COMPARING THE EFFICACY OF DELIVERY SYSTEMS AND ACTIVE INGREDIENTS OF DEER REPELLENTS

DALE L. NOLTE, and KIMBERLY K. WAGNER, USDA/APHIS/WS/NWRC, 9730-B Lathrop Industrial Drive, Olympia, Washington 98512.

ABSTRACT: Deer (*Odocoileus* spp.) occur across the United States and provide many desirable recreational and aesthetic opportunities. Unfortunately, deer foraging, particularly where population densities are high, can negatively impact agricultural resources or damage ornamental plants. Repellents are often regarded as a desirable approach to limit deer browsing. Although many products are marketed for use as repellents, the efficacy of these products in actually reducing deer browsing is varied. This paper reviews the results from efficacy tests we have conducted at the NWRC Olympia Field Station over the past several years as well as repellent work conducted by others. General efficacies of delivery systems and active ingredients incorporated in a variety of products are compared. Generally, products which have repeatedly demonstrated good efficacy in our trials are those products that produce sulfurous odors. These products have significantly reduced deer browsing for 8 to 12 weeks.

KEY WORDS: browsing damage, deer, *Odocoileus*, repellents

Proc. 19th Vertebr. Pest Conf. (T.P. Salmon & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 2000.

(March 6-9, 2000, San Diego, California)

INTRODUCTION

Wild ungulates (e.g., *Odocoileus* spp., *Cervus* spp.) occur across the United States and provide many desirable recreational and aesthetic opportunities. People generally enjoy watching these native species exhibiting their "natural" behaviors. Unfortunately, ungulate foraging activities, particularly where population densities are high, often negatively impact desirable resources. These resources range from a homeowner's ornamental shrubs to valuable agricultural crops to native plant communities.

Ungulates damage a variety of grain crops, forage crops, vegetables, fruit trees, nursery trees, and ornamentals (Craven and Hygnstrom 1994). Beyond the immediate browse damage there is often residual crop damage, such as future yield reductions or growth deformities. Expanding ungulate populations also are a widespread detriment to reforestation efforts in the Pacific Northwest (Rochelle 1992). Ungulate browsing causes growth suppression and regeneration delay, as well as mortality among seedlings that are repeatedly browsed or pulled out of the ground (Crouch 1976; Tilghman 1989).

Wild ungulates also thwart efforts to improve wildlife habitat. Considerable resources are currently being expended to establish native plants to increase forest diversity, improve riparian areas, re-vegetate disturbed sites, restore endangered or threatened plants, or to create or improve wildlife habitat. Regardless of the original objective of the project, wildlife species ultimately benefit through improved cover or increased forage availability. Whether these benefits are long-term via established stands or merely a single meal, is often uncertain. Ungulates can be extremely detrimental to a plant project, particularly if animals make use of the plantings before the seedlings are well established or if their use of the resource is particularly intense.

Natural ecosystems are being altered by high populations of ungulates (Stromayer and Warren 1997). Over-browsing by herbivores can severely reduce seed production, plant establishment, and plant vigor and survival (Case and Kauffman 1997). Deer browsing has significantly impacted wildlife habitat in some northeastern forests by inhibiting the regeneration of stands or by altering tree species composition of regenerating stands (Curtis and Rushmore 1958; Brehand et al. 1970; Horsley and Marquis 1983). Under-story habitat changes have affected the presence of some bird species (DeGraaf et al. 1991). Foraging by wild ungulates has delayed the recovery of some riparian species following the removal of cattle (Case and Kaufman 1977). Ungulates also are reported to be responsible for changing forest regeneration in Europe (Motta 1996; Ammer 1996). There is increasing concern regarding the impact of expanding deer populations on British woodland vegetation (Mitchell and Kirby 1990; Ratcliffe 1992; Kay 1993), and the concurrent indirect influences on invertebrates (Pollard and Cooke 1994). Habitat responses to grazing and browsing pressures also directly and indirectly affect other vertebrates and, ultimately, the future survival of ungulates (Putman 1996).

Given these potential problems, resource managers may consider manipulating behavior as a reasonable alternative, dependent on one's perspectives and objectives, to suffering depredation losses. Exclosures are probably the most effective means of reducing depredation by ungulates (Palmer et al. 1985). Where ungulates are abundant or crops are particularly valuable, fencing may be the only feasible means to minimize damage (Craven and Hygnstrom 1994). However, permanent structures are expensive and require maintenance (Caslick and Decker 1979). In situations where resource vulnerability varies with season or plant size, as in forestry, chemical barriers are becoming increasingly attractive alternatives (Mason 1997). Repellents are less expensive than fencing if the resource is vulnerable for finite periods (two to five years), and they permit flexibility, such as treating crops only when ungulate populations are unusually high or migration patterns are disrupted. The greatest benefit to repellents, however, may be the public's general perception of repellents as an acceptable means to resolve damage situations.

The Olympia Field Station of the National Wildlife Research Center continues to conduct work directed at identifying new aversive agents (Nolte et al., 1994a, 1994b, 1995a, 1995b, 1995c; Nolte and Mason 1995), and assessing the efficacy of commercial products (Nolte et al., 1993, 1995a, 2000; Nolte 1998; Wagner and Nolte 2000a, 2000b). This paper presents an overview of our efforts to identify potential repellents to protect forest resources. General efficacies of delivery systems and active ingredients incorporated in a variety of products are compared. The use of trade, firm, or corporation names in this publication does not constitute an endorsement by the United States Department of Agriculture of any product or service to the exclusion of others that may be suitable.

SYSTEMIC REPELLENTS

Systemic repellents are compounds absorbed and translocated by the plant rendering the foliage less desirable. Systemics provide the ideal delivery system; contained within the plant, they cannot be washed off and the aversive agents are translocated to new foliage as it is produced. An effective systemic repellent needs to be absorbed, metabolized and volatilized by the plant at levels sufficient to repel the target animal (Gustafson 1983). However, to be feasible the compound also must be nontoxic to the herbivore, not be phytotoxic at effective levels, and present a low risk of secondary toxicity or environmental contamination (Angradi and Tzilkowski 1986).

Researchers continue to assess compounds as potential systemic repellents. Rediske and Lawrence (1962) first tested efficacy of selenium to reduce the clipping of Douglas-fir seedlings by snowshoe hares (*Lepus americanus*). They detected snowshoe hare avoidance of selenate ions (SeO^4), but only at concentration levels toxic to Douglas-fir. Allan et al. (1984), subsequently reported success in using sodium selenite (SeO_3) at subphytotoxic levels to reduce black-tailed deer browsing for a single season. However, the authors are unaware of any product that has emerged using sodium selenite as a systemic repellent. Whether difficulties arose in developing a marketable product is unknown. The selenite ion is unstable and readily reduced to selenide ion or elemental selenium which is not readily absorbed by plants (Rediske and Lawrence 1962) and can be quite toxic to higher plants (Shrift 1958).

Denatonium benzoate, an active ingredient in several repellents, also has shown systemic properties. Douglas-fir seedlings will absorb and translocate denatonium benzoate when it is placed in the soil next to the plant (Russ Mason, National Wildlife Research Center, pers. comm.). However, Anipel tablets (bittering agent) placed at the base of seedlings had no significant repellent effect at the recommended dose and caused significant phytotoxic effects (Berquist and Orlander 1996). Further, the efficacy of topically applied products using denatonium benzoate as an active ingredient to reduce deer browsing has been very low (Swihart and Conover 1990; Andelt et al. 1991; Nolte 1998). Herbivores commonly ingest naturally occurring bitter compounds. Bittering agents that fail to induce gastrointestinal malaise are largely ineffective as repellents for herbivores (Nolte et al. 1994a). Thus, the authors are doubtful of the utility of denatonium benzoate as a systemic repellent.

AREA REPELLENTS

Area repellents are those products that create a chemical barrier which animals will not cross, or products that permeate an area with an odor rendering it undesirable and avoided by animals. However, there is little evidence to support the claim that animals will abandon areas treated with area repellents except occasionally when highly palatable alternative foods are readily available elsewhere (Milunas et al. 1994). Some odiferous materials do protect specific plants when the materials are applied to the plant or placed in very close proximity. Conover and Kania (1987) reported reduced winter deer browsing of apple trees when human hair balls were hung in the tree. However, the continued, albeit reduced (approximately 50%), browse damage served as an indicator that deer remained in the area. Soap bars also have been reported to reduce deer damage (37.6%) when placed at no greater than 1 m intervals (Swihart and Conover, 1990). Predator odors topically applied to food (Swhihart et al. 1991), or placed in very close proximity, such as in their food bowls (Muller-Schwarze 1972), have deterred feeding by deer. However, deer do feed in the vicinity of predator odors (Swihart et al. 1991) and predator odors used as chemical barriers are marginally effective at deterring deer from established food sources and are ineffective at deterring deer from using established trails (Belant et al. 1998).

Capsules, impregnated with synthetic wolf urine, have been created as a means to create a chemical "fence" avoided by ungulates. The manufacturer recommends attaching the capsules at 1.5 m above the ground every 10 m to inhibit entry by ungulates. Wildlife and vehicle encounters were reported to have been reduced by 25% to 30% along roadways where this chemical fence had been installed (Johansson 1994). A similar fence, however, did not reduce road crossings by ungulates in subsequent tests conducted in Sweden and Alberta (Peers 1993; K. Smith, Alberta Natural Resources Service, pers. comm.).

We conducted a series of tests to assess whether black-tailed deer avoided areas treated with this synthetic predator odor (Nolte et al. 2000). First, we monitored whether deer would move through narrow (3 m) corridors with the product placed at the entrance. We then assessed the ability of the product to restrict deer movements within pastures when we created a "fence" as recommended by the manufacturer, although we placed capsules at 5 m intervals rather than the suggested 10 m spacing. Lastly, we assessed whether the product would inhibit deer browsing if placed in close proximity to western red cedar (*Thuja plicata*) seedlings. Deer did not demonstrate an avoidance in any of these tests.

Several products continue to be marketed as containing offensive odors that deter deer for various distances. However, outside of anecdotal evidence or testimonials, there is virtually no data demonstrating the distance animals avoid these odors. We are currently conducting a study to provide insight as to the distance some odors may deter animals. Products or compounds being tested are those previously demonstrated to reduce deer damage when topically applied or products advertised as "odor" repellents. The tests consist of affixing a western red cedar to the center of a board extending several meters to each side of the seedling. The seedling then is treated with the product or the product is attached near the terminal bud of the seedling if it is contained within a capsule or sachet. Apple pieces attached to the board at increasingly distant intervals, initially at 2 cm intervals then increasing to 0.5 m intervals, permit us to monitor the distance to which deer approach the treated seedling. Preliminary data suggest that the distance avoided is minimal (Table 1). The range of avoidance for all products includes zero, and the greatest mean distance avoided for any product is less than 1 m and less than 10 cm for most products.

CONTACT REPELLENTS

Contact repellents are products that are topically applied or attached directly to a plant. Chemical repellents are most effective when they are applied directly to foods with the aim of reducing consumption (Mason 1998). We conducted an efficacy study to more directly compare most of the commercially available deer repellents (Wagner and Nolte 2000). These products represented various active ingredients with different modes of action (fear, pain, taste, and aversive conditioning) and application techniques (topical, scent packages) (Table 2). The test consisted of treating western red cedar seedlings planted in pastures containing small herds of black-tailed deer and monitoring the number of bites taken from each seedling at weekly intervals for 18 weeks. The results, which supported previous findings, are discussed below according to our perspective of the active ingredient's mode of action.

Fear

"Fear" inducing repellents contain compound(s) which emit sulfurous odors (e.g., predator urine, meat proteins, garlic). These repellents are rendered ineffective if the sulfur compounds are removed (Nolte et al. 1994b; Lewison 1995). Sulfur compounds are ubiquitous components in carnivores scents produced in the course of meat digestion or degradation (Nolte et al. 1994b; Epple et al. 1993, 1995; Lewison et al. 1995). We anthropomorphically interpret the avoidance of these odors as a "fear" response, suggesting herbivores perceive sulfurous odors as indicators of predator activity.

Five of the six most effective repellents in our winter tests contained active ingredients which we regard as "fear" inducing compounds (Figure 1). However, not all repellents with sulfurous odors are effective in deterring deer for extended periods ($\geq$12 weeks). Differences among compounds primarily relate to the active ingredient or its concentration. Putrescent whole egg solids (Big Game Repellent) effectively inhibited deer in our tests, as has been demonstrated in numerous other studies (Harris 1983; Palmer et al. 1983; Conover 1984; Andelt et al. 1991, 1992; Sayre and Richmond 1992; Nolte et al. 1995; Nolte 1998). The lower efficacy for BGR liquid relative to the BGR powder has been previously reported (Melchoirs and Leslie 1985), and probably reflects a reduced egg concentration, 4.93% versus 36%, respectively. Products containing 3.12% putrescent eggs or dehydrated (88%) rather than putrescent eggs reduced foraging for a shorter period of time. Deer also avoided higher concentrations of other proteins (87% edible animal protein, 99% meat meal) and sodium salts of mixed fatty acids (85%). Sachets soaked in predator urines and placed at the corners of 3 m^2 plots effectively reduced browsing for a few weeks. Ammonium soaps of higher fatty acids (Hinder) did not deter deer. Hinder also has demonstrated limited or variable effectiveness in other studies (Harris et al. 1983; Palmer et al. 1983; Conover 1984; Hygnstrom and Craven 1988; Andelt et al. 1991, 1992). Garlic is ineffective to repel deer. Prior studies have indicated that garlic deters foraging herbivores only as long as other palatable options are readily available (Nolte et al. 1992).

Table 1. Preliminary results in a test of the effective distance of olfactory repellents.

	Pretreatment			Treatment		
	Cedar Damage	Aversive Distance (cm)		Cedar Damage	Aversive Distance (cm)	
Repellent	(Bites)	x̄	Range	(Bites)	x̄	Range
Renerdine	20	0.8	0-6	8.7	6.7	0-50
BGR-P Bye Deer	25	0	0	0	5.8	0-40
Sachet - Deerbuster's	25	0	0	18	5.4	0-40
Sachet - Coyote Urine	16	0	0	10.5	31.25	0-150
Dripper	16.7	0	0	10.3	0.75	0-4
Plantskydd	9	0.75	0-6	0	87.5	0-450

Table 2. Product names, active ingredients, and delivery systems for deer repellents tested (Wagner and Noble 2000).

Mode of Action	Product	Active Ingredient	Delivery System
Conditioned Aversion			
	Detour	7% thiram	Topical spray
Fear			
	Deerbuster's Coyote Urine	50% coyote urine	Odor sachet
	Wolfin	Di (N-alkyl) sulfides	Odor capsule
	Dr. Deer - Deer and Insect Repellent	99.3% garlic juice	Topical spray
	Deer Away - Big Game Repellent	36% putrescent whole egg solids	Topical powder
	Deer Away - Big Game Repellent	4.93% putrescent whole egg solids	Topical spray
	Bye Deer	85% sodium salts of mixed fatty acids	Odor sachet
	Hinder	0.66% ammonium soaps of higher fatty acids	Topical spray
	Plantskydd	87% edible animal protein (in concentrate)	Topical spray
Pain			
	Hot Sauce	0.53% capsaicin and related compounds	Topical spray
	Deer Away - Deer and Rabbit	0.625% capsaicin and related compounds	Topical spray
	Repellent (DRR)	0.21% allyl isothiocyanate	
Taste			
	Ropel	0.065% denatonium benzoate, 0.35% thymol	Topical spray
	Tree Guard	0.2% denatonium benzoate	Topical spray
	Orange TKO	d-limonene	Topical spray
Combination			
	Deerstopper	3.8% Thiram, 0.05% capsaicin, 1.17% egg solids	Topical spray
	Not Tonight Deer	88% dehydrated whole egg solids, 12% Montok pepper (in concentrate)	Topical spray
	Plant Pro-Tec	10% oil of garlic, 3% capsaicin and related compounds	Odor capsule
	Mr. T's Deer Blocker	3.12% putrescent whole eggs, 0.0006% capsaicin, 0.0006% garlic	Topical spray
	Deerbuster's Deer Repellent	99% meat meal, 1% red pepper	Odor sachet
	N.I.M.B.Y.	0.027% capsaicin and capsaicinoid product, 4.3% castor oil	Topical spray

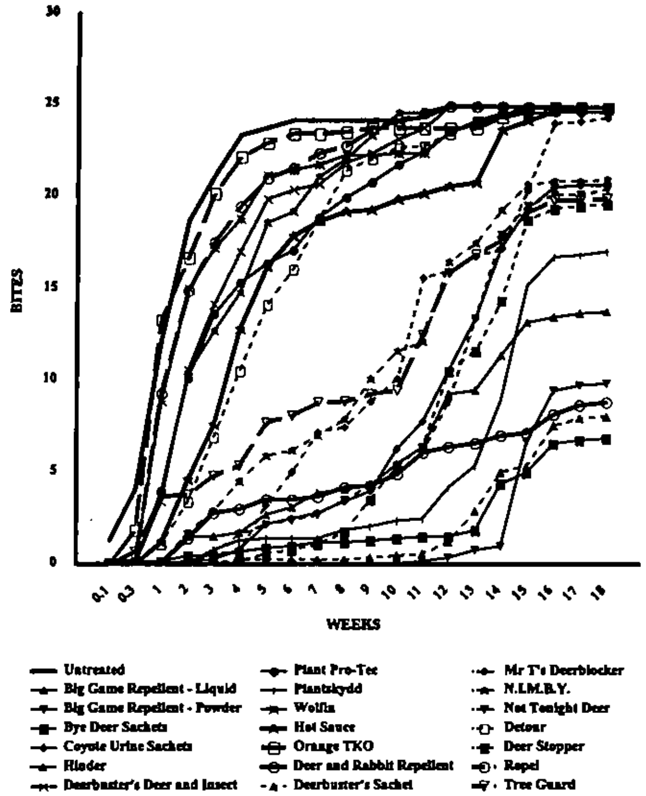

Figure 1. Average number of lateral bites (max. =25) taken from repellent-treated Western red cedar seedlings by black-tailed deer in an outdoor pen study conducted from October 1998 to March 1999 in Olympia, Washington (Wagner and Nolte 2000).

Taste

The active ingredients of repellents deemed dependent on taste in our comparative experiment were bittering agents, either denatonium benzoate or d-limonene. None of these products inhibited deer browsing of cedar seedlings relative to controls for more than a few weeks. Bittering agents in other studies also have failed to deter deer foraging over prolonged periods (Swihart and Conover 1990; Andelt et al. 1991, 1992; Berquist and Orlander 1996; Nolte 1998). Wright and Milne (1996) demonstrated that Red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) differentiated between denatonium treated and untreated food and, when offered a choice, restricted their intake of treated relative to untreated. However, in single choice they did not reduce their daily intake when offered food adulterated with 1,000 ppm denatonium benzoate.

Conditioned Avoidance

Conditioned food aversions occur when ingestion of a novel food is paired with nausea or gastrointestinal distress (Garcia 1989). Thus, any flavor paired with gastrointestinal distress can become an effective deterrent. Efficacy of repellents based on conditioned aversions, however, is generally limited because animals must be trained to avoid these materials. Therefore, damage inflicted on seedlings during training or subsequent sampling can be extensive. The use of conditioned-based repellents is especially problematic if the damage is inflicted by a transitory or migratory species (i.e., elk moving from summer to winter ranges).

At present, thiram is the only active ingredient commonly used in repellents reported to induce conditioned avoidance (Campbell and Bullard 1972). Andelt et al. (1991) reported the efficacy of thiram to increase with progressive test days, while deer increased their intake of rations treated with other repellents. Several studies report products containing thiram to deter herbivores (Harris et al. 1983; Conover 1984; Andelt et al. 1991; Nolte 1998). Although in our comparative study the single thiram-based product was marginally effective (Wagner and Nolte 2000). A second product, Deerstopper, containing thiram, egg, and capsaicin reduced damage for approximately 12 weeks, but the role that thiram played in achieving efficacy is unclear.

Pain

Substances that cause sensory pain ought to be the most effective active ingredients. Sensory pain elicits immediate avoidance independent of learning, and repellency does not diminish for as long as the repellent chemical is present (Mason 1998). However, surprisingly few commercial repellents have effectively incorporated trigeminal irritants as active ingredients. Most likely, current repellents that depend on pain to induce avoidance are ineffective because the active ingredient is present at an inadequate concentration. Most repellents contain less than 0.5% capsaicin, and several studies indicate this to be a minimum amount to deter deer (Andelt et al. 1994; Wagner and Nolte 1999, 2000). An inherent problem of using pain repellents is that they are universally aversive to all mammals. Therefore, concentrations sufficient to deter pest also are likely to negatively impact non-targets, including humans (Mason 1998). A recent study indicates that herbivores are probably less sensitive to capsaicin than omnivores (B. Bryant, Monell Chemical Senses Center, pers. comm.).

CONTEXT

Repellency is always relative and thus, always susceptible to failure (Mason 1998). Many factors other than aversive properties impact the efficacy of a repellent to reduce damage. Ultimately, avoidance of the protected plant is affected by: 1) the number and density of animals inflicting problems; 2) mobility of the problem animals; 3) prior experience of animals with foods and familiarity with surroundings; 4) accessibility of alternative sites; 5) the availability of alternative foods in relation to treated plants; 6) the palatability of the treated commodity relative to alternative food; and 7) weather conditions (Dolbeer et al. 1994; Mason 1997; Nolte 1999). Materials with good efficacy demonstrated under stringent conditions, such as protecting a highly palatable plant in the midst of dense animal populations with few alternative foods, in all probability will be effective under less stringent conditions. However, the reverse in not necessarily, and rarely, true. Thus, it is difficult for someone to predict the efficacy of repellents in the field by extrapolating from empirical data, and more worrisome to take even truthful anecdotal or testimonial evidence as indicators of repellent performance.

SUMMARY

Irritation is a more effective repellent principle than conditioned avoidance, and conditioned avoidance is probably a more effective repellent principle than fear (Mason 1998). Why then, are so few effective products available that rely on irritation or conditioned avoidance? In part this may reflect the inherent problems associated with products that pose potential hazards to humans, low concentrations are less hazardous. Another aspect is how little is known concerning the chemosensory perception of most wildlife species. Tolerance levels of most species towards most irritants is unknown. Ongoing research, however, indicates tolerance levels of herbivores may be higher than predicted as extrapolated from work with omnivores (Bryant, Monell Chemical Senses Center, pers. comm.).

At present, few repellents are available that effectively deter deer browsing. Effective repellents generally are topically applied and provide good protection for approximately three months depending on weather conditions. A reduced efficacy may continue beyond this period, though there is generally a continued decline. We have not worked with any repellent that has demonstrated the ability to protect plants for six months.

LITERATURE CITED

ALLAN, G. G., D. I. GUSTAFSON, R. A. MIKELS, J. M. MILLER, and S. NEOGI. 1984. Reduction of deer browsing of Douglas-fir seedlings by quadrivalent selenium. Forest Ecology and Management 7:163-181.

AMMER, C. 1996. Impact of ungulates on structure and dynamics of natural regeneration of mixed mountain forests in the Bavarian Alps. Journal of Forest Ecology and Management 88:43-53.

ANDELT, W. F., K. P. BURNHAM, and D. L. BAKER. 1994. Effectiveness of capsaicin and bitrex repellents for deterring browsing by captive mule deer. Journal of Wildlife Management 58:330-334.

ANDELT, W. F., D. L. BAKER, K. P. BURNHAM. 1992. Relative preference of captive cow elk for repellent-treated diets. Journal of Wildlife Management 56:164-173.

ANDELT, W. F., K. P. BURNHAM, and J. A. MANNING. 1991. Relative effectiveness of repellents for reducing mule deer damage. Journal of Wildlife Management 55:341-347.

ANGRADI, T. R., and W. M. TZILKOWSKI. 1986. Uptake and phytoxicity of selenium in black cherry and white ash seedlings. Forest Science 32:806-811.

BELANT, J. L., T. W. SEAMANS, and L. A. TYSON. 1998. Predator urines as chemical barriers to white-tailed deer. Proceedings of the Vertebrate Pest Conference 18:359-362.

BERQUIST, J., and G. ORLANDER. 1996. Browsing deterrent and phytotoxic effects of roe deer repellents on *Pinus sylvestris* and *Picea abies* seedlings. Scandinavian Journal of Forest Research 11:145-152.

BREHAND, D. F., G. F. MATTFELD, W. C. TIERSON, and J. E. WILEY. 1970. Deer density control for comprehensive management. Journal Forestry 68:695-700.

CAMPBELL, D. L., and R. W. BULLARD. 1972. A preference-testing system for evaluating repellents for black-tailed deer. Proceedings of the Vertebrate Pest Conference 5:56-63.

CASE, R. L., and J. B. KAUFFMAN. 1997. Wild ungulate influences on the recovery of willows, black cottonwood, and thin-leaf alder following cessation of cattle grazing in Northeastern Oregon. Northwest Science 71:115-126.

CASLICK, J. W., and D. J. DECKER. 1979. Economic feasibility of a deer-proof fence for apple orchards. Wildlife Society Bulletin 7:173-175.

CONOVER, M. R. 1984. Effectiveness of repellents in reducing deer damage in nurseries. Wildlife Society Bulletin 12:399-404.

CONOVER, M. R. 1987. Comparison of two repellents for reducing deer damage to Japanese yews during winter. Wildlife Society Bulletin 15:265-268.

CONOVER, M. R., and G. S. KANIA. 1988. Effectiveness of human hair, BGR, and a mixture of blood meal and peppercorns in reducing deer damage to young apple trees. Eastern. Wildlife Damage Control Conference 3:97-101.

CRAVEN, S. R., and S. E. HYGNSTROM. 1994. Deer. Pages D25-D40 *in* Prevention and Control of wildlife Damage, S. E. Hygnstrom, R. M. Timm, and G. E. Larsen, eds. University of Nebraska Cooperative Extension, Lincoln, Nebraska.

CROUCH, G. L. 1976. Deer and reforestation in the Pacific Northwest. Proceedings Vertebrate Pest Conference 7:298-301.

CURTIS, R. O., and F. M. RUSHMORE. 1958. Some effects of stand density and deer browsing on reproduction in an Adriondack hardwood stand. Journal of Forestry 56:116-121.

DEGRAAF, R. M., W. M. HEALY, and R. T. BROOKS. 1991. Effects of thinning and deer browsing on breeding birds in New England oak woodlands. Forest Ecology and Management 41:179-194.

DOLBEER, R. A., N. R. HOLLER, and D. W. HAWTHORNE. 1994. Pages 474-506 *in* Research and management techniques for wildlife habitats, T. A. Bookhout, ed. The Wildlife Society, Bethesda, Maryland.

EPPLE, G., J. R. MASON, E. ARONOV, D. L. NOLTE, R. A. HARTZ, R. KALOOSTIAN, D. CAMPBELL, and A. B. SMITH. 1995. Feeding responses to predator-based repellents in the mountain beaver (*Aplodontia rufa*). Ecological Applications 5:1163-1170.

EPPLE, G., J. R. MASON, D. L. NOLTE, and D. L. CAMPBELL. 1993. Effects of predator odors on feeding in the mountain beaver (*Aplodontia rufa*). Journal of Mammalogy 74:715-722.

GARCIA, J. 1989. Food for Tolman: cognition and cathexis in concert. Pages 45-85 *in* Aversion, avoidance and anxiety, T. Archer and L. Nilsson, eds. Lawrence-Earlbaum, Hillsdale, New Jersey.

GUSTAFSON, D. I. 1983. Controlled release technology: development of a slow release systemic repellent for the protection of tree seedlings from deer. PhD. Thesis. University of Washington, Seattle, Washington. 216 pp.

HARRIS, M. T., W. L. PALMER, and J. L. GEORGE. 1983. Preliminary screening of white-tailed deer repellents. Journal of Wildlife Management 47:516-519.

HORSELY, S. B., and D. A. MARQUIS. 1983. Interference by weeds and deer with Allegheny hardwood production. Canadian Journal of Forest Research 13:61-69.

HYGNSTROM, S. E., and S. R. CRAVEN. 1988. Electric fences and commercial repellents for reducing deer damage in cornfields. Wildlife Society Bulletin 16:291-296.

JOHANSSON, L. O. 1994. Scent fences of synthetic wolf urine. Unpublished report of Swedish National Road Administration, Borlange, Sweden. 6 pp.

KAY, S. 1993. Factors affecting severity of deer browsing damage within coppiced woodlands in the south of England. Biological Conservancy 63:217-222.

LEWISON, R., N. J. BEAN, E. V. ARNOV, and J. R. MASON. 1995. Similarities between Big Game Repellent and predator urine repellency to white-tailed deer: the importance of sulfur and fatty acids. Proceedings of the Eastern Wildlife Damage Control Conference 6:145-148.

MASON, J. R. 1997. Repellents in wildlife management. Colorado State University Press, Ft. Collins, CO. 447 pp.

MASON, J. R. 1998. Mammal Repellents: options and considerations for development. Proceedings of the Vertebrate Pest Conference. 18:325-329.

MELCHOIRS, M. A., and C. A. LESLIE. 1985. Effectiveness of predator fecal odor as black-tailed deer (*Odocoileus hemionus columianus*) repellents. Journal of Wildlife Management 49:358-362.

MILUNAS, C. M., A. F. RHOADS, and J. R. MASON. 1994. Effectiveness of odour repellents for protecting ornamental shrubs from browsing by white-tailed deer. Crop Protection 13:393-397.

MITCHELL, F. J. C., and K. J. KIRBY. 1990. The impact of large herbivores on the conservation of semi-natural woodlands in the British uplands. Forestry. 63:333-353.

MOTTA, R. 1996. Impact of wild ungulates on forest regeneration and tree composition of mountain forests in the Western Italian Alps. Forest Ecology and Management 88:93-98.

MULLER-SCHWARTZE, D. 1972. Responses of young black-tailed deer to predator odors. Journal of Mammalogy 53:393-394.

NOLTE, D. L. 1999. Behavioral approaches to limiting depredation by wild ungulates. Pages 60-70 *in* Grazing behvior of livestock and wildlife, K. L. Launchbaugh, J. C. Mosely, and K. D. Sanders, eds. Idaho Forest Wildlife and Range Experiment Station Bulletin Number 70, Moscow, Idaho.

NOLTE, D. L. 1998. Efficacy of selected repellents to deter deer browsing on conifer seedlings. International Biodeterioration and Biodegradadation. 42:101-107.

NOLTE, D. L., J. P. FARLEY, D. L. CAMPBELL, and J. R. MASON. 1993. Potential repellents to prevent mountain beaver damage. Crop Protection 12:624-626.

NOLTE, D. L., J. P. FARLEY, and S. HOLBROOK. 1995a. Efficacy of BGR-P and garlic to inhibit browsing of cedar by black-tailed deer. Tree Planter's Notes 46:4-6.

NOLTE, D. L., K. L. KELLY, B. A. KIMBALL, and J. J. JOHNSTON. 1995b. Herbivore avoidance of digitalis extracts is not mediated by cardiac glycosides. Journal of Chemical Ecology 21:1447-1455.

NOLTE, D. L., B. A. KIMBALL, K. L. KELLY, Z. ZHANG, and D. L. CAMPBELL. 1995c. Herbivore (*Aplodontia rufa*) avoidance of a simple digitalis extract. Journal of Agricultural Chemistry 43:830-832.

NOLTE, D. L., and J. R. MASON. 1995. Maternal ingestion of ortho-aminoacetophenone during gestation affects subsequent intake by offspring. Journal of Physiology and Behavior 58:925-928.

NOLTE, D. L., J. R. MASON, and S. L. LEWIS. 1994a. Tolerance of bitter compounds by an herbivore, *Cavia porcellus*. Journal of Chemical Ecology 29:303-308.

NOLTE, D. L., J. R. MASON, G. EPPLE, E. ARONOV, and D. L. CAMPBELL. 1994b. Why are predator urines aversive to prey? Journal of Chemical Ecology 29:303-308.

NOLTE, D. L., F. D. PROVENZA, and D. F. BALPH. 1992. Food preferences in lambs after exposure to flavors in solid foods. Applied Animal Behavior Science 32:337-347.

NOLTE, D. L., L. A. SHIPLEY, and K. K. WAGNER. 2000. Efficacy of Wolfin to induce place avoidance in deer. Western Journal of Applied Forestry. Submitted.

PALMER, W. L., R. G. WINGARD, and J. L. GEORGE. 1983. Evaluation of white-tailed deer repellents. Wildlife Society Bulletin 11:164-166.

PALMER, W. L., J. M. PAYNE, R. G. WINGARD, and J. L. GEORGE. 1985. A practical fence to reduce deer damage. Wildlife Society Bulletin 13:240-245.

PEERS, G. 1993. Wildlife conflict in Baniff National Park. Annual Report, Warden Service, Baniff National Park, Baniff, Canada. 13 pp.

POLLARD, E., and A. S. COOKE. 1994. Impact of Muntjac deer *Muntiacus reevesi* on egg-laying sites of the white admiral butterfly *Ladoga camilla* in a Cambridgeshire wood. Forest Ecology and Management 86:189-191.

PUTMAN, R. J. 1996. Ungulates in temperate forest ecosystems: perspectives and recommendations for future research. Forest Ecology and Management 88:205-214.

RATCLIFF, P. R. 1992. The interaction of deer and vegetation in coppice woos. Pages 233-245 *in* Ecology and management of coppice woodlands, H. C. Black, ed. Chapman and Hall, London.

REDISKE, J. H., and W. H. LAWRENCE. 1962. Selenium as a wildlife repellent for Douglas-fir seedlings. Forest Science 8:142-148.

ROCHELLE, J. A. 1992. Deer and elk. Pages 339-349 *in* Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests, H. C. Black, ed. U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station, Portland, Oregon.

SAYRE, R. W., and M. E. RICHMOND. 1992. Evaluation of a new deer repellent on Japanese yews at suburban homesites. Proceedings Eastern Wildlife Damage Control Conference 5:38-43.

SHRIFT, A. 1958. Biological activities of selenium compounds. Botany Review 24:550-583.

STOMAYER, K. A. K., and R. J. WARREN. 1997. Are overabundant deer herds in the eastern United States creating alternate stable states in forest plant communities? Wildlife Society Bulletin 25:227-234.

SWIHART, R. K., and M. R. CONOVER. 1990. Reducing deer damage to yew and apple trees testing Big Game Repellent, Ro-Pel, and soap as repellents. Wildlife Society Bulletin 18:156-162.

SWIHART, R. K., J. J. PIGNATELLO, and M. J. I. MATTINA. 1991. Aversive responses of white-tailed deer, *Odocoileus virginianus*, to predator urine. Journal of Chemical Ecology 17:767-777.

TILGHMAN, N. G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management 53:524-532.

WAGNER, K. K., and D. L. NOLTE. 2000. Evaluation of Hot Sauce as a repellent for forest mammals. Wildlife Society Bulletin 28(1): In Print.

WAGNER, K. K., and D. L. NOLTE. 2000. Comparison of active ingredients and delivery systems in deer repellents. Wildlife Society Bulletin. Submitted.

WRIGHT, I. A., and J. A. MILNE. 1996. Aversion of red deer and roe deer to denatonium benzoate in the diet. Forestry 69:1-4.