Only D5, D21, and D34 spent more than 40 days during the spring on the intermediate range, and D5 was a summer resident. D34 stayed on the intermediate range until early August both years before moving to higher elevations.

During the very light snow year of 1980-1981, at least 200 deer did not leave the fall or intermediate range. D46, in fact, stayed south about 20 miles above Saratoga for both winters of 1979-1980 and 1980-1981. This fact was also reflected in the lower counts of deer moving through the underpasses along I-80, especially during 1980-1981.

Radio tracking data show the individual animals migrating at the same relative time each year. Mature doe D45 was tracked through two migrations and spent 5-14 days on the intermediate or fall range in October. D20 (a mature doe) was tracked through five fall migrations and moved to her winter range in a period of 11-45 days in October and November. D37 was tracked for two migrations and both years arrived at the highway in December after spending only 8 and 19 days, respectively, on the intermediate range. However, she spent both summers on the northeast side of Elk Mountain, 18 miles southeast of Walcott, at about the same elevation as the intermediate range on the west side of Elk Mountain. D45 moved to the fall range in late October both years and proceeded to her winter range along the North Platte River, 6 miles west of Walcott, on the south side of I-80.

Deer classification was summarized by month from October through January when bucks, does, and fawns were easily identified, both in the field and on film. October consistently had the lowest number of deer counted and the lowest ratios of does to fawns. The number of deer increased in November and again in December with a corresponding increase in the ratios of does to fawns. Both figures decreased in January. The yearly totals followed the same trend with a few notable exceptions. It appears that the major factor that accounts for the low fawn ratios of early migrants is the length of time spent

Table 4. Summary of days spent by telemetered mule deer on seasonal ranges.

Deer Collar Number	Fall Arrival Date	Spring Departure Date	Days Spent on Seasonal Ranges			
			Spring	Summer	Fall	Winter
2		5/28/74	12	133	-	-
	10/28/74		-	-	6	-
3	12/17/74		-	-	65	-
5	12/28/73		-	-	-	88
		3/30/74	68	157	14	-
14	12/17/75		-	-	58	137
		5/3/76	23	135	-	-
	12/5/77		-	-	59	-
16	12/18/76		-	-	67	-
20	12/1/76		-	-	45	162
		5/13/77	2	150	-	-
	11/10/77		-	-	29	176
		5/6/78	19	150	-	-
	11/19/78		-	-	26	176
		5/17/79	8	147	-	-
	11/1/79		-	-	11	196
		5/17/80	9	142	-	-
	11/26/81		-	-	40	179
		5/19/81	7	-	-	-
21	12/23/76		-	-	73	119
		4/21/77	41	-	-	-
24		5/11/77	7	144	-	-
	12/17/77		-	-	71	-
25		5/6/77	13	185	-	-
	12/6/77		-	-	16	-
28	12/5/77		-	-	63	-
33		4/29/78	16	151	-	-
	12/5/78		-	-	49	153
		5/7/79	12	142	-	-
34		5/19/78	156	110	-	-
	12/2/78		-	-	40	168
		5/21/79	144	100	-	-
37		5/13/78	16	187	-	-
	12/11/78		-	-	8	157
		5/11/79	17	169	-	-
	12/3/79		-	-	19	141
45		5/18/79	9	142	-	-
	10/24/79		-	-	5	204
		5/17/80	9	142	-	-
	10/17/80		-	-	14	194
		5/15/81	5	-	-	-
46	12/14/78		-	-	15	157
		5/19/79	10	160	237	-[a]
		6/2/80	-	130	221	-[a]
		5/28/81	-	-	-	

[a]Intermediate range.

on the intermediate or fall range on the west side of Elk Mountain, about 8-10 miles southeast of the Dana Ridge area. There is no indication that the late arrivals with high productivity are from any particular summer or winter areas. Both summer and winter ranges have telemetered deer staying in the same general area but moving at different times. With its diversity of browse species, the intermediate range would be expected to have greater nutritive value of food supply as expressed by Dietz (9) in Colorado and by Julander and Robinette (10) and by Robinette and others (11) in Utah. Thus, the deer in the high-producing segment of the deer herd that spend more time on the intermediate range are in better condition than the deer that go directly to the winter range.

The ratio of 61 fawns/100 does in 1979-1980 was the lowest for any year and reflects the results of the harsh winter of 1978-1979. Strickland (6) reported that a severe winter affected production of deer in a similar way in an area 35 miles south of Walcott.

The percentage of bucks in the migrating population was consistently low (7-19 percent). All counts were made after the hunting season, which was geared to put heavy pressure on the bucks.

CONCLUSIONS

Mule deer are using machinery and box-type underpasses to cross under I-80 since the construction of 8-ft-high big-game fencing to replace the regular right-of-way fence. Deer-vehicle accidents have been reduced more than 90 percent--a significant savings of deer life and vehicle damage. Major difficulties associated with big-game fencing on I-80 were (a) overcoming deer anxiety and reluctance to use the underpass the first time, (b) extending the high fence to a length great enough to prevent end-runs, (c) preventing deer from crossing cattleguards on the ramps, (d) finding and promptly repairing holes either under or through the fence, and (e) building one-way gates at the proper distance from the underpass.

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Abridgment

How Research Benefits California's Roadsides

D.V. CASSIDY

Seven research projects that were directed toward the development of nonchemical pest-managment programs are reviewed. Both insect and weed pest control are discussed, and examples of specific successful research projects are given. Some of the pest-management programs are unique to highway roadsides while others have much in common with agricultural pest-management programs. These research projects have convinced the California Department of Transportation that research studies on the development of balanced programs will improve the environment not only of the highway roadside but also of the surrounding lands.

The state highways of California cover a vast area, which includes many differing climatic zones. There are more than 225 000 acres of roadside, and more than 17 200 acres are fully landscaped and require intensive care. The landscaped acres are generally in urban areas and planted with exotic plant species that are selected both for their aesthetic appeal and for their tolerance of highway roadside conditions.

In less-populated areas, aesthetic treatment frequently consists of preserving as much as possible of the existing flora. Some form of management is required along most of these highways. These natural landscapes range from low desert to alpine flora to redwood forest. It is the policy of the California Department of Transportation (Caltrans) to retain as much native vegetation as possible on highway roadsides. In most of California, land adjoining the highways is put to some productive use--growing of crops, feeding of livestock, timber production, or urban uses. These uses have greatly altered or partly destroyed the characteristic native plants, and for these reasons greater management and understanding of plant growth are required.

In 1966, the California State Legislature requested each state department to look at their operations and do whatever possible to reduce chemical pesticide use. At that time, Caltrans initiated contacts with the University of California in looking into practical methods of reducing chemical use.

Caltrans' first informal research project was on possible nonchemical control of California oak moth (Phrganidia californica) because this insect pest was causing in each succeeding year increasingly severe damage to the foliage of California live oaks. The use of the bacterium Bacillus thuringiensis on this insect pest with correct dosages and timing proved that it was possible to control certain insect pest populations without using chemical insecticides.

The following year a contract with the University of California, Berkeley, for nonchemical pest management in California's highway landscape was initiated. Although the research project was with the Department of Entomology, the Division of Biostatistics provided essential statistical advice.

Since this time, Caltrans has developed research projects with a number of universities and with the Agricultural Research Service of the U.S. Department of Agriculture (USDA). Research efforts show that the management of pests on highway roadsides and in landscape plantings involves the solution of various interacting problems, some in common with agricultural pest management but others conditioned by the unique features of highway roadside conditions. The results of the research have led to recommendations that no chemical insecticides be used on any harmful caterpillars on highway plantings. Some of the caterpillars that previously required repeated applications of insecticides are red-humped caterpillars (Schizura concinna), fruit tree leafrollers (Archips argyrospila), and tent caterpillars (Malacosoma constrictum and Malacosoma californicum). Because many beneficial insects are left unharmed by the use of relatively specific disease agents such as Bacillus thuringiensis, less control by man has been necessary and a balance has been struck that keeps any damage within acceptable limits. Another result of this research is that control of aphids is now done by spraying a pure liquid soap and water mixture with high-pressure spray equipment; this has given better results than previously used insecticides.

The use of these materials does not harm most beneficial insects or vertebrates, and the probability of pest resurgence is greatly reduced. It will be further reduced if the beneficial insects can be managed in a way to keep the pests in check. In California, most insect pests can be controlled by the use of insecticides, but each application of these chemicals tends to diminish the periods of control following each application. This tendency of diminishing control following each application would appear to be due to lack of specificity of the chemicals used because practically all beneficial species of insects are also eliminated during the insecticide treatment. An important factor in this chemical treatment and retreatment is the exposure of maintenance workers and the public to potentially hazardous materials. A further complication is that the pests may develop resistance to the insecticide being used for control. This retreatment and resistance has been noted in agriculture and in public health work; it is often called the chemical treadmill.

Another successful research project conducted between Caltrans and the University of California, Berkeley, was on the importation of insect predators of Acacia psyllid, an insect pest that was accidently introduced from Australia a number of years ago and had become a major pest on the thousands of acacia trees and shrubs planted along California's highways. Acacia trees are generally fast-growing, low-maintenance plants, and this has led to their wide use in ornamental plantings in California. Large numbers of flying adult psyllids were often a source of complaint from nearby residents and highway personnel working in and near infested acacias. At the time, it was obvious that insecticide spraying was not reducing the numbers of this insect pest. Predators of the psyllid were collected in Australia and imported and released on roadside acacias. Since that time no chemical spraying has been done on this insect pest and Caltrans has received adequate control of a serious infestation.

Since 1978, Caltrans and the Federal Highway Administration (FHWA) have been funding a research project with the University of California, Berkeley, on an extensive ecological and biological control of two species of iceplant scale (Pulvinaria). This insect pest was first found in California in 1971. Although it was believed to have been eradicated by 1977, it had become apparent that this insect pest was out of control on iceplants throughout most of the San Francisco Bay area. It has now spread throughout much of California.

Caltrans has more than 6000 acres of iceplant growing along California state highways. Iceplant was chosen as a ground cover because of its ability to grow well under poor soil conditions, its relatively low maintenance costs, and its adaptability to both cool coast and hot interior California growing conditions.

The Pulvinaria scale is so serious that the infestation threatens the survival of iceplants and possibly other succulent plants as well. Researchers have introduced a number of parasites and predators of these Pulvinaria scales from a search that was made in Africa and in southern Europe. These parasites and predators have been processed through quarantine facilities and have been released on infestations of Pulvinaria scale on roadsides in many areas of California.

Caltrans' involvement in research to reduce pesticide use and also to reduce the cost of roadside care has not been limited to insect pests. Caltrans has funded, with participation from FHWA, a number of research projects on the control of pest weeds. Most troublesome weeds on California's roadsides are introduced species, such as Russian thistle or tumbleweed (Salsola kali), puncture vine (Tribulus terrestris), field bindweed (Convolvulus arvensis), and yellow star thistle (Centaurea solstitialis).

About 20 years ago Caltrans watched with great interest the research work that was done with the importation of a beetle to control Klamath weed (Hypericum perforatum), a weed pest that had made thousands of acres of California agricultural land unfit for any productive use. Chemical control was tried and was found to be economically impossible. Several years after the release of these beetles only scattered stands of Klamath weed could be found. This example of biological control is an outstanding success, and these thousands of acres of previously infested land have been returned to the production of economic crops.

In 1960, host-specific insects were released on puncture vine in California. Caltrans has funded a research project with the USDA Biological Control of Weeds Laboratory, Albany, California, to collect and transfer the insects, to import different insects, and to explore the availability of pathogens against this weed pest. [A copy of the final report on the use of weed-feeding insects for the nonchemical management of puncture vine along California highways is available through the National Technical Information Service, Springfield, Virginia (number 282541) or by request to Caltrans.]

Caltrans has also funded a research project with USDA in Albany, California, to control Russian thistle by the use of imported moths. It is interesting to note that, until several years ago, Caltrans had been spending more than $1 million a year attempting to control and clean up this weed pest. Populations of this weed pest have been noticeably reduced, and the cost of control has been reduced greatly. Caltrans believes this to be at least partly due to the beneficial insects.

Caltrans is convinced of the desirability of spending money on research studies for the development of balanced systems that do not have the disruptive effects on the environment that has marked the widespread use of pesticides.

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Abridgment

Nylon Erosion-Control Mat

GARY L. HOFFMAN AND ROBERT ADAMSKY

The Pennsylvania Department of Transportation (PennDOT) has placed, and continues to place, emphasis on value engineering—the use of alternative cost-effective materials or procedures to perform a common function. As a result of this emphasis, a nylon erosion-control mat was recently field tested as a ditch lining on a project that was originally designed for rip-rap or paved-concrete lining. This nylon mat, installed with either a bituminous or wood cellulose surface treatment, provided a functional and economic erosion-control measure. In the trapezoidal ditches calculated, nonvegetated velocities were as high as 20 ft/s and vegetated velocities were as high as 8 ft/s. The mat installation resulted in a 60-70 percent cost saving over the rip-rap or paved-concrete lining alternatives. PennDOT has included this nylon mat in its general specifications as a result of the positive findings on this project. A significant benefit of this stabilizing fabric was the structural integrity it provided to the vegetation root system. The use of the nylon mat instead of the rip-rap or paved-concrete alternatives also resulted in slower final velocities and lower flow concentrations.

The Pennsylvania Department of Transportation's (PennDOT's) Design Manual provided for the use of erosion-control lining made of sod, jute matting, rock, gabions, or paved concrete, depending on anticipated velocities. The use of the last items, where higher velocities were expected, added substantial cost to the project.

Prompted by PennDOT's value engineering emphasis and by reports (1-3) of successful uses of the nylon mat by a few other state highway departments, a substitution of the nylon erosion-control mat for the designed rip-rap or paved-concrete lining was proposed. The substitution was allowed on two ditches with the stipulation that a formal research project, funded in combination by the Federal Highway Administration (FHWA) and the state, be initiated to evaluate the performance of the nylon mat. A final report (4), which this paper summarizes, was prepared by PennDOT as required by the research program.

INSTALLATION

The nylon mat was substituted for the rip-rap or concrete lining on two sections of trapezoidal ditches on the Monongahela Valley Expressway (Legislative Route 1125) in Washington County in the southwestern part of the state. The nylon mat was a flexible soil-reinforcement matting made from nylon monofilaments that are fused at the intersections (see Figure 1). It was a bulky mat, and its three-dimensional structure (about 0.75 in thick) allowed 90 percent of its volume to be filled with soil, gravel, or other appropriate material.

The first section was by the bituminous surface method and was placed on July 18 and 19, 1979. The trapezoidal ditch had a bottom width of 2 ft, side slopes of 1.5 on 1.0, and a depth of 3 ft. This

Figure 1. Close-up view of nylon mat.

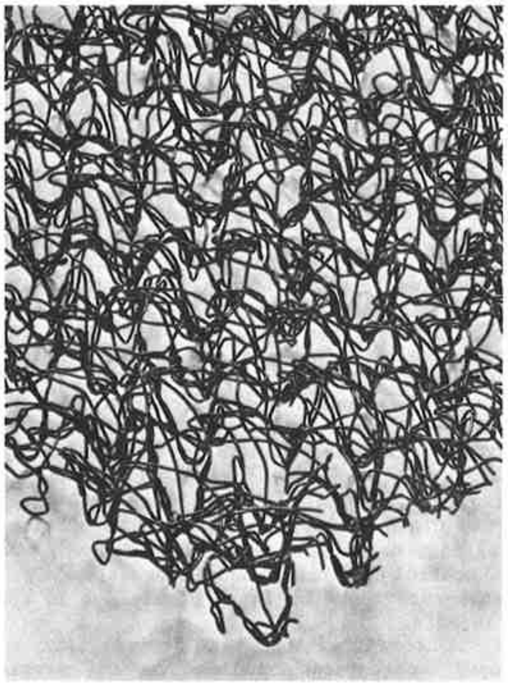


Figure 2. Construction details.

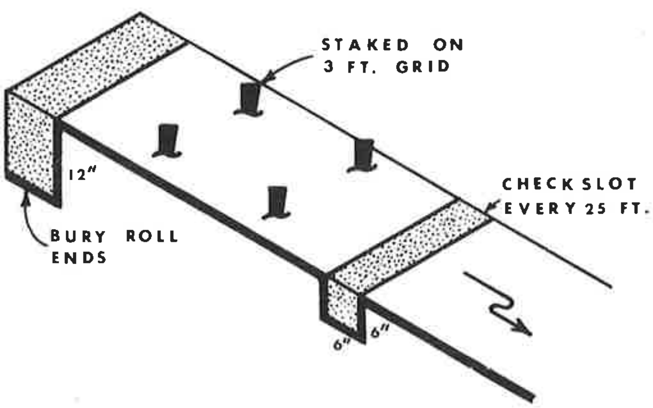
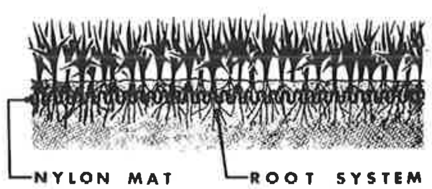


Figure 3. Schematic of integral mat and root system.



wet-bottom ditch had an average slope of 16.5 percent and carried the outfall from a 30-in-diameter corrugated metal pipe culvert. The outfall water was temporarily diverted during construction. First, a nonwoven geotextile was placed on the ditch bottom; then three strips of the nylon mat, one on the bottom and one on each of the two side slopes, were placed. Both the nylon mat and the geotextile were provided in 3-ft-wide rolls. After placing, staking, and trenching in accordance with the schematic shown in Figure 2, the seed (45 percent crown vetch and 55 percent ryegrass) and soil supplements were placed. A crushed slag aggregate--which had gradations of 0.50 in, 100 percent; 0.375 in, 95-100 percent; No. 8, 30 percent; and No. 100, 8 percent--was then broomed into the mat and tack-coated with 0.3-0.4 gal/ yard² of E-6 emulsified asphalt.

The second section was by the wood cellulose surface method and was placed on September 13, 1979. The ditch in this area had a cross section similar to that in the first section, had an average slope of 22.5 percent, and carried water from a paved-concrete slope interceptor ditch. Again, three strips of the nylon mat were placed in the trapezoidal ditch, and the manufacturer's recommended installation procedures shown in Figure 2 were followed. The nonwoven geotextile was not used in this section, since the ditch bottom was not continually wet. After placing the nylon mat, wood cellulose was hydrosprayed over the entire mat at the rate of 320 lb/1000 yard². Portions of this section were seeded and supplemented before spraying, and the other portions were seeded and supplemented simultaneously with the spraying operation.

PERFORMANCE DATA

Both sections of the nylon mat have performed well after two years in service. The crown vetch initially had established itself along both sides of the trapezoidal ditches and, for the most part, it now has encroached across the bottom of even the continually wet ditch. The nylon mat has become an integral part of and reinforcement to the vegetation root system, as claimed by the manufacturer (Figure 3).

Velocities were established from actual field measurements and from calculations by using Manning's formula for open channel flow. These velocities are listed below for the bituminous and wood-cellulose-treated sections:

1. Bituminous method velocities: vegetated (measured)--5 ft/s, gravel bottom (calculated)--9 ft/s, and concrete paved (calculated)--14 ft/s.
2. Wood cellulose method velocities: vegetated mat (calculated)--8 ft/s, nylon mat only (measured)--10 ft/s, and gravel bottom (calculated)--14 ft/s.

The measured velocity of 5 ft/s in the bituminous section was made about three months after construction when a full stand of ryegrass existed on the side slopes of the ditch. A roughness coefficient (n) of 0.05 was established for the measured velocity and flow conditions. This n value agreed well with published ranges. Published estimated n values of 0.03 for the unlined gravel bottom ditch and 0.012 for the paved-concrete lining were used to calculate the 9 ft/s and 14 ft/s in the wood-cellulose-treated section made shortly after construction when no vegetation or siltation was present on the mat. An n value of 0.04 was calculated for these measured hydraulic conditions. Velocities of 8 ft/s for the vegetated ditch and 14 ft/s for the unlined ditch were calculated by using the n values given above. If this section of ditch had been lined with paved concrete, a velocity in excess of 30 ft/s would have resulted for these hydraulic conditions. Detailed hydraulic calculations are provided in the previously mentioned research report (4).

The portions of the wood cellulose section that were seeded and supplemented simultaneously with the hydrospray operation developed a grass stand at the same rate as the portions that were seeded as a

Table 1. Cost breakdown for mat-lined sections.

Material and Installation	Cost[a] ($)
Bituminous Surface Method[b]	
Labor: 3 people at $7.46/h x 16 h	358
Equipment: hydroseeder, truck, and high lift	100
Nylon mat: 174 yard² at $3.42/yard²	595
Geotextile: 57 yard² at $0.63/yard²	36
Seeding: $0.07/yard² (Formula C)	20
Stone: 4 yard³ at $7.50/yard³	30
Asphalt emulsion: 60 gal at $0.58/gal	35
Stakes: 155 wooden at $0.11/stake	17
Total	1191
Wood Cellulose Method[c]	
Labor: 4 people at $7.46/h x 8 h	240
Equipment: hydroseeder, truck, and high lift	60
Nylon mat: 245 yard² at $3.42/yard²	838
Seeding: $0.07/yard² (Formula C)	17
Stakes: 228 wooden at $0.11/stake	25
Total	1180

[a] Cost data are given in rounded figures.
[b] Alternate methods of calculating for bituminous surface method: 146 yard² at $8.15/yard² or 155 linear ft at $7.68/linear ft.
[c] Alternate methods of calculating for wood cellulose method: 215 yard² at $5.50/yard² or 228 linear ft at $5.23/linear ft.

separate operation before hydrospraying. There was no difference in overall performance between these two sections.

The geotextile was used to prevent soil erosion under the mat when used in a continuously wet-bottom ditch. After several inspections over a period of time, it was determined that this fabric material provided additional protection under these conditions. There was some initial concern that the geotextile would retard vegetation growth. Although the fabric would retard germination and prevent growth if seed was placed below the geotextile, this nonwoven fabric did not prevent root penetration from the top down. This was evidenced by the crown vetch encroaching completely across the bottom of the ditch.

COST DATA

A substantial unit-cost saving was realized by using the nylon mat lining in lieu of paved-concrete or rip-rap lining. The original contract was bid at $19.30/linear ft of ditch for rip-rap, and the contractor was in favor of providing paved-concrete lining as an alternative at this same unit cost. These unit costs were high because of the relatively few sources of quality aggregates in the southwestern part of the state. The actual costs for the nylon mat with bituminous surface and wood cellulose methods were $7.68 and $5.23/linear ft of ditch, respectively. The itemized cost breakdown for the mat-lined sections are tabulated in Table 1.

A typical cost for a jute matting installation is $2.50/yard². However, jute matting is less effective and is only a temporary erosion-control measure. It would not be applicable in the same situations where the nylon mat could be used.

CONCLUSIONS

The nylon mat installed with both the bituminous surface and wood cellulose treatments provided an effective and economical erosion-control measure in ditches with initial nonvegetated velocities up to 14 ft/s and final vegetated velocities on the order of 8 ft/s. The mat installation resulted in a significant unit-cost savings over the rip-rap or paved-concrete lining alternatives on this relatively small experimental project. It is expected that unit costs for the installed mat may decrease on projects with larger quantities and when subcontractors become more familiar with this material and its installation techniques.

The use of the nylon mat in promoting vegetated ditches provided the advantages of groundwater recharge and additional lag time in runoff flow concentrations. By allowing more water to percolate back into the subsoil than a concrete-lined ditch, the vegetated mat-lined ditch reduced the total quantity of water discharged into the downstream water basin. Furthermore, by reducing the maximum velocity to about one-third of the velocity anticipated with a concrete-lined ditch, discharges were not concentrated as rapidly downstream. The need for energy dissipation was also lessened. The potential for undermining of the ditch lining, which is prevalent with paving or rip-rap, was minimized, since the mat provided structural integrity to the vegetation root system.

From the results of the experimental projects, the following items are recommended:

1. Specify nylon mat with either of the two surface treatments in PennDOT's general specifications as an alternative to rip-rap or paved-concrete ditch lining where calculated flows in the unlined trench do not exceed 10 ft/s;
2. Allow the application of seed, soil supplement, and wood cellulose mulch in a single operation;
3. Specify a wood cellulose mulch application rate of 640 lb/1000 yard² to provide better seed cover at only a 1 percent cost increase; and
4. Use longer wooden stakes (18 in) in check slots and terminal ends when soft subsoil material is encountered instead of the specified 12-in stakes.

ACKNOWLEDGMENT

The manufacturer's (American Enka Company, Enka, North Carolina) specifications for product #7020 were used for this work. C.S. Kemic, technical advisor for American Enka, provided assistance during the installation. Suburban Spray Service of Pittsburgh was the subcontractor that made the installation.

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Notice: The Transportation Research Board does not endorse products or manufacturers. Trade and manufacturers names appear in this paper because they are considered essential to its object.

Abridgment

Operation and Maintenance of Safety Rest Areas

DONALD L. CORNELISON

People in America are highly mobile. A partial network of safety rest areas has been completed on the Interstate highway system so drivers can stop for a short period and return to the road as safer drivers. Operation and maintenance costs vary from $16 000 to $60 000/site/year. This is a significant cost in maintenance budgets; therefore they should be operated as efficiently as possible. Supervision, staffing, training, methods, and materials used are key elements that influence cost-effectiveness. Proper attention to these elements will produce well-maintained safety rest areas that provide a valuable service to the motoring public at the least possible cost.

People in America are highly mobile. A partial network of safety rest areas (SRAs) has been built on the Interstate highway system to provide facilities where the traveling public can pull off the road safely and enjoy a time of rest and relaxation. This results in safer drivers.

The costs for operation and maintenance of SRAs are a significant portion of the budgets for most state highway agencies. It is imperative, therefore, that engineers and managers be well informed of the key elements that affect service to the public and the cost-effectiveness of the operation.

The cost of maintaining SRAs varies from $16 000 to $60 000/year/site, depending on size, location, facilities provided, and level of service. Three broad categories of SRA operation and maintenance costs are grounds maintenance, building maintenance, and utilities. Proper attention to these three can minimize the dollars spent and maximize the service to the public.

Efficient and cost-effective operation and maintenance of SRAs are influenced by four key elements. They are the following:

1. Supervision,
2. Staffing,
3. Training, and
4. Methods and materials used.

In many states, SRAs are added as another responsibility of a highway maintenance crew supervisor. Good results occur when the supervisor takes pride in the SRA. If the supervisor resents the inclusion of an SRA as a responsibility, the operation and maintenance suffer. Supervision that is receptive to rest areas is essential for their proper operation and maintenance.

In many instances rest areas are staffed by highway maintenance workers whose talents and expertise are in the area of roadway maintenance work. When placed in a rest area they are ill-equipped to perform without proper training, which can result in inefficiency as well as necessitate expensive repairs. Ideally, the individual should have previous experience in landscaping and building maintenance (including minor repair work) and in dealing with the public.

Labor is the major cost of rest area operation. Most SRAs are open to the public year-round. Michigan, however, closes every other rest area on some routes during winter months. Some states staff the rest areas on a 24-h basis while others only staff for 8 h/day, usually during daylight hours. The New York State Department of Transportation closes restrooms in some SRAs between 11:00 p.m. and 6:00 a.m. Signs are posted with this information.

Maintenance of SRAs is performed by state personnel or by contract. South Dakota contracts maintenance of some SRAs. Illinois and Minnesota contract maintenance of some SRAs to federally funded senior citizen organizations. Each state's policy on the level of service to the motoring public directly affects the staffing level and, consequently, the total cost of the operation.

Proper training and supervision are essential in order to achieve cost-effective operation and maintenance. When a new person starts work at an SRA, he or she should be given an intensive training course that involves classroom instruction, on-the-job training, and hands-on experience. Periodic refresher training should also be provided for all rest area personnel in order to keep them abreast of new methods, materials, and techniques. Many states have rest area maintenance manuals or handbooks to cover some of the specific details of daily maintenance. California and Missouri have extensive training courses that include training in landscape maintenance.

Methods of performing the work and the materials used have a tremendous impact on the total cost of rest area operation and maintenance. Sharing information between rest area personnel and between states can provide better methods of accomplishing the work activities that are common within SRAs.

The materials portion of the operation and maintenance of SRAs is approximately 25 percent of the cost. Without proper control and supervision, this cost can increase by as much as 300 percent. Some salesmen convince the rest area manager that their product will perform better than the product currently being used. As a consequence, large quantities are sometimes purchased without product evaluation and cost analysis. Investigation sometimes reveals that the product costs three to four times as much as a similar product with a different name that has the same ingredients and performs just as well. As an example, a recent requisition came in for "brand Y" product. Investigation revealed that the cleaning product cost $3.67/quart. "Brand X" contained the same ingredients, performed the cleaning just as well, and only cost $1.06/quart. In other words, brand Y was 3.46 times as much as brand X.

The best method of keeping materials costs under control is to evaluate materials and products for performance. Those that perform well should then be put on an approved products list as being equally effective for a particular application. When materials or products are needed, bids should be called for from companies that have products on the list. The materials or products supplied by the low bidder can then be stocked for use.

Security and safety of rest area personnel, the motoring public, and the facilities within the SRA are directly affected by vandalism. Vandalism is not a major cost of rest area operation and maintenance. In 1979 and 1980, both Michigan and Illinois experienced an average cost of $500/site due to vandalism. In Pennsylvania the average cost of vandalism is $300/site/year. In Michigan, a single incidence of vandalism in one rest area cost $2600 to repair. In Arizona, costs of vandalism were recorded for a three-year period. The average yearly cost per site was $225. Some vandalism repairs are probably reported as normal maintenance.

Operation and maintenance of SRAs is big business, and maintenance dollars are in short supply. To conserve maintenance dollars it is imperative that operation and maintenance of SRAs be accomplished in the most efficient way possible. Provision for good supervision, adequate (but not excessive) levels of staffing, proper personnel training, use of the best methods possible (including innovative alternatives), and proper control and use of materials will produce well-maintained SRAs that will provide satisfactory service to the motoring public at the lowest dollar value. Another result will be safer drivers.

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Fertilization and Legume Establishment on Highway Slopes

RUPERT F. STAFFORD

A fertilizer study illustrated the feasibility of discontinuing the use of loam in the construction of highway slopes in Maine. Protective grass sods can be established and maintained on subsoils devoid of organic matter through hydroseeding and subsequent top dressed fertilization. Spring and early summer seedings should be top-dressed in early fall, while late summer or early fall seedings may not require topdressing until the following spring. Research was also conducted to develop a practical way of establishing crown vetch on steep roadside slopes already in grass sod. Application of the transplanting method was limited to relatively small areas where the erosion hazard was great enough to justify the labor costs of hand planting. The crown vetch transplantings were successful at all highway sites studied and had vegetative spreading in excess of 122 cm within two years. A related study showed that, on slopes where equipment can be used, good establishment of both crown vetch and bird's-foot trefoil can be obtained by scarifying the surface of a grass sod prior to overseeding. The overseeding of bird's-foot trefoil (Empire) on relatively steep grassed slopes by using a herbicide (paraquat) was also studied. The herbicide reduced the competition from the initial ground cover and was advantageous in trefoil establishment.

Establishment and maintenance of the vegetative cover along highways is an expensive proposition. However, this must be done to prevent erosion and rutting of the roadsides. This is especially important along the steep backslopes of many highways in Maine. Also, the most practical and economical means available must be used. Answers are needed to such questions as

1. Do we need topsoil?
2. How much nitrogen do we need and how often?
3. How can legumes be introduced into a grass sod?

This study dealt with questions such as these, and enough data were collected to obtain some of the answers.

One objective of the study was to determine the fertilization requirements of grass sods on highway slopes constructed of subsoil materials without added topsoil loam. This was conducted on grass-covered embankments of the Back Cove Project of Interstate 295 in Portland, Maine.

A second objective was to determine the potential value of crown vetch and bird's-foot trefoil (Empire) as an indirect source of nitrogen for a legume and grass cover. These species were overseeded in 1972 on scarified grass-sod embankments in Old Town, Orland, and Portland.

A third objective of this study was to determine the transplanting and overseeding methods for legume establishment. One phase of the study concentrated on an evaluation of the effectiveness of the transplant method of establishing crown vetch in grassed highway slopes. This study was conducted over the period June 1973 to September 1975. Two principal sites were studied, one on US-1 at Orland and the other on ME-16 at Old Town. A supplementary study was carried out on an eroded highway off ME-201 in Caratunk and on embankments of I-295 in Portland. Another phase concentrated on overseeding bird's-foot trefoil (Empire) in grassed slopes by using a herbicide to reduce the grass competition and was conducted over the period October 1975 through November 1978. Studies were made at four principal sites in the towns of Orland, Old Town, Lincoln, and Dedham.

EXPERIMENTAL PROCEDURES

Fertilization of Grass Sod

The grass sod was seeded initially in August 1971 at the Back Cove site by the contractor, Leon E. Gordon, Inc. Standard hydroseeding practices were employed, including the equivalent of 1121-kg limestone/hm^2 and 1345-kg 10-10-10 fertilizer/hm^2. The typical roadside mixture of tall fescue, red fescue, K. bluegrass, redtop, and white clover was sown directly onto the unloamed embankments. The seeding was mulched with chopped hay at approximately 2242 kg/hm^2 and sprayed with emulsified asphalt.

A representative section of these grassed embankments was selected for fertilization studies in April 1972. Soil samples from this area were tested to determine their fertility level. Average values of pH were 6.8; medium phosphorus (P) and low potassium (K) were obtained.

Two experiments that used top-dressed fertilizers were established on April 26, each in a randomized complete-block design with four replications. One study involved a comparison of ammonium nitrate (AN) versus sulfur-coated urea (SCU) applied at several rates of nitrogen (N). The other study compared several rates of P and K. The N study received 672-kg 5-20-20/hm^2 to ensure unlimited phosphorus and potassium. The P-K study received two applications of 336-kg 33-0-0/hm^2 annually to ensure unlimited nitrogen. The experimental treatments are indicated in Tables 1 and 2.

Note that these studies were conducted with pure grass sods comprised mainly of red fescue and tall fescue. To avoid any significant contribution of fixed nitrogen, white clover and volunteer legumes were kept at a low level throughout the study by repeated application of 2,4-D and dicamba. These two herbicides also served to keep the grass sods virtually free of all broad-leafed weeds.

The response of the grass sod to the experimental treatments was evaluated by harvesting and chemical analysis in 1972 and 1973. Dry matter yields and nitrogen uptake were determined in harvests made on July 6, 1972, and June 5, 1973. All harvested forage was removed from the plots on these two dates.

Following the June 1973 harvest, no further removal of forage occurred. The study was modified instead to permit recycling of any nitrogen subsequently taken up by the grasses. A rotary mower was used to leave the clippings in place on the respective subplots. The field experiments were mowed in this manner in late August 1973 and in mid-May and mid-June 1974. Fertilizer nitrogen for this recycling was applied to the N fertilization study at a uniform rate of 100-kg N/hm² on August 23, 1973, and again on April 29, 1974.

Observational notes and colored photographs were taken at periodic intervals throughout the three-year study. The field experiment at Portland was concluded in October 1974; samples were taken to determine the average depth of rooting of the grasses grown in the N fertilization study.

Two supplementary field studies were conducted at the Forage Research Center at Orono concurrent with the studies in Portland. In one of these studies, data were collected to determine the actual recirculation of nitrogen in clippings of repeatedly mowed grass sods. In the other study, a comparison was made between AN and SCU with regard to the seasonal pattern of nitrogen uptake by sod grasses over a three-year period.

Legume Establishment

Overseeding Crown Vetch and Bird's-foot Trefoil

Highway sites were picked at Portland, Orland, and Old Town. The Orland and Old Town sites were selected to be representative of relatively newly established slopes that had deteriorating grass cover. Soil conditions at the two sites were quite different; the relatively fine-textured material at Orland contrasted with the coarse, sandy material at Old Town.

The overseeding studies were initiated in 1972 at Portland and in 1973 at Old Town and Orland. These consisted of a direct broadcasting of crown vetch (Penngift) and bird's-foot trefoil (Empire) onto grass sod that had been lightly scarified by disking (Portland and Old Town) or by a hand-pulled harrow (Orland). Prior to scarification, these sods were top-dressed with 2242 kg/hm² of agricultural limestone and 672 kg/hm² of 5-20-20 fertilizer. All legume seed was heavily inoculated with the appropriate rhizobium inoculent prior to seeding and sown at the rate of 22 kg/hm². The seeding at Portland was made on May 10, at Orland on June 8, and at Old Town on July 19. No attempt was made to cover the seed either by mechanical means or by mulching.

Transplanting Crown Vetch

Crown vetch varieties (Penngift and Chemung) were used for transplantings made in 1973 and repeated in 1974. These were transplanted at three locations, as shown in the table below:

Location	Date	No. of Plants
Orland	June 12, 1973	92
	August 9, 1974	192
Old Town	July 20, 1973	180
	June 10, 1974	180
Caratunk	June 25, 1974	336

A greenhouse procedure was developed through which vigorous seedlings were grown from seed in 7.62x7.62-cm peat pots that could be planted directly in the field without root disturbance. The seedlings used ranged in age from two to nine months. Relatively simple transplanting procedures were followed to establish these seedlings at 1.8-m spacings in the field plots. Two pots that contained two seedlings each were planted close together in a shallow hole in which superphosphate fertilizer, equivalent to 224-kg P_2O_5/hm², had been mixed with the soil.

Maintenance practices for both the overseeding and transplanting studies were quite simple. The legume plots and transplants were left unmowed but were top-dressed with a borated high-potash fertilizer during the season following the year of establishment. Moderately high levels of soil fertility were maintained. Observational notes and photographs were obtained throughout the study.

Overseeding Bird's-foot Trefoil by Using a Herbicide

Four roadside sites were selected in eastern Maine during fall 1975 to represent soil textural condi-

Table 1. Dry matter yields and mineral content of harvested grass forage as influenced by levels of P-K fertilization top-dressed in April 1972 (Portland).

Treatment No.	Fertilization (kg/hm²)		Dry Matter (kg/hm²)		Mineral Content of Dry Matter (%) (6/5/73)	
	P_2O_5	K_2O	7/6/72	6/5/73	P	K
1	0	0	5919	5551	0.42	2.36
2	0	112	5224	5112	0.43	2.42
3	112	112	5807	6166	0.53	2.75
4	112	224	5381	6502	0.53	2.36
5	112	336	5649	5583	0.51	2.54

Table 2. Dry matter yields, nitrogen uptake, and recovery of fertilizer nitrogen as influenced by rate, timing, and source of nitrogen top-dressed in April 1972 (Portland).

Treatment No.	Nitrogen (kg/hm²)		Dry Matter (kg/hm²)		Nitrogen Uptake (kg/hm²)		Nitrogen Recovery (%)
	AN	SCU	7/6/72	6/5/73	7/6/72	6/5/73	
1	0	0	3318	0	48	0	-
2	112	0	5426	67	90	1	38
3	224[a]	0	5157	2825	80	34	30
4	336[a]	0	5201	5605	84	88	37
5	0	224	5246	2264	91	27	31
6	0	336	5515	3453	112	54	36
7	112	112	5403	1457	103	17	32
8	112	224	5157	3363	107	43	31

[a]Split applications in increments of 100 kg N on April 26, July 18, and September 13 (all other N applications on April 26).

Table 3. Trefoil stand rankings based on visual observations.

Location	Treatment No.[a]					
	1	2	3	4	5	6
1976						
Orland	2.6	2.4	1.0	1.8	6.4	4.8
Dedham	1.6	1.8	1.0	2.0	3.4	4.0
Old Town	1.2	2.4	3.6	2.2	3.8	4.8
Lincoln	1.4	1.6	1.2	1.8	4.0	3.8
Mean	1.7	2.1	1.7	2.0	4.4	4.6
1977						
Orland	4.8	4.4	3.2	3.8	7.2	7.6
Dedham	3.0	3.4	3.4	2.8	6.2	6.8
Old Town	4.2	4.6	5.2	4.4	5.6	5.6
Lincoln	3.4	2.4	3.0	2.0	3.8	4.8
Mean	3.8	3.7	3.7	3.2	5.7	6.2
1978						
Orland	7.0	6.0	5.8	6.4	7.4	8.8
Dedham	4.4	6.0	5.0	5.8	7.8	8.6
Old Town	4.4	5.6	5.4	5.2	6.0	6.6
Lincoln	4.6	4.0	4.0	3.0	4.6	5.2
Mean	5.1	5.4	5.1	5.1	6.5	7.3

Note: Rank numbers are 1 = very poor through 9 = excellent.

[a]Figures within table are averages of five replications.

tions that ranged from gravel to clay. The sites with clay soils were at Lincoln and Orland, and the lighter sandy soils were at the Old Town and Dedham sites. At each location, a representative area of backslope sod was selected for legume overseedings to be made in early spring 1976. Each area was essentially a grass sod with variable amounts of herbaceous and woody weeds. Ground cover by the grass sod ranged from low to moderate density.

In October 1975 the following operations were carried out at each site. The experimental area was measured and staked out in preparation for the spring overseeding. Agricultural limestone was top-dressed over the entire area at a rate equivalent of 2242 kg/hm². The individual plot size was 2.4x9.1 m. There were six treatments replicated five times for a total of 30 plots/location. The individual treatments and seeding dates are shown in the table below:

Treatment No.	Seeding Date	Paraquat, 4.7 L/hm², May 11-12	K Application, 224-kg K_2O/hm², July 26
1	April 9	No	No
2	April 9	No	Yes
3	April 9	Yes	Yes
4	May 11-13	No	Yes
5	May 11-13	Yes	Yes
6	May 11-13	Yes	No

Soil pH levels prior to liming ranged from pH 5.9 at Old Town to pH 6.4 at Dedham. Phosphorus and potassium levels ranged from very low to medium, and there was considerable variability between replicates at the Lincoln and Old Town sites.

In spring 1976, the entire area at all locations was top-dressed with 112-kg P_2O_5/hm² prior to the April seeding. On April 9, treatments 1, 2, and 3 were seeded with bird's-foot trefoil (Empire) at the rate of 22 kg/hm². Treatments 4, 5, and 6 were seeded at the same rate on May 11 at Orland and Dedham, and May 13 at Old Town and Lincoln. Paraquat was applied at the rate of 4.7 L/hm² on treatments 3, 5, and 6 at all four sites immediately after the May seedings were completed. Potassium was applied annually on treatments 2, 3, 4, and 5 in July at the rate of 224-kg K_2O/hm².

Visual observations were made at all sites during the season, and more detailed observations were made during October 1976, 1977, and 1978 (Table 3). These observations of trefoil stands were ranked on a number system that ranged from 1 (very poor) to 9 (excellent).

RESULTS AND DISCUSSION

Fertilization of Grass Sod

The P-K fertilization study indicated little response to additional phosphorus and potassium by the grass sod at the Back Cove site. Forage yields and chemical analyses from the spring harvests of 1972 and 1973 (Table 1), along with subsequent visual observations of the grasses, showed that there was adequate carry-over of minerals from the 1971 hydroseeding. However, chemical analyses of soil samples obtained in November 1972 and October 1973 indicate that the available potassium supply had declined with the removal of harvested forage. Without forage removal, the recirculation of potassium in grass clippings would probably be adequate to satisfy the long-term needs of a pure grass sod on this site. A legume and grass sod would have greater need for top-dressed potassium, since the critical concentration of K is considerably higher in legumes than in grasses.

The N fertilization study indicated the need for repeated nitrogen top-dressing during the year following hydroseeding. Nitrogen deficiency symptoms were clearly evidenced by the grasses in early October 1971 in spite of the liberal rate of N supplied with hydroseeding on August 9. Dry matter and nitrogen yields in the 1972 and 1973 harvests (Table 2) were greatly inferior in the unfertilized plots. These plots continued to decline in vegetative cover throughout the 1972 and 1973 seasons; bare spots of soil were increasingly evident. They showed dramatic recovery, however, when nitrogen top-dressing of the entire study area was initiated in August 1973.

The data in Table 2 also indicate that the heavy rates of SCU application in April 1972 were effective for continued release of nitrogen for grass growth into spring 1973. However, when compared with 335 kg/hm² of nitrogen from AN (split application), the amount of available nitrogen was too low to support a maximum growth rate in 1973. Delayed application of AN (September 1972) proved more effective in this regard than the use of SCU in 1972.

The supplemental study of SCU conducted at Orono showed results similar to those of the Portland study (Table 4). The SCU material that was rated as 20 percent rapid release (same material as used at Portland) gave good carry-over into the second year but little or none into the third year. Spring-applied AN released virtually all of its nitrogen during the year of application but resulted in a much higher rate of nitrogen recovery than that obtained with SCU.

The final year of study at Portland clearly illustrated the significance of nitrogen recirculation through clippings left in place by the rotary mower. The nitrogen top-dressed in April 1974 supported vigorous grass growth and rapid recovery after mowings made in mid-May and mid-June. However, grass growth slowed during the latter half of the 1974 season.

The supplemental study at Orono gave some quantitative measure of the amount of recirculation of nitrogen in grass clippings. A comparison of clippings removed versus clippings deposited on the sod showed that the equivalent of 36 percent of the

Table 4. Nitrogen uptake and recovery of fertilizer nitrogen as influenced by rate and source of nitrogen top-dressed in May 1972 (Orono).

Treatment No.	Nitrogen Source	Nitrogen Rate (kg/hm^2)	N Uptake (kg/hm^2) 1972 (3 cuts)	1973 (3 cuts)	1974 (1 cut)	Nitrogen Recovery (%)
1	None	0	32	39	20	-
2	AN	168	170	49	20	89
3	SCU[a]	336	164	70	19	48
4	SCU[b]	336	82	124	38	46
5	SCU[b]	672	139	185	58	44

[a]20 percent rapid release. [b]5 percent rapid release.

Table 5. Nitrogen uptake and recovery of fertilizer nitrogen applied July 6, 1971, as influenced by clippings returned and clippings removed (Orono).

N (kg/hm^2)	Method[a]	N Uptake (kg/hm^2) Aug. 5	Sept. 9	Oct. 15	Total	Recovery (%) Total	Cuts 2 and 3
0	C	47	11	13	71		
0	H	53	6	9	68		
75	C	98	28	26	152		36
75	H	99	15	13	127	70	

[a]C = clipped and returned, and H = harvested and removed.

fertilizer N applied in the spring was later reabsorbed by the grasses following rotary mowing (Table 5).

Legume Establishment

Overseeded Crown Vetch and Bird's-foot Trefoil

Observations in 1974 of the legume overseeding study at Portland that was seeded in spring 1972 showed growth of crown vetch and Empire trefoil to be very vigorous. The legume overseeding at Orland on June 8 proved to be highly successful. Essentially complete ground cover was obtained with each of the legume species sown--bird's-foot trefoil (Empire) and crown vetch (Penngift and Chemung). The stands of trefoil and crown vetch have persisted throughout the study.

In contrast, the overseeding at Old Town proved to be relatively ineffective. Initial germination in 1973 appeared adequate but subsequent seedling survival was poor. It appears that the delayed seeding date (July 19) did not permit adequate plant growth before winter. In addition, the native vegetative cover at the Old Town site contained a considerable amount of red clover and was therefore more competitive than that at Orland. However, spots of trefoil and crown vetch that were evident in 1975 had grown considerably larger during 1976 and 1977, which suggests that delayed germination of hard seed may provide improved stands in future years. Recent observations made in 1981 showed that nearly complete ground cover had been obtained.

Crown Vetch Transplants

The crown vetch transplantings were universally successful at all the highway sites studied. Detailed notes of the extent of vegetative spreading were obtained in September 1975 and July 1976 and are presented in Tables 6, 7, and 8. The delayed 1974 transplantings at Caratunk and Orland were not sufficiently developed for detailed measurement of rhizome spread, so only general observations were possible. It is apparent from the older (1973) plantings that vegetative spreading in excess of 122 cm was generally obtained within two years. The Chemung variety proved somewhat more rapid spreading than Penngift. Seedling age at the time of transplanting appeared to have relatively little effect on subsequent plant growth.

Observations of the crown vetch transplanting sites in 1977 showed excellent plant survival and spreading. At Orland the slopes were completely covered. Caratunk did not have complete cover; however, the plants were spreading and should give good cover and minimize a serious erosion problem in the future. The Old Town site was affected by drought in 1976, but observations made in 1981 showed the site to have complete cover.

Overseeding Bird's-foot Trefoil by Using a Herbicide

Observations made in 1976 showed variations in stand densities between replications, and observations ranged from very poor to good; thus, the treatment means in Table 5 were never higher than a rating of fair in 1976. However, some individual replications at all sites received ratings of good. Treatments 5 and 6 had the best stands of trefoil, and treatments 1 and 3 were the poorest (Table 3). Treatment 3 was best at the Old Town site with a rating of fair compared with very poor at the other sites. This may be explained in part by the heavy ground cover at the Old Town site that formed a protective canopy prior to application of the herbicide paraquat. It appeared that there was some injurious effect from use of paraquat in treatment 3, which was seeded on April 9. The four-week interval between seeding date and time of paraquat application could have allowed the seed coat to become more permeable to the herbicide. This seemed to be evident at Dedham and Orland. Overall, the May seeding was best, regardless of the herbicide application. The trefoil stands obtained in treatments 5 and 6 indicate a definite advantage in the use of a herbicide such as paraquat to reduce competition, especially where the density of the initial ground cover is quite high (Table 3).

Observations made in 1978 still showed treatments 5 and 6 to be the best with ground cover rated excellent at Orland (Table 3). All treatments at all locations improved over ratings given in 1977.

The differential potassium treatments showed no visible effects on plant stands until 1978, when differences began to show between treatments 5 and 6.

CONCLUSIONS AND RECOMMENDATIONS

Fertilization of Grass Sod

The results obtained in this study support certain

Table 6. Vegetative spreading of crown vetch seedlings transplanted June 1973 (Orland).

Variety	Age of Seedling (months)	Maximum Lateral Spread of Rhizome (cm)			
				All Plants (avg)	
		Poorest	Best	Sept. 1975	Sept. 1976
Penngift	2	75	114	92	cc
Chemung	2	93	150	124	cc
	6	91	154	126	cc

Note: cc = complete cover.

Table 7. Vegetative spreading of crown vetch seedlings transplanted July 1973 (Old Town).

Variety	Age of Seedling (months)	Maximum Lateral Spread of Rhizome (cm)			
				All Plants (avg)	
		Poorest	Best	Sept. 1975	July 1976
Penngift	2	30	81	56	79
	3	17	56	34	66
Chemung	2	53	124	85	112
	3	30	85	55	74
	7	38	102	70	102

Table 8. Vegetative spreading of crown vetch seedlings transplanted June 1974 (Old Town).

Variety	Age of Seedling (months)	Maximum Lateral Spread of Rhizome (cm)			
				All Plants (avg)	
		Poorest	Best	Sept. 1975	July 1976
Penngift	3	16	61	36	48
	9	0	52	22	36
Chemung	3	41	90	63	71
	9	25	72	47	53

conclusions and recommendations regarding the fertilization requirements for successful establishment and maintenance of grass sods on highway slopes constructed on unloamed subsoil materials. Current hydroseeding specifications should be followed with regard to lime and fertilizer rates and mulching practice. Seedings should be made during the cooler parts of the growing season. The risk of poor germination and inadequate cover is relatively serious from early July through mid-August. All seedings should be completed by early October to ensure adequate cover before winter.

The phosphorus fertilization needs can be satisfied largely or wholly at the time of the initial seeding, and there is little need for top-dressed phosphorus for several years after seeding. Soil samples should be obtained from the roadside slope prior to seeding and chemically analyzed for available phosphorus content. Based on previous work, fertilization rates at the time of hydroseeding should range from the equivalent of 112- to 224-kg P_2O_5/hm^2, depending on soil test results. All hydroseeding should receive at least 112-kg P_2O_5/hm^2 to ensure rapid seedling growth and protective cover of the slope.

The potassium fertilization needs for sod maintenance are less readily satisfied by a single application of fertilizer in the initial hydroseeding. Fertilizer rates in excess of 112- to 168-kg K_2O/hm^2 may result in salt injury to germinating seeds during prolonged dry weather. Soil sites that test very low in available potassium may require a supplemental top-dressing of fertilizer potassium within a year or two following the initial seeding. This top-dressing is especially important whenever a legume is desired in mixture with grasses. Rates up to 224-kg K_2O/hm^2 may be top-dressed without any concern for injury to the established grass or legume-grass sod.

The nitrogen needs of grasses on subsoil embankments cannot be satisfied by heavy rates of fertilization at the time of seeding. Rates in excess of 100-kg N/hm^2 should rarely be used in the initial hydroseeding. These rates result in significant losses of nitrogen through leaching and denitrification and in dry weather may result in seed injury and reduced seedling populations. Excessive nitrogen may also suppress the establishment of an associated legume through unusually rapid growth of the competing grasses.

In general, grass sods on unloamed slopes should receive top-dressed nitrogen within 2-4 months after the initial hydroseedings. Spring and early summer seedings should be top-dressed in early fall, while late summer or early fall may not require top-dressing until the following spring. The rate of fertilization should rarely exceed about 100-kg N/hm^2. A second top-dressing will often prove necessary within 3-6 months after the first. Top-dressed nitrogen should be scheduled for the cooler periods of the growing season and avoid mid-June through mid-August when grass roots are largely inactivated by heat and drought.

Nitrogen top-dressing may be terminated 1-2 years after the initial hydroseeding. By this time, grass roots will be deep enough and sufficiently extensive to ensure efficient absorption of nitrogen recycled back to the soil by dying vegetation. The period of time in which nitrogen fertilization may be omitted is presently unknown but is estimated to be as much as five years or longer. At some point, however, grass sods grown on subsoils with little or no organic matter will run out of recycled nitrogen and will require one or more applications of fertilizer nitrogen to recharge the nitrogen cycle.

Based on the results of this study, there does not appear to be any clear-cut advantage to the use of SCU in dry matter yields or nitrogen uptake. The more protracted release of nitrogen appears to be offset by lower rates of recovery by the grass sod. However, the high rate of SCU did maintain good cover and needed only one application compared with three for AN. More research is needed to define the economic role of slow-release nitrogen fertilizers for highway sods.

Legume Establishment

Legume Overseeding and Crown Vetch Transplants

The results obtained in this portion of the study justify certain conclusions regarding management practices for the successful establishment of legumes in grass sods on Maine roadsides. In particular, practices for the establishment of crown vetch transplants appear well defined. Less-definitive results were obtained in regard to direct overseeding.

The results of a direct overseeding of crown vetch and trefoil on untreated grass sods appear to be quite unpredictable. The low seedling vigor of these legumes species may often result in their suppression below the spring growth of established grasses. However, legume stands may develop in subsequent years from delayed germination of hard seeds or from natural reseeding. Good establishment of crown vetch and bird's-foot trefoil was obtained, however, by scarification of the grass sod prior to overseeding.

The transplant method can be readily employed for ensured establishment of crown vetch on steep slopes or on other difficult areas where erosion effects make direct overseeding of dubious value. Virtually 100 percent survival was obtained during the initial establishment period at all three locations, including the badly eroded site of Caratunk. In addition, transplant seedlings are easily maintained until the actual planting date, which is in contrast to the short storage life of rhizome cuttings.

Seedling transplants of crown vetch suitable for field use can be readily produced in greenhouse flats within 2-3 months after seeding. Key factors in rapid seedling growth are adequate watering and supplemental fertilization. The soil used in the peat pots should be well fertilized and limed prior to seeding. In some cases, it may be desirable to top-dress a high-potash fertilizer over the flats of seedlings a month or two after seedling emergence.

The desired spacing of crown vetch transplants will vary with soil conditions (moisture and fertility), slope exposure, and other factors. Vegetative spreading by rhizome elongation (below ground) generally did not begin until early spring of the year following the year of transplanting. Further spreading then occurred during the cooler parts of each growing season; there was little or no rhizome extension during midsummer. By fall of the second year after the planting year, the more vigorous plants had spread laterally 122-152 cm under conditions of adequate fertilization and reasonably good soil moisture supply (Orland). Under more droughty conditions (Old Town), spreading was more limited. For all sites it appeared that supplemental fertilization was highly important to vigorous rhizome growth. Potassium was the key nutrient element in this regard, and it is recommended that crown vetch transplantings should be top-dressed with a high-potash fertilizer (e.g., 0-10-40) sometime during the year following the year of planting.

Winter survival of both crown vetch and bird's-foot trefoil was very good during the period of study (1976-1978). It appeared that these two legume species would prove to be long-lived on highway slopes in Maine. However, in 1979, 1980, and 1981, visual observations indicated that trefoil stands were beginning to thin at all locations but may improve from natural reseeding. Potential heaving problems were minimized by the natural surface drainage of these slopes. Low-temperature injury was minimized by the protected position of rhizome buds of crown vetch and the deep set crown of trefoil. Natural mulching by dead vegetation on these overwintering slopes was also an important factor that contributed to legume survival.

Overseeding of Bird's-foot Trefoil by Using a Herbicide

The overseeding of bird's-foot trefoil (Empire) in grassed slopes justifies certain conclusions regarding management practices for the successful establishment of bird's-foot trefoil in grass sods on Maine roadsides. They are summarized as follows:

1. Fewer established plants were obtained from the April 9 seeding; however, good stands may develop in subsequent years from delayed germination of hard seeds or from natural reseeding;
2. There is a definite advantage to using a herbicide such as paraquat to reduce competition, especially where the density of the initial ground cover is high;
3. Observations made during the growing season indicate that some initial ground cover is beneficial in protecting the seed from the herbicide and helps prevent the seed from being washed downslope during heavy spring rains;
4. Differences due to fertility treatments were not observed until the 1978 season;
5. No observed differences in trefoil stands could be attributed to the different clay and sandy soil types; and
6. The observations made in 1978 indicate that treatments 5 and 6, both of which had a May seeding and received paraquat, gave the best ground cover.

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The opinions, findings, and conclusions expressed in this paper are mine and not necessarily those of the Maine Department of Transportation. No endorsement of named products is intended nor is criticism implied of similar products that are not mentioned.

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Abridgment

Environmentalism, Pesticide Use, and Rights-of-Way

RON ARNOLD

A spectrum of organized environmental groups is attempting to stop the use of pesticides that are vital to rights-of-way maintenance. Managers must supplement their scientific training with an understanding of social and political dynamics in order to preserve chemical programs. Affluence and occupational shift to the service sector are among the primary forces that gave rise to the environmental movement of the 1960s and shaped new laws and regulations. Five types of antipesticide groups are discussed, and differences in their internal dynamics and tactics are examined. The campaign to ban 2,4,5-T is a typical case that shows how antipesticide groups use sympathetic media coverage and political pressure on government agencies to obtain their purposes. The development of this campaign is outlined by using expert witness testimony at Administrative Law Hearings of the U.S. Environmental Protection Agency (EPA) to show how pressure tactics appear to have changed EPA policy from its original position that scientific opinion found no causal link between 2,4,5-T forestry spraying and miscarriages near Alsea, Oregon, to the position that statistical data showed a danger sufficient to ban 2,4,5-T for certain uses.

Rights-of-way managers are feeling pressures from groups opposed to chemical pest-control methods and, in general, they are ill-prepared to deal with such social and political forces. Most roadside managers are trained in a scientific discipline and tend to underestimate the power of laypersons who invade their field of expertise. Rights-of-way managers who wish to defend chemical programs are more likely to succeed by supplementing their scientific training with an understanding of society and politics and by familiarizing themselves with the nature of antipesticide activism. There is no predictive theory on these subjects, but a study of events and sociological analysis can yield useful information.

Environmental protection attitudes have become an integral part of American life. A 1978 survey (1) by the Washington, D.C., based group Resources for the Future found that 53 percent of the respondents felt that "protecting the environment is so important that the requirements and standards cannot be too high." A 1981 New York Times survey found that a plurality of respondents still support environmental protection despite a weak economy. Twenty years ago such feelings had little popular appeal. What forces were behind this change?

BACKGROUND

Of the numerous attempts to explain the rise of environmentalism, the most thoroughly documented is Inglehart's The Silent Revolution: Changing Values and Political Styles Among Western Publics (2). By using the mass survey method, Inglehart traced a shift from overwhelming emphasis on material values and physical security during the 1950s toward greater concern about the quality of life during the 1970s and an increase in the political skills enabling the public to play a larger role in decision-making. Inglehart isolated six major forces at the root of this shift, including technological innovation, economic growth, and changes in occupational structure, which created unprecedented physical and economic security. The expansion of higher education developed cognitive skills and raised political consciousness, while the growth of mass communications was a force for change by presenting dissatisfaction, alternative life-styles, and other dissonant signals. The final force studied by Inglehart was the rise of a new generation that was distinctive because it grew up in this affluent, communications-rich society, which was very different from that of its grandparents. This new generation was interested in ecology and natural beauty and willing to impose and endure substantial economic penalties to obtain related values. Inglehart characterized this population as "post-materialists" and looked for a psychological mechanism to explain their value changes.

He found it in Maslow's study, Motivation and Personality (3). Maslow suggested a specific direction in which values will change under given circumstances. He argued that physiological needs for food and shelter are given top priority while they are in short supply, and the need for physical safety comes next. However, once an individual has attained economic and physical security, discontent sets in and new nonmaterial goals arise. The first of these new needs is for love and a sense of belonging, then self-esteem becomes increasingly important, and then comes what Maslow calls self-actualization, or the need to be all that one can be. At the highest level, the desires to know and to understand, and also aesthetic needs, are powerful motivators. This scale, which ranges from basic physiological needs to aesthetics, is called the "needs hierarchy".

Inglehart was satisfied that the needs hierarchy explained the behavior of the new generation, but I find that Maslow had more to say that is pertinent. Maslow's studies showed that as one rises up the needs hierarchy, a feeling of independence from and a certain disdain for the old satisfiers and goal objectives sets in. The lower-level needs, once gratified, may seem boring or even repulsive, and one tends to undervalue the lower levels and overvalue higher, ungratified needs. Maslow calls this phenomenon postgratification forgetting and devaluation. I have found it to be a major factor in shaping attitudes about environmental protection standards that "cannot be too high" (4).

Kahn of the Hudson Institute found a similar phenomenon at the social level in societies that emphasize professional specialization; the more educated and expert people become, the more they are affected by educated incapacity, by which Kahn means "an acquired or learned inability to understand or see a problem, much less a solution" (5). Thus, in our modern world, in which the service sector makes up nearly 70 percent of the labor force, the lower levels, that is, agriculture, forestry, mining, construction, and manufacturing, can be collectively forgotten and devalued in the search for quality of life, and unrealistic attitudes about them can gain widespread acceptance.

Once these underlying dynamics of environmentalism are understood, it is important to understand the group dynamics of environmental and antipesticide organizations. Sociologists call organizations that fight for a cause "struggle groups" and note that they have certain structural features in common. Coser points out in The Functions of Social Conflict that "an organization must disintegrate if it cannot accomplish its purpose. It also destroys itself by accomplishing its purpose" (6). Typically, new purposes are found in order to avoid dissolution, and my study of the history of environmental groups indicates that most evolved in this way (7), including the Sierra Club and the Friends of the Earth, and, most obviously, the Environmental Defense Fund, which started as a single-purpose antipesticide group and branched into other fields when it won its campaign to ban dichlorodiphenyltrichlorethane (DDT) in June 1972. [See lawsuits Yannacone v. Dennison (55 Misc.2d 468, 285 N.Y.S. 2d 467, 1967) for denying injunctive relief against use of DDT for mosquito control in Suffolk County, New York; and Environmental Defense Fund, Inc. v. U.S. Environmental Protection Agency (DDT III) (160 U.S. App. D.C. 123, 489 F.2d 1247, 4 ELR 20031, 1973) for the full report of federal action against DDT.]

Simmel, in his study Conflict, found another important factor: "Struggle groups may actually attract enemies in order to help maintain and increase group cohesion. Continued conflict being a condition of survival for struggle groups, they must perpetually provoke it" (8). Environmental groups have a long record of provoking conflicts, perhaps best documented in the text Environmental Law by Rodgers, which lists more than 500 lawsuits initiated by environmental groups since 1960 (9).

ENVIRONMENTAL GROUPS

There is a distinct spectrum of groups that oppose pesticide use. The most familiar type is the general-purpose environmental group that has an antipesticide department, such as the National Wildlife Federation, Audubon Society, Natural Resource Defense Council, Greenpeace, and many others. These groups tend to be run by a paid professional staff, be directed by volunteer leaders on an elected board, and have paid lobbyists and paid attorneys. They also tend to have well-developed communication networks and members who execute effective pressure campaigns aimed at legislative and regulatory bodies.

A second type of group is the single-purpose organization devoted solely to opposing pesticides, such as Protect Our Environment from Sprayed Toxins (PEST) in Maine and Citizens Against Toxic Herbicides (CATH) in Washington State. The organization of these groups is typically nonhierarchical, with no single leader; they have more of a network structure without specific responsibilities, which can make working with them somewhat difficult. Personal devotion to the cause and its attendant personality maintenance functions seem more important in single-purpose antipesticide groups, since most of them have no paid staff.

A third type of group is the ad hoc organization that forms around a specific incident such as a chemical spill, a miscarriage in which pesticides are suspected, or other such events, as in the case of the Succotash Alliance, which formed around miscarriages in Ashford, Washington. These groups tend to work with larger groups; the Succotash Alliance works closely with Greenpeace.

A fourth type of antipesticide group is not of the struggle-group class, but consists of life-style groups that oppose pesticide use as a matter of personal belief and have no activist program fighting legislative or litigable battles. Such groups may include health food cooperatives, organic gardening clubs, counterculture communes, and others who oppose pesticides for personal, ideological, or life-style reasons. A particularly influential example is the Rodale Press, an organic gardening publishing house that has a substantial mailing list, which opposes pesticides in many of its publications (10).

A final and worrisome type of antipesticide group is the sabotage organization, several of which have surfaced within the past two years. One made headlines on June 3, 1981, when two masked women calling themselves members of the People's Brigade for a Healthy Genetic Future told television reporters their group was responsible for blowing up a forestry herbicide spray helicopter (11). Three spray helicopters have been destroyed in such attacks since May 1980, and two incidents of ground spray crews being attacked by protesters have been reported in Oregon (12).

The most active antipesticide organization in America is the Northwest Coalition for Alternatives to Pesticides (NCAP) in Eugene, Oregon, which has 33 member groups from northern California to British Columbia, Canada. Social change is a prominent motive of NCAP, which is funded in part by a group describing itself as a progressive fund for social change in the Pacific Northwest. NCAP leader Fred Miller was quoted as saying, "I'm for centralization....I want to wipe out capitalism, eradicate it from the face of the earth" (13). Radical and activist statements are conspicuous in NCAP publications (14).

An NCAP affiliate published a handbook entitled The Toolkit (15), which contains 13 rules for fighting toxic sprays. Rule 3 advises, "Raise enough hell politically and through the media to get the spray plan postponed 'for further study'. From the start, spend time consulting your elected officials. They may not agree, but they're wary of offending active voters. If your name is in the paper a lot, that helps even more. In this way, you can at least neutralize some people who might be speaking out against you otherwise." Rule 9 states, "If your job [in the antipesticide group] is evaluating research, never trust the conclusions of the author." Rule 11 says, "Stay on the attack. You select the issues."

Toolkit author Merrell of NCAP told an April 16, 1981, meeting of the Izaak Walton League in Waldport, Oregon, "It doesn't matter how many studies are done. It doesn't matter what the facts are. This is a political issue and the political realities are that these chemicals are going" (16).

2,4,5-T CONTROVERSY

NCAP was prominent in the campaign to ban 2,4,5-T, along with Friends of the Earth and certain individuals. The 2,4,5-T campaign began with Bonnie Hill of Alsea, Oregon, who had suffered a miscarriage in 1975 for which her physician had no explanation. On April 11, 1978, Hill and seven other women wrote a letter to the U.S. Environmental Protection Agency (EPA), which contained charts correlating the dates of their miscarriages with spraying of nearby forest lands that used 2,4,5-T during routine brush-control programs. The eight women noted the high toxicity of 2,4,5-T contaminant 2,3,7,8 tetrachlorodibenzo-para-dioxin (TCDD) and asked EPA to investigate their concerns (17, p. 21).

The EPA agreed and sent a scientific team to Oregon, which administered a medical history questionnaire to nine women (one original letter writer refused to participate and two others volunteered). The medical questionnaires were evaluated by a panel of 10 experts, who were all medical doctors except for Robert C. Duncan, Director of Biostatistics, University of Miami School of Medicine. All 10 concluded that the data showed no causal connection between forest herbicide spraying and reproductive wastage. The reviewers also noted that there were more than a dozen other factors that might have caused the miscarriages, which could confound the statistical correlation asserted by the Alsea women. (Data are from evaluation letters of the 10 Alsea I scientists who reviewed the medical questionnaires. They are available in censored form from EPA, 401 M Street, N.W., Washington, DC 20004.) EPA did not release the experts' findings, but only their conclusion that 2,4,5-T was not causally connected to the Alsea miscarriages. Bonnie Hill, NCAP, and Friends of the Earth claimed EPA was whitewashing the issue, while defenders of 2,4,5-T asserted that marijuana smoking was the real cause of the Alsea miscarriages. The release of the expert review data might have prevented this media furor. I attempted to obtain the review data via the Freedom of Information Act, but all substantive facts had been deleted by EPA as "privileged personal information", including the numbers telling how many women were exposed to various other potential causes of miscarriage other than 2,4,5-T.

Of significance is the fact that the panel of experts recommended against further retrospective anecdotal studies of the issue and urged that laboratory testing and examination be the core of any future study relating 2,4,5-T and miscarriages. EPA did not follow these recommendations, but began another retrospective study called Alsea II, and the initial study became known as Alsea I. Alsea II investigators did not pursue laboratory testing or examination but sought statistical correlations between the spraying of 2,4,5-T and miscarriages in the Alsea Basin. The Alsea II report (18) claimed to find such a correlation and was used as a basis for the emergency cancellation of 2,4,5-T announced by EPA Deputy Director Barbara Blum in March 1979.

Bonnie Hill was lionized in the popular press as a folk heroine (19,20). The Alsea II report, however, was subsequently critiqued and denounced as unscientific and politically motivated by nearly 30 institutions, including the Oregon State University Environmental Health Sciences Center (21). NCAP, which had centered its anti-2,4,5-T campaign around the high toxicity of TCDD, immediately went to work on a campaign to ban 2,4-D, no sample of which has ever been found to contain a measurable amount of 2,3,7,8 TCDD, although some have been found to contain other dioxin isomers (22). NCAP's behavior in these circumstances appears to demonstrate the struggle-group pattern of Simmel.

Dow Chemical U.S.A. and others defended 2,4,5-T in Administrative Law Hearings beginning in 1980, which raised some questions about antipesticide tactics. During the hearings, Jack D. Griffith, chief of the EPA Hazard Evaluation Division, who headed both Alsea I and II, testified, "I think for a lady who is untrained in epidemiology, that [Bonnie Hill's] letter is remarkable....In fact, I might say it is better than reasonably good, it is better than some graduate students I have worked with....I'd like to know if she has a tutor--I'd like to employ him" (23). Bonnie Hill has never been cross-examined concerning collusion or conspiracy despite Griffith's statement in testimony.

A question arose concerning the role of political pressure in EPA's decision to reverse its original stand that there was no connection between 2,4,5-T and the Alsea miscarriages. Hill, NCAP, Friends of the Earth, and Congressman James Weaver (D-Oregon) had pressured EPA in the media (24). Dow Chemical counsel Rudolf Schroeter pursued this question for more than a day when cross-examining Griffith with no direct answer, and the question remains unanswered by EPA to this day (25).

Another serious question arose over the role of life-styles in the Alsea miscarriages. Defenders of 2,4,5-T, without adequate documentation, had asserted that marijuana smoking was to blame. Bonnie Hill refused to respond to such intimations "because they are not true, and because they are not an issue, but are rather attempts to distract people from the real issue," and she asserted that "such intimations, even if only implied, are slanderous and totally without substantiation" (17, p. 20). The question was settled in the hearing testimony of Steven Lamm (26), who revealed the findings of the Alsea I panel of experts in summary form and finally made the facts known. Life-style factors that could have caused miscarriages were in fact abundant among the Alsea women. Data from the medical questionnaires showed that all nine of the women in the study obtained their water from surface streams that could carry disease organisms capable of causing spontaneous abortions. Five women drank raw unpasteurized milk from local cows that could transmit brucellosis. Eight of the nine women had eaten deer meat, which the experts felt could transmit toxoplasmosis. Five smoked cigarettes (less than 1 pack/day). One was a regular marijuana user. Another experimented with marijuana and psychedelic drugs. Another was a heavy drinker. Household pesticides were used by several women, which led some of the experts to postulate houseflies and deerflies as a vector for tularemia. At least one household had no electricity and no modern refrigeration. Various types of contraceptives were used by several of the women for varying lengths of time. These potential causes of reproductive failure are substantiated by data taken from the women themselves and are all life-style related. Life-style is a documented issue in the Alsea case, but it never would have been positively known if Lamm had not revealed the findings that EPA refused to make known.

After the 2,4,5-T ban, NCAP continued its campaign to ban 2,4-D and other chemicals by hiring its own scientific experts (27) and rallying scientists of known antipesticide persuasion. The minority views of such scientists as David Pimentel of Cornell University and Melvin Reuber of the National Cancer Institute (NCI) were pitted against the majority view that most pesticides are safe when applied according to label directions, and a divisive "my expert's better than your expert" syndrome appeared in public debate. Such dissension among the ranks of scientists created public distrust. The unfortunate case of Reuber, who was censured by his superiors at NCI for raising unfounded alarms over certain chemicals and subsequently resigned (28), illustrates that a trained scientist with strong antipesticide beliefs may be tempted to make unrestrained interpretations of test results in a public forum and cause widespread but groundless alarm.

CONCLUSION

This discussion should alert rights-of-way managers to the complex social and political dimensions of antipesticide activism and to those group dynamics that may affect public disputes over pesticide use. It should be clear that a straightforward belief in the power of scientific facts must be tempered by the realities that government agencies, such as EPA, do not always make all the facts known; that popular sentiments in antipesticide issues are sometimes colored by life-style preferences that include anticapitalist views; and that antipesticide groups may act for personality maintenance reasons and from group preservation motives as well as for the public good and regard for the facts.

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Report from Committee on Roadside Maintenance

The Landmark Reference subcommittee of the Transportation Research Board Committee on Roadside Maintenance, appointed by Committee Chairman Charles Edson in February 1979, included W.M. Gere, South Dakota Department of Transportation, subcommittee chairman; George Romack, Federal Highway Administration (FHWA), Washington, DC; Gerald Rowe, National Park Service, Washington, DC; and Carl Wells, Kentucky Department of Transportation. Allen Childers, Bill Morris, Larry Perkings, Robert Ross, and Laurence Stainton were later added to the initial group to complete the assignment.

Their assignment was to identify the 20 most widely used references that relate to the broad scope of the committee. Identification would result in a state-of-the-art document that includes available references and committee areas of concern.

In July 1979, Chairman Gere requested each member of the Committee on Roadside Maintenance to solicit responses to the task from neighboring agencies. The Chairman was informed that 55 agencies were requested to list the 20 most widely used roadside maintenance references. Although not all agencies responded, the committee felt the response was adequate to provide the following listing (by category) of roadside maintenance references most frequently used.

The committee believes that publication of this information not only provides guidance to individuals newly entering the field, but also provides insight into a mechanism by which technology transfer occurs.

LISTING OF ROADSIDE MAINTENANCE REFERENCES MOST FREQUENTLY USED

Government Agency Manuals, Publications, and Bulletins, Including Research Groups and Associations

Various agency manuals
American Association of State Highway and Transportation Officials (AASHTO) Maintenance Manual, 1976
Highway Research Information Service (HRIS) responses and National Cooperative Highway Research Program (NCHRP) reports, Transportation Research Board
Herbicide Handbook of Weed Society of America
FHWA reports
Bulletins, U.S. Department of Agriculture (USDA)
Manual on Uniform Traffic Control Devices
American Standard for Nursery Stock, American Association of Nurserymen
Roadside Vegetation Control
Trees--Yearbook of Agriculture, USDA, 1949
American Association of State Highway Officials (AASHO) guide for Highway Landscape and Environmental Design, 1970
Shade Tree Evaluation, International Shade Tree Conference
Sources of Plants and Related Supplies, American Association of Nurserymen
Forest Diseases and Insects
Golden Book Guide on Tree Identification
Landscape architectural site construction details
Seeds--Yearbook of Agriculture, USDA, 1961
Visual Resource Management for Highways
FHWA Litter Study, 1974
Turf Managers Handbook
A Guide to Site and Environmental Planning
Landscape Design for the Disabled
The Impact of Highway Systems on Water Quality, The National Highway Institute
Turf Science, American Society of Agronomy
Concrete Pipe Field Manual, American Concrete Pipe Association
Proceedings of the Northwest Weed Science Society
Planning for Wildlife in Cities and Suburbs, 1978
Biological services of the U.S. Fish and Wildlife Service

National Electrical Safety Code, U.S. Department of Commerce
Forages: The Science of Grassland Agriculture, 3rd ed.
Handbook of Steel Drainage and Highway Construction Products, American Iron and Steel Institute
American Public Works Association
Street and Urban Road Maintenance, Public Administrative Services
Western Fertilizer Handbook, Interstate Printers and Publishers, California Fertilizer Association
Manual on Accepted Procedure and Practice in Cross Connection Control, Pacific Northwest Section, American Water Works Association
Important Trees of Eastern Forests, Forest Service, USDA, Southern Region
Plant Location, Ornamental Growers of Northern Illinois
Index of Plant Diseases in the United States, USDA, Agriculture Handbook 165, 1960
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Common Poisonous Plants of the Southeastern United States, Air Training Command, Maxwell Air Force Base, Alabama
Understanding and Using Asphalt Emulsions, The Asphalt Institute
Proceedings of the Southern Weed Science Society
Alabama Seed Law--Rules and Regulations, Alabama Department of Agriculture and Industries
Rules for Testing Seeds, Association of Official Seed Analysis
Insects--Yearbook of Agriculture, USDA, 1952

Magazines

Weeds, Trees, and Turf Magazine
Grounds Maintenance Magazine
Better Roads Magazine
Rural and Urban Roads Magazine
Park Maintenance
American City and County
American Nurserymen Magazine

University and College

College and university extension service publications and bulletins
Nebraska Weeds
Proceedings of Ohio Short Course on Roadside Development
Guidelines for Erosion and Control Planning and Implementation
Dendrology
Heath, Metcalf, and Barnes, Iowa State University
Street Trees, Rhode Island Division of Forest Environment
Weeds of the Southern United States, University of Georgia Extension Service
Common Weed Seedlings of the United States and Canada, University of Georgia Extension Service
Poison Plants of the Southern United States, University of Georgia Extension Service
Weed Identification, University of Georgia Extension Service
Trees of North America: A Guide to Field Identification, Frank Brockman, University of Washington
North Dakota Plants, Stevens, North Dakota Institute for Regional Studies, Fargo, 1963
Trees and Shrubs for the Northern Plains, Hoag, North Dakota Institute for Regional Studies, Fargo, 1965
The Highway and the Landscape, Rutgers University
100 Forest Trees of Alabama, Alabama Department of Conservation
Alabama Insect Control Guide, Alabama Cooperative Extension Service

Commercial

Pesticide and herbicide container labels
Nursery catalogs
Roadside Vegetation Control: The Program Approach, The DuPont Company
Farm Chemicals Handbook, Meister Publishing Company
Pasture and Range Plants, Phillips Petroleum Company
Golden Book Guide on Insects in Trees
1979 Pesticide Dictionary, Meister Publishing Company
Irrigation System Design Handbook, Rain Bird
Sears, Roebuck catalog
Service and Maintenance Guide, Rain Bird
Nursery and greenhouse supply catalogs
Public Works Magazine
Agricultural Age
Spraying systems company catalogs

Other Reference Sources the Committee Is Unable to Positively Categorize

Hortus, 2nd and 3rd eds., L.H. Bailey
Tree Maintenance, P.P. Pirone
Shrubs, Vines, and Trees for American Gardens, Wyman
Western Garden Book, Sunset Books
Field Guide to Wild Flowers, R.J. Peterson
Field Guide to Trees and Shrubs, Petrides
Diseases and Pests of Ornamental Plants, P.P. Pirone
Standardized Plant Names, H.P. Kelsey, Washington Dayton
Weed Science: Principles and Practices, Kling Maw, Ashton
Grounds Maintenance Handbook, H.S. Conover
Destructive and Useful Insects, Metcalf and Flint
Nature and Properties of Soils, 8th ed., Buckman and Brady
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