SPREADSHEETS, RESPONSE SURFACES, AND INTERVENTION DECISIONS IN WILDLIFE DAMAGE MANAGEMENT

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Abstract: An *a priori* approach to examining the economics of performing management activities to reduce agricultural and resource damage by wildlife is described. Computer spreadsheet procedures are used to derive response surfaces of potential net savings and benefit:cost indices for selected crop- or resource-protection activities. Tabular and graphical displays of these indices afford decision-making aids for wildlife-damage interventions. An example based on the use of an acute rodenticide, zinc phosphide (Zn_3P_2), for vole *(Microtus* spp.) control in alfalfa *(Medicago sativa)* is described. Iterative calculations were derived for 1,260 possible combinations of 3 field-size, 6 crop-loss, 7 bait-effectiveness, and 10 application-fee variables. Average 1998 USDA alfalfa yield and price data (7.77 $\text{Mton}\cdot\text{ha}^{-1}$ and US\$100.33$\cdot\text{Mton}^{-1}$), plus commercial placebo- and Zn_3P_2-bait costs (US\$0.42$\cdot\text{kg}^{-1}$ and US\$2.73$\cdot\text{kg}^{-1}$), served as the point of comparison. Effects were transitive, with greater net savings and benefit:cost ratios linked with larger field-size, crop-damage and bait-effectiveness variables, but decreased bait-application fees. Potential net savings were essentially negative when damage was <10%. Minimum and maximum benefit:cost ratios were 0.40 and 6.45; ratios ≥2.0 occurred typically when damage was ≥15%. The utility of the illustration and the approach are discussed.

Key words: alfalfa, computers, economics, rodenticide, spreadsheets, voles, wildlife damage

Numerous attempts have been made to program computer-based decision-making models for crop protection (see Teng 1991). Most of these have focused upon plant-disease and entomological models for the use of insecticides in specific crop situations (Kim and Mackenzie 1991, Walker 1991). Few have addressed vertebrate issues and intervention decisions in wildlife damage management situations, and only a subset of these have provided economic estimates.

Computer spreadsheet software (e.g., Lotus® 1-2-3®, Microsoft Excel®) makes iterative calculations of potential net crop savings and benefit:cost ratios relatively easy. This software is widely available to most farmers, ranchers and wildlife professionals. Plots of the response surfaces for varied crop-damage, management-effectiveness and application-cost variables, with 1 variable changed per calculation afford systematic *a priori* estimates of the potential fiscal expenses and returns likely from the use of wildlife-damage-management techniques.

Here, I describe a computational approach for such spreadsheet, response-surface analyses of crop or resource damage by wildlife and management activities. An analysis involving the use of Zn_3P_2 to control vole abundance and damage in alfalfa provides a detailed illustration.

METHODS

Approach

Essentially, 4 parameters characterize the economics of wildlife damage management activities: (1) crop (resource) value, (2) crop (resource) damage, (3) cost of the wildlife-management method (i.e., both personnel and materials), and (4) effectiveness of the damage reduction. The current approach uses Lotus® 1-2-3®, 9.5 software (Lotus Development, Cambridge, MA) to make iterative calculations of net savings and benefit:cost ratios for all possible combinations of selected variables (i.e., 1-altered/computation) used to characterize these parameters. Actual product costs are input to improve estimates of specific methods. Reported yield/price data are used to derive potential crop or resource valuations, losses (i.e., values of damaged crops or resources) and savings. The computed indices are then plotted as 3-dimensional graphical displays to show the response surfaces.

Assumptions

Numerous assumptions are inherent to this approach. Computations assume that potential savings from the prevention of crop, livestock, or resource losses due to wildlife can be derived using average price and yield data for specific crops. Although losses due to other causes such as weather, insects, and plant diseases are subsumed in these data, economic projections based on these means will reflect effects of gains and losses attributed to wildlife damage. A "threshold" of damage is implied whereby gains on investments for wildlife damage control or mitigation become cost effective. Additionally, the effectiveness of a wildlife damage management method is assumed to be a simple proportion of the potential crop savings. That is, despite the complex interactions among methods, species, applicator, and field conditions (e.g., bait acceptance, population densities, applicator skill, weather conditions, etc.), effectiveness is viewed as a simple gain in yield of harvested crop or conserved resource.

Formulas

An estimate of maximum crop or resource valuation can be determined. This value is derived using an accepted baseline (average) or other subjective estimate of value. It specifies the upper monetary or aesthetic value associated with a particular agricultural or environmental resource. While determining a baseline for crops such as corn or sunflower is relatively straightforward based upon the use of U.S. Department of Agriculture production data, making such estimates for resource protection such as endangered species or altered ecosystems is more tenuous. Often these estimates lack a basis for valuation (Loomis and Walsh 1997, Loomis and Gonzales-Caban 1998). The maximum value (in US$) for a resource is defined as

$$V_{max} = Y \cdot P \cdot A \tag{1}$$

where Y is the yield of the resource (production per unit), P is the price of the resource (US$·production per unit), and A is the area considered (ha).

As a next step, the maximum potential crop savings (S_{max1}) is computed as a simple percentage of the total valuation. This refers to the portion of the crop (or resource) that is projected to be damaged by wildlife. It is the saving of that portion of a crop or resource which could be protected (harvested) if the wildlife-damage method was 100% effective. This value is the maximum return (in US$) that can be recouped by wildlife-damage intervention and is defined as

$$S_{max^1} = V_{max} \cdot D \tag{2}$$

where V_{max} is defined in Eq 1 and D is the damage to the resource caused by wildlife (%).

Calculating the application costs involves an estimate of specific personnel and material charges. Personnel costs (C_p) are derived as the product of a unit rate times the area (i.e., US$·$ha^{-1}$ for the personnel·ha). Material costs (C_m) associated with the specific management tool (e.g., rodenticide baits, traps, repellents) are based on commercial prices charged for the quantities needed according to a chemical registration (label) or other recommended guideline. These estimates are the product of the area (ha) times the price/unit/area (e.g., ha · US$·$kg^{-1}$·$ha^{-1}$, ha·US$·traps·ha^{-1}). Of course, special adjustments are required for this calculation if wildlife damage tools can be recycled (e.g., a pro-rated price would be needed to accurately depict the estimates for trapping since steel traps would be reusable). Thus, the application cost (C_{app}) for a specific area is

$$C_{app} = (C_p \cdot A) + (C_m \cdot A). \tag{3}$$

An estimate of potential net crop savings (i.e., S_{net^1}, the maximum potential saving adjusted for wildlife damage method outlays) is calculated as

$$S_{net^1} = (S_{max^1} \cdot E) - C_{app} \tag{4}$$

where E is the method effectiveness and is considered to be a simple portion (%) of crop or resource protected.

Finally, a benefit:cost ratio (BC) is computed for each combination of field-size, crop-damage, method-effectiveness, and application-cost variables and is defined as

$$BC = (S_{net^1} / C_{app}) + 1. \tag{5}$$

BC renders field size (ha) irrelevant. A ratio of 1.0 refers to parity of application costs and potential net savings. Values <1.0 or >1.0 indicate that benefits are smaller or larger than the costs, respectively.

EXAMPLE: USE OF A RODENTICIDE TO REDUCE VOLES IN ALFALFA

Problem

Sixty-seven species of voles (*Microtus* spp.) are identified worldwide (Nowak 1991). These ubiquitous, mouse-like rodents impact forage and grain crop production in many regions (Witmer et al. 1995).

About 20 years ago researchers in eastern Europe reported that local populations of the common vole *(M. Arvalis)* can severely reduce alfalfa *(Medicago sativa)* biomass and quality (Tertil 1977, Babińska-Werke 1978, 1979). Crop damage was mainly indirect, with losses greatest in heavy runway-use areas of voles where increased weed growth occurred. Vole indices between 145-220, 220-411 and 411-682·ha^{-1} were associated with 8.7%, 35.6% and 60.2% reductions in alfalfa biomass (kg dry mass·ha^{-1}) for first (spring), second, and third cuttings, respectively (Babińska-Werke 1979).

Zinc phosphide (Chemical Abstract Service Registry Number® 1314-84-7) is an acute rodenticide registered for vole control in U.S. alfalfa. Typical registrations specify broadcast of ≤2% Zn_3P_2 grain baits onto the dormant crop at ≤11.2 kg·ha^{-1} (≤10 lb·ac^{-1}) (Gratz 1973, Sterner 1994, Sterner et al. 1996).

Assumptions

In the current example, iterative estimates of net crop savings and benefit:cost ratios for 1,260 combinations were obtained assuming the following conditions and values for the variables. First, it was assumed that a single pre baiting with placebo baits occurred. Second it was assumed that a uniform 11.2 kg·ha^{-1} (10 lb•ac^{-1}) application rate of both plain steam-rolled-oat (pre-baiting) and 2% Zn_3P_2 steam-rolled-oat baits occurred throughout the entire field. Third, it was assumed that fiscal returns were based upon a single cutting. Sterner et al. (1996, 1999) showed that pre-baiting prior to use of Zn_3P_2 greatly improved the rodenticide's efficacy. Moreover, while vole damage is often localized and the broadcast of baits in only densely-populated portions of fields greatly lowers costs, the second assumption avoids the plethora of combinations posed by "patch" baiting. Finally, although the use of an acute rodenticide could result in multiple-year benefits via population reduction, the third assumption provides for a conservative estimate of return by avoiding tenuous projections of post-baiting vole recruitment, weed invasion and runway recovery.

The mean yield *(Y)* for alfalfa was set at 7.77 mton $\cdot ha^{-1}$ based on 1998 production values (U.S. Department of Agriculture 1999). The mean price *(P)* for alfalfa was also based on 1998 values and set to US$100.33 · $mton^{-1}$ (U.S. Department of Agriculture 1999). Three sizes for areas *(A)* were used, with values set to: 64.8, 129.6, and 259.2 ha. Six levels of crop loss *(D)* were assumed, with values set to: 5, 10, 15...30%. Seven rates of bait effectiveness (E), i.e., the control method effectiveness, were assumed: 0.70, 0.75, 0.80...1.00. Ten values for the labor cost of applying the method (C_p) were assumed: (1, 2, 3...10) · $(0.405)^{-1}$ (US$ $\cdot ha^{-1}$) to reflect Certified Pesticide Applicator (CPA) fees, normally expressed as US$ $\cdot ac^{-1}$. The material cost for the control method (C_m) reflects the sum of the costs of materials for plain (placebo) and 2% Zn_3P_2 steam-rolled-oat baits as required by label specifications. Thus, in this case

$$C_m = (A_{placebo} \cdot B_{placebo} \cdot R_{placebo}) + (A_{Zn3P2} \cdot C_{Zn3P2} \cdot R_{Zn3P2}) \qquad (6)$$

where A is the area treated with the placebo or Zn_3P_2, which in this case was assumed to be the general areas defined for the general term, A, as per above; B is the cost of the bait for the placebo or Zn_3P_2 (US0.42\cdot kg^{-1}$ and US2.73\cdot kg^{-1}$, respectively, B. L. Hosman, personal communication, 1997), and R is the application rate for the placebo or Zn_3P_2 (in this case both are set to 11.2 $kg \cdot ha^{-1}$).

RESULTS

Potential Crop Values and Loss Effects

Maximum crop values for single cuttings of 64.8-, 129.6- and 259.2-ha alfalfa fields at average 1998 U.S. prices were: US$50,515.75,US$101,031.51 and US$202,063.01, respectively.

As dictated by the formulas, alfalfa loss estimates (i.e., potential net savings) to these valuations showed consistent, transitive effects as damage and field size increased. Projections of minimum vs. maximum loss projections (i.e., 5-30%) were US$2525.79 vs. US$15,154.73, US$5,051.58 vs. US$30,309.45 and US$10,103.15 vs. US$60,618.90 for 64.8, 129.6 and 259.2 ha fields, respectively.

Maximum Potential Savings

Maximum potential crop savings also yielded transitive effects, with greater field size, greater damage, and greater bait effectiveness linked with increased values (Fig. 1).

Regarding these maximum potential savings, increased returns for each 0.05 increase in bait effectiveness were constant. That is, for each 0.05 gain in Zn_3P_2-bait effectiveness in a 64.6-ha field, crop savings (i.e., ±US$2 for rounding errors) of US$126, 252, 378, 504, 630 and 756 were projected for vole-caused damage of 5, 10, 15, 20, 25 and 30%, respectively. As field sizes doubled, these savings also doubled (i.e., each 0.05 increase in bait effectiveness for 129.6- and 259.2-ha fields afforded multiples of US$253 and US$505 for 5, 10, 15, 20, 25 and 30% damage, respectively).

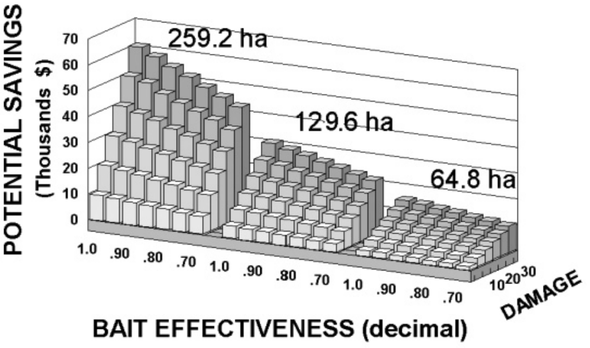

Fig. 1. A 3-dimensional graph of potential alfalfa savings as a function of crop damage, field size, and Zn_3P_2-bait effectiveness.

Minimum vs. maximum potential net savings were -US$1,166.09 vs. +US$12,803.78, -US$2,332.19 vs. +US$25,607.56 and -US$4,664.37 vs. +US$51,215.13 for 64.8-, 129.6- and 259.2-ha fields, respectively. As damage increased so did the potential net saving from broadcast of Zn_3P_2 baits; these savings were invariably negative when damage was projected at 5%, except for a few cases involving ≤US$3 per 0.405 ha personnel charges and ≥0.95 bait effectiveness.

Potential Benefit-Cost Ratios

Minimum and maximum benefit:cost ratios were 0.40 and 6.45, respectively (Fig. 2). Again, ratios increased transitively as vole-caused damage and bait effectiveness increased, but application costs decreased. In the current problem, ratios of ≤1.0 (i.e., net crop

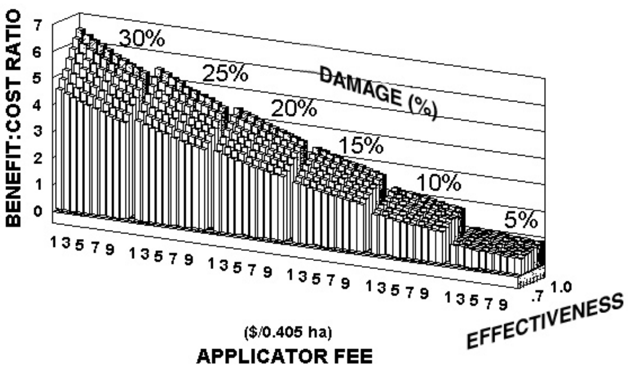

Fig. 2. A 3-dimensional graph of benefit:cost ratios as a function of crop damage, Zn_3P_2-bait effectiveness, and applicator cost.

savings ≤application costs) occurred invariably when vole-caused damage was 5%; whereas, crop losses of ≥15% consistently yielded ≥2:1 returns on investment for Zn_3P_2 baiting. Moreover, as alfalfa damage exceeded 15%, lesser bait effectiveness (i.e., 0.80-0.70) and greater application fees (US$8-10•0.405 ha^{-1}) still afforded multiple returns on expenditures.

Throughout this paper, I have focused on the parsimonious case where benefit-cost ratios were derived based on the valuation of a single cutting of alfalfa. If the benefits of a single, homogenous pre-bait and Zn_3P_2-bait application (11.2 kg/ha) were assumed to produce a 2-year (i.e., assuming 3 cuttings/year) stable reduction in vole damage, fiscal returns and benefit-cost ratios increase dramatically (Fig. 3).

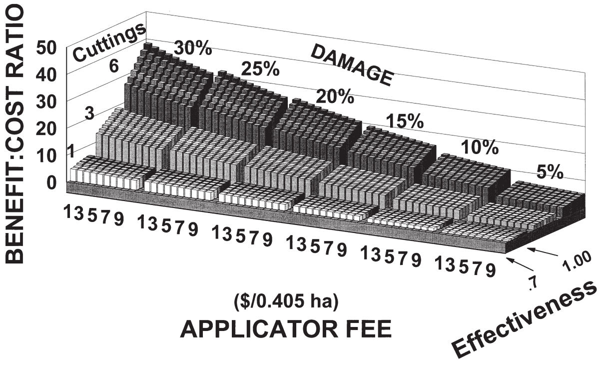

Fig. 3. The benefit:cost ratios as a function of crop damage, Zn_3p_2 bait effectiveness, and applicator cost when crop values are summed over 3 or 6 cuttings and vole damage is assumed stable.

Here, minimum and maximum ratios ranged between 0.40 (i.e., 1 cutting, 0.70 effectiveness, US$10.00/ha labor fee, and 5% vole damage) and 38.68 (i.e., 6 cuttings, 1.00 effectiveness, US$1.00/ha labor fee, and 30% vole damage). Although the familiar transitive patterns are evident in these data, the dramatic result is that 5% damage with suppressed vole damage over 2 years now becomes economically feasible for use of the rodenticide – benefit-cost returns between 3.6 to 6.4 times investments.

DISCUSSION

Alfalfa growers expect multiple economic returns on expenditures for crop protection. Under the current scenarios benefit:cost ratios ≥2.0 (i.e., assuming full return on investment by the next cutting) occurred generally for alfalfa losses of 15%, depending on specific bait-effectiveness and applicator-fee combinations. The seasonal timing of Zn_3P_2 applications can affect crop savings and these ratios. Control of rodents before adequate forage is available to sustain outbreaks (crop dormancy) can improve overall effectiveness. A management plan that incorporates this idea can be gleaned from periodic plagues of house mice *(Mus musculus)* in Australia. Prediction of population outbreaks relies upon careful monitoring of the over-winter survival of mice (Redhead et al.1985, Redhead 1988, Ramsey and Wilson 2000). High spring densities in years following drought are key predictors of outbreaks, and these data are used to determine the initiation of wide-scale baiting efforts (J. Wilson, personal communication, 1993).

The U.S. Environmental Protection Agency has set a 70% efficacy criterion for registration of rodenticide products in the United States (U.S. Environmental Protection Agency 1982). While Sterner et al. (1996) reported >94% efficacy in a controlled enclosure study of Zn_3P_2 broadcast, typical commercial baitings are expected to yield 80-90% efficacy. Current outputs show that potential net savings and benefit:cost ratios for Zn_3P_2 baiting are economical whenever vole-caused damage to alfalfa is >10% (actually, equivalence is attained at roughly 8% damage), assuming broadcast costs are within US$1-10 • 0.405 ha^{-1}. Slow, post-baiting recruitment of vole populations, coupled with alfalfa coverage of former runways, would only improve these estimates.

To provide perspective for these computations, estimates of fixed-winged-aircraft- (FWA), all-terrain-vehicle- (ATV) and manually-carried broadcasts were obtained from several Certified Pesticide Applicators (CPAs). All quoted prices were based on a CPA applying baits with mechanical- or rotator-disk-type spreaders.

An estimate of ~US$7.00•0.405 ha^{-1} (US$17.28•ha^{-1}) was received from Precissi Air Applicators, Lodi, California (B. L. Hosman, personal communication, 1997) for aerial application of baits, but the grower was responsible for supplying placebo- and Zn_3P_2-baits. This pricing yields roughly 2:1 benefit:cost ratios for scenarios involving ≥15% damage and ≥0.75 bait effectiveness (Fig. 2). However, this vendor cautioned that most aerial applicators limit their flights to ≤32 km of the home airstrip. Greater flight distances would increase the charges. Also, many aerial applicators in the United States will also impose a special per flight charge (~US$200.00) to cover miscellaneous costs of operation if only small-field applications (<129.6 ha) are requested. Not surprisingly, these auxiliary charges would alter profitability and essentially mandate that aerial applications be used only for fields ≥129.6 ha.

The use of ATV-mounted spreaders is probably the most common method of bait application for rodenticides in the United States. An estimate of US$4.00•0.405 ha^{-1} (US$9.87•ha^{-1}) was obtained for this method (B. L. Hosman, Personal Communication 1997); however, materials, equipment, taxes, and surcharges were added to the base rate (California charges a US$50.00 surcharge for rodenticide applications). These extra charges made the actual estimate roughly US$5.00-US$6.00(0.405 ha^{-1} (US$12.35-US$14.81•ha^{-1}).

ATV broadcasts afford ≥2:1 returns when ≥15% crop losses and ≥85% vole control is expected; however, counter to the FWA data, the ATV application is well suited for small to moderate size fields (≤129.6 ha).

Manual broadcast of baits is the most expensive and labor-intensive method. An estimate of US$37.75•h^{-1} (time based, not area based) was obtained for a CPA to apply baits (C. Lessley, personal communication, 1997). This price would limit manual baiting to relatively small fields (<10 ha), possibly in experimental situations or where a localized dense population of voles could be targeted and controlled before they dispersed. Sterner et al. (1996) used manual broadcast to assess efficacy of the baiting regimen. Approximately 5 ha (~12 ac) required ~4 h per CPA. This equated to a US$12.58•0.405 ha^{-1} (US$31.06•ha^{-1}) fee, a prohibitive rate for quickly recovering baiting costs under practically all widespread uniform vole densities involving sizable areas.

CONCLUSION

Despite numerous assumptions involved in this approach, use of spreadsheet software makes projections of benefit:cost ratios and net-crop savings readily available to farmers, ranchers and wildlife professionals. Graphical and tabular displays of the net-saving and benefit-cost response surfaces allow identification of simple heuristics for profitable/non-profitable applications of diverse methods to protect crops or resources. While validations are needed, current outputs afford a quick, inexpensive, relatively effortless way of examining best- and worst-case scenarios affecting wildlife-intervention decisions. The work lies mainly in the setting up of appropriate spreadsheet formulas, gathering appropriate cost data (i.e., materials), displaying outputs and interpreting charts. Collection of auxiliary data related to actual prices of materials and likely efficacy of methods can further improve the utility of these analyses. Economic projections of this type for diverse wildlife-damage-management situations (e.g., methyl anthranilate for reducing Canada goose grazing at parks or golf courses, capsaicin for deterring rodent gnawing of cables, aerial gunning for reducing coyote predation of livestock) are needed.

ACKNOWLEDGMENTS AND DISCLAIMER

I thank Barton Hosman and Jake Lessley for aerial, ATV, and manual broadcast price estimates. Rex Marsh, Gerry Miller, the late Joe Brooks and Kathleen Fagerstone provided helpful comments on early drafts of the manuscript.

Use of trade names does not constitute endorsement by the U.S. Government.

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