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Net Costs of Wildlife Damage on Private Lands

Kimberly Rollins, Lori Heigh, and Vinay Kanetkar

This study models net welfare impacts on producers who receive utility from on-farm wildlife populations that are not costlessly disposable. Wildlife damage levels where net benefits are zero indicate producers' maximum willingness to pay for on-farm wildlife. An empirical model is developed. Results for Ontario producers suggest the net welfare loss from damage is approximately half of the value of the yield loss for those with damage. In aggregate, however, on-farm wildlife generates net benefits to producers that outweigh costs by about 10-to-1. The distribution of net benefits is highly skewed across producers.

Key words: random effects probit, tolerance thresholds, wildlife benefits, wildlife damage

Introduction

In response to problems caused by wildlife damage on private lands, various jurisdictions have implemented policies that include compensation, crop insurance, cost sharing for abatement and prevention expenditures, wildlife management regimes that target problem areas and species, and contracting for control services. Policies vary with institutional structure, type of loss, wildlife population status, and other circumstances. Much of the economics literature regarding wildlife damage to agriculture focuses on problems posed by specific policy instruments, including implications for property rights arrangements, market mechanisms, moral hazard, and maintaining damage prevention incentives (Schwabe and Schuhmann, 2002; Rondeau and Conrad, 2002; Yoder, 2000; Van Tassell, Phillips, and Yang, 1999; Wagner, Schmidt, and Conover, 1997; Gray and Sulewski, 1997; Rollins and Briggs, 1996; Gray and Rollins, 1996; U.S. Department of Agriculture, 1993).

Successful formulation and implementation of most of these policies requires that aggregate and individual damage costs are quantifiable. Several authors focus on problems in measuring costs of wildlife damage (Yoder, 2002; McNew and Curtis, 1997; Conover, 1994; Wywialowski, 1994; Conover and Decker, 1991; Decker and Brown, 1982; Connelly, Decker, and Wear, 1987). These studies tend to emphasize methods for estimating agricultural yield losses, and subsequently calculate costs by multiplying yield losses by commodity market prices. Yoder (2002), for example, addresses problems associated with estimating yield losses with censored data from wildlife damage claims.

In the context of many wildlife damage policies, however, it is desirable to measure the cost of an on-farm wildlife population as the welfare change to the landowner. The

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Kimberly Rollins is associate professor, Department of Resource Economics, University of Nevada Reno; Lori Heigh is an employee of Agriculture Canada, Ottawa; and Vinay Kanatkar is professor, Department of Consumer Studies, University of Guelph, Guelph, Ontario Canada.

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market value of yield loss may be an incomplete measure of welfare change for many landowners. For a landowner who receives utility from an on-farm wildlife population, the utility loss would need to be greater than utility received in order for an on-farm wildlife presence to result in a net loss.[1] Wildlife can be thought of as an environmental good that exhibits costly disposal. Reducing an on-farm wildlife presence is not costless. On-farm populations can be too large to produce net marginal utility gains, and net marginal utility can become negative. On the other hand, managing populations so as to minimize the financial cost of damage may cause a net welfare loss at the margin, if on-farm wildlife benefits are not taken into account. The net welfare change for landowners from on-farm wildlife populations would therefore need to take into account utility impacts that are not fully captured by the market value of yield losses.[2]

A marginal increase in an on-farm wildlife population permits a quality or quantity increase in on-farm wildlife-dependent activities, such as wildlife viewing or hunting. All else equal, a landowner who receives utility would be willing to forego some income to achieve benefits associated with a greater on-farm wildlife presence. As populations increase, however, marginal damage costs may increase. A number of studies document landowners who indicate they will tolerate some damage as an unavoidable cost of on-farm wildlife because they enjoy its presence on their land for recreation and aesthetic reasons; or they value their role as stewards of land and habitat (Schusler, Chase, and Decker, 2000; Gigliotti, Decker, and Carpenter, 2000; Pomerantz, Ng, and Decker, 1986; Siemer and Decker, 1991; Craven et al., 1992; Decker and Gavin, 1985; Enck, Purdy, and Decker, 1988; Purdy and Decker, 1985). At least one study concludes that for many landowners the presence of on-farm wildlife is not the problem; the problem is the quantity of wildlife [Ontario Soil and Crop Improvement Association (OSCIA), 2000].

These studies suggest there is an optimal nonzero on-farm wildlife population for landowners who value wildlife, beyond which the net marginal impact on utility becomes negative. The wildlife management literature defines this point as a "tolerance threshold" (Craven et al., 1992; Pomerantz, Ng, and Decker, 1986; Purdy and Decker, 1985; Siemer and Decker, 1991). For example, Connelly, Decker, and Wear (1987) define a tolerance threshold as the maximum amount of damage people are willing to tolerate in return for the benefits of having wildlife (in this case deer) in their neighborhood. Results from this literature indicate that producer tolerance thresholds vary with landowner characteristics, attitudes toward wildlife, farm characteristics, wildlife species, regional wildlife population levels, and commodity (Decker and Brown, 1982; Craven et al., 1992). Many of these studies are motivated by the need for criteria to set wildlife population goals and to predict circumstances for which damage may result in undesirable conflicts between farmers and wildlife managers (Carpenter, Decker, and Lipscomb, 2000; Decker and Gavin, 1985; Gigliotti, Decker, and Carpenter, 2000). In the case of valuable wildlife species, identifying policy options that increase tolerance thresholds for some landowners can rationalize management goals to increase regional populations (Schusler, Chase, and Decker, 2000).

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[1] Similarly, people who may not like particular species of wildlife on their land for reasons other than crop and property damage could experience a welfare loss without a loss in a market-valued commodity.

[2] In addition, wildlife damage has been suffered by the agricultural sector historically, much like variability in productivity due to the quality of land and weather conditions. It can be argued that markets have incorporated crop yield losses and reflected them in the prices. If this were the case, then farmers would be at least partially compensated for their losses from wildlife damage to crops. Multiplying yield losses by market price would then overestimate farmers' actual welfare losses. We thank an anonymous referee for clarifying this point.

The tolerance threshold is easily interpreted as the point where marginal utility from additional on-farm wildlife is no greater than the marginal disposal (damage) cost. The tolerance threshold is therefore a landowner's maximum willingness to tolerate damage, which in turn indicates her or his maximum willingness to pay for the benefits associated with on-farm wildlife. Compensating surplus is the amount of income loss that would keep a landowner at a constant level of utility while obtaining the welfare-enhancing higher quality or quantity of wildlife benefits, assuming the original wildlife population is low enough such that marginal increases generate a net increase in utility. If the on-farm wildlife population is so large that marginal damage costs more than offset utility from wildlife benefits, then the landowner experiences a net utility loss. Here, the compensating surplus is the minimum amount the landowner would be willing to accept to bear the increase in on-farm wildlife above the optimum.

This analysis builds on contributions from the wildlife damage literature on measuring observable maximum willingness to tolerate damage levels for agricultural producers. It is hypothesized that an individual landowner's willingness to tolerate wildlife damage is a function of net utility which accrues from wildlife, and that this hypothesis can be tested in a random utility framework. The random utility framework provides the basis for estimating net welfare change associated with wildlife damage. The next section presents an economic model that explicitly incorporates tolerance for wildlife damage into a welfare measure for wildlife damage net of benefits. The model is then applied to data for field crop producers in Ontario, Canada.

The Model

Suppose a farmer's utility depends on the on-farm wildlife population, W, and all other goods that can be purchased with farm income. The on-farm wildlife population is exogenous from the farmer's perspective, and affects utility in two ways. Marginal changes in on-farm wildlife affect the quality and quantity of activities that generate utility, such as wildlife viewing or recreational hunting, while crop damage and abatement expenditures decrease income. This is indicated by the indirect utility function, where $\mathbf{P}$ is a vector of prices for all other goods:

$$V = V(B(W), I^0 - D(W), \mathbf{P}). \tag{1}$$

Income when the on-farm wildlife population is zero is represented by I^0, and $D(W)$ is income loss from wildlife damage. $B(W)$ represents the level of activities landowners enjoy which depend on on-farm wildlife. Wildlife damage and benefits are also functions of other variables:

$$D = D(W, L, G), \tag{2}$$

$$B = B(W, L, F, H, E), \tag{3}$$

where L is proximity to protected areas, G is crop acreage, F describes farmers' attitudes toward wildlife and H attitudes toward hunting, and E represents farm attributes. Equations (2) and (3) describe supply and demand for wildlife on private land.[3]

[3] Public benefits accruing to off-farm residents are not accounted for in this model. For many wildlife species and locations, on-farm forage and habitat support wildlife populations at greater numbers than could be achieved without the contribution of private lands. This has been identified as the crux of the market failure problem posed by public ownership of wildlife

We assume wildlife does not increase farm income; therefore, $\partial D/\partial W \geq 0$. It follows from equations (1)–(3) that the net effect of a marginal change in the on-farm wildlife population on utility is represented by:

$$\frac{\partial V}{\partial W} = \frac{\partial V}{\partial B}\frac{\partial B}{\partial W} + \frac{\partial V}{\partial D}\frac{\partial D}{\partial W}, \tag{4}$$

where the first term on the right-hand side, the marginal utility of wildlife-related activities, is nonnegative, while the second term, the marginal utility of damage, is strictly negative. Therefore, the sign depends on the relative magnitudes of marginal wildlife damages and benefits.

If the farmer receives no benefit from on-farm wildlife, then the first term on the right-hand side of equation (4) is zero. In this case, as the wildlife population in panel A of figure 1 increases from 0 to W^1, crop damage increases from 0 to $D(W^1)$ and income decreases from I^0 to I^1. The decrease in income reduces utility from V^0 to V^1. However, if the farmer receives some utility from on-farm wildlife, the net effect on utility from a change in W depends on the marginal wildlife benefits.

Panel B of figure 1 indicates how marginal damage costs (right-hand axis) and marginal wildlife benefits (left-hand axis) change with on-farm wildlife population levels (horizontal axis). If wildlife benefits are increasing at a decreasing rate, then $\overline{W}$ is the point where marginal wildlife benefits and marginal wildlife damages are equal. The net effect is shown in panel C, where utility is greatest at $\overline{V}$ with on-farm wildlife population $\overline{W}$. Where $W < \overline{W}$, net marginal value of on-farm wildlife is positive, $\partial V/\partial W > 0$. At $\overline{W}$, the net marginal value of on-farm wildlife is zero, $\partial V/\partial W = 0$. And where the marginal value of damage is greater than the marginal benefit of on-farm wildlife, $\partial V/\partial W < 0$. Therefore, a farmer who derives benefits from on-farm wildlife maximizes utility at $\overline{W}$. This implies that damage costs, $D(\overline{W})$, may be nonzero when utility is maximized. In cases where individual farmers derive zero utility from wildlife, however, any level of damage causes a decrease in utility since there are no offsetting benefits. Hence, these farmers would have a zero tolerance for damage, i.e., $D(\overline{W}) = 0$.

$D(\overline{W})$ represents the maximum damage a landowner would be willing to tolerate from on-farm wildlife—or alternatively, the landowner's maximum willingness to pay for the associated on-farm wildlife benefits. In the context of the wildlife management literature, $D(\overline{W})$ is the damage tolerance threshold. When the value of yield losses is small compared to total income, the change in marginal utility of income induced by wildlife damage is negligible, and $\overline{W}$ may be strongly influenced by on-farm wildlife benefits.

Panel D of figure 1 illustrates the situation where damage $D(W^1) > D(\overline{W})$. $\overline{V}$ is utility associated with $\overline{W}$, V^1 is utility associated with W^1, and net income is $I^0 - D(W^1)$. The difference between $D(W^1)$ and $D(\overline{W})$ is the money, M, that would need to be given to the landowner in order to leave him or her as well off as at utility $\overline{V}$:

$$M = D(W^1) - D(\overline{W}).$$

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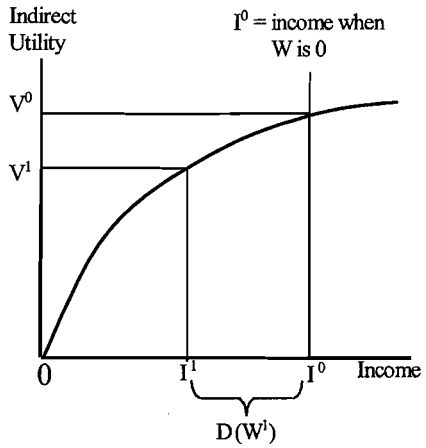
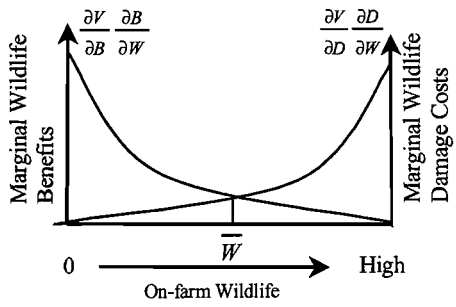
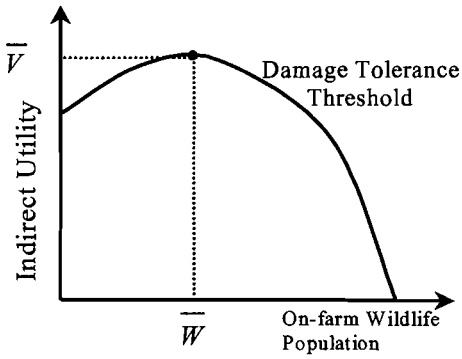
requiring private lands inputs. The contribution to public good benefits from private lands may be substantial, but is beyond the scope of this study. The main implication for interpreting the tolerance thresholds and subsequent net welfare measures estimated in this study is that the measures are solely in terms of landowners' net welfare. If marginal increases in public good benefits are greater than the net marginal loss to farmers, then wildlife management policies may incorporate means to increase tolerance thresholds, or otherwise compensate for damage above these thresholds using transfers from those who experience net gains.



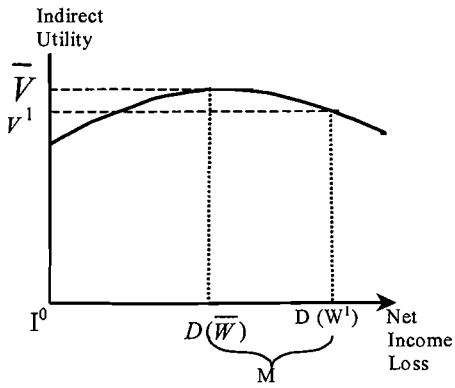
Panel A. Wildlife damage, indirect utility, and net income with no wildlife benefits



Panel B. Net marginal utility of on-farm wildlife



Panel C. Maximum damage tolerance threshold



Panel D. Net loss from damage

Figure 1. Utility loss from wildlife damage

In this case, M is the landowner's minimum willingness to accept compensation for an on-farm wildlife population greater than $\overline{W}$, or compensating surplus. Depending on whether the on-farm wildlife population is greater or less than $\overline{W}$, a marginal change in on-farm wildlife may result in a net gain or net loss in welfare. Thus, for an on-farm wildlife population less than $\overline{W}$, M would be the willingness to pay to achieve a greater level of wildlife benefits.[4]

The tolerance threshold $D(\overline{W})$ can be directly estimated and then netted from reported damage costs to calculate the net welfare change M. To do so, we consider $D(\overline{W})$ in the context of a random utility model. The farmer's indirect utility function can be written:

$$V^1 = V\left[B(W^1), I^0 - D(W^1)\right] + \varepsilon,$$

where $V(\cdot)$ is the portion of utility attributable to observed factors, and ε is an error term that represents the unobservable portion of utility. $I^0 - D(W^1)$ is income net of damage. A landowner would be willing to tolerate a given level of damage $D(W^1)$ if it is less than or equal to $D(\overline{W})$:

$$V^1\left[B(W^1), I^0 - D(W^1)\right] + \varepsilon_1 \geq \overline{V}\left[B(\overline{W}), I^0 - D(\overline{W})\right] + \varepsilon_0,$$

where V^1 is utility with an on-farm wildlife population of W^1, and $\overline{V}$ is utility with on-farm wildlife population of $\overline{W}$. The probability that a farmer would be willing to tolerate wildlife damage W^1 is expressed as:

$$\Pr(\textit{Tolerable}) = \Pr\left(V^1 + \varepsilon_1 \geq \overline{V} + \varepsilon_0\right). \tag{5}$$

Rewriting equation (5), we obtain:

$$\Pr(\textit{Tolerable}) = \Pr\left((V^1 - \overline{V}) \geq \varepsilon_0 - \varepsilon_1)\right). \tag{6}$$

An average individual tolerance threshold can be estimated in a random utility framework using a sample of farmers who experience a range of damages. The necessary data for each observation include income I^0, damage $D(W^1)$, and a "yes" or "no" response as to whether the farmer is willing to tolerate that level of damage. The model could include additional variables which are hypothesized to affect the probability of a "yes" response.

The Data

A 1999 survey provides data on wildlife damage to field crops in Ontario for the 1998 growing season. Participants were selected at random from a list of Ontario producers representative of the Ontario farm population. An overall 62% response rate to the mailed survey resulted in a sample of 241 field crop producers. Data include yield losses by crop from wildlife damage, species causing damages, landowner characteristics, and farm characteristics. There were no options available for these producers to receive any type of damage compensation, insurance, or cost recovery for abatement effort.

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[4] We thank an anonymous referee for pointing this out.

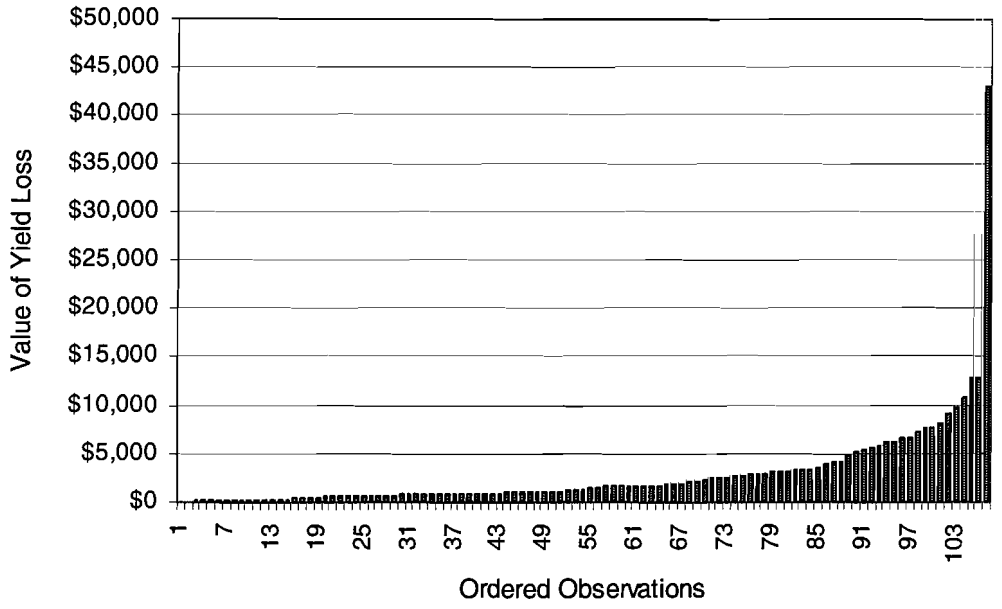

Figure 2. Distribution of yield losses for Ontario field crop producers reporting wildlife damage

A total of 108 respondents, about 45%, reported wildlife damage to field crops during 1998. For farms with damage, the mean value of loss by crop ranged from $221 for wheat to $1,385 for corn. The distribution of the yield losses is highly skewed, as illustrated in figure 2, suggesting damages do not occur evenly across farms. The data reveal that a small number of farmers incur a significant amount of loss, while the majority sustains very little. These results are consistent with other wildlife damage studies (e.g., Wywialowski, 1994).

As indicated from focus group results, individuals from the survey population considered losses to wildlife to be tolerable if these losses fell within a range they felt was reasonable to expect as part of their normal operations. The notion of "reasonable" in this case is a farmer's subjective assessment that appears strongly affected by past experience, and personally held opinions on what constitutes a healthy wildlife population.[5] Participants did not see damage losses as a widespread problem, except for extreme cases which occasionally can occur to a small number of landowners. Moreover, survey respondents believed that agricultural producers are good stewards of the land and wildlife habitat, and are willing to provide for reasonable levels of wildlife and crop production. The majority reported undertaking projects on their lands for enhancing wildlife habitat.

[5] We essentially assume that landowners' notions of "reasonable" damage levels correspond to levels of what they believe are "reasonable" wildlife populations, consistent with other focus group results. This notion of a reasonable wildlife population is subjective from the farmer's perspective. Here, it is assumed to derive from the utility farmers receive from wildlife, which includes utility gained from direct use of wildlife, from the knowledge they are contributing to a healthy natural environment by providing habitat, from the public's perception of them as good stewards of the natural environment, or even as a type of bequest value where utility derives from an altruistic motive of providing habitat for wildlife for its own sake.

Table 1. Proportion of Producers Taking Past Preventative Action, and Average Annual Investment (N = 241)

Wildlife Species	Percent of Total Producers Taking Preventative Action During Last Five Years	Average Annual Investment for Farms Taking Preventative Action in 1998–1999	
		Material Investment	Number of Hours
Geese	16%	$115	20
Blackbirds	11%	$142	12
Deer	12%	$175	24
Raccoons	40%	$167	25

Table 2. Percentages of Producers Who Took Preventative Action in the Last Five Years and Also Received Damage in 1998, by Wildlife Species

	Geese		Deer		Raccoons		Blackbirds	
Action	Damage	No Damage	Damage	No Damage	Damage	No Damage	Damage	No Damage
Prevention	4.1	3.9	12.8	1.0	28.4	3.0	2.8	1.4
No Prevention	7.7	84.3	25.2	60.9	15.5	53.0	9.0	86.7

Focus group participants pointed out they were not "anti-wildlife," and, as land stewards, they stated they were willing to absorb losses associated with maintaining healthy wildlife populations. A common sentiment among participants was that where problems did exist, wildlife populations were "too large," and wildlife management agencies were not adequately responding to these "problem" wildlife populations. When losses tended to consistently exceed "reasonable" levels, many producers felt "something should be done" by wildlife management agencies to reduce local wildlife populations (OSCIA, 2000).

Respondents were queried about crop yields, damage, species causing damage, damage prevention effort, perceptions of on-farm wildlife population changes, and farm characteristics. Respondents were asked to rate the losses they experienced during the 1998 growing season, by each crop type and wildlife species, as "tolerable" or "not tolerable." An example of this survey question format appears in the appendix.[6]

Respondents were asked whether they had undertaken any measures to prevent wildlife damage at any time during the five years previous to the 1998 growing season, by crop type and species of wildlife. This variable indicates past preventative activities, even if producers had not undertaken preventative actions during 1998. Table 1 reports the percentage of producers who indicated they had undertaken preventative actions within the past five years, the average annual dollars spent, and the number of hours invested in these damage prevention activities.

Table 2 shows the relationship between producers who took past preventative actions and those who reported losses in 1998. The majority of producers who undertook past

[6] Since there was no history in Ontario of wildlife damage compensation or insurance programs, we assume a farmer's willingness to tolerate a given level of damage does not include an implicit adjustment for any administrative costs or efforts for wildlife damage program compliance on the landowner's part.

prevention also reported sustaining damage in 1998. Meanwhile, the majority of farmers who did not report past preventative actions did not indicate sustaining damage in 1998. For example, 90% of those who took preventative action against raccoon damage in the prior five years reported damage from raccoons in 1998, while 30% of those who did not previously undertake raccoon damage prevention had damage in 1998. A similar trend is seen with geese, deer, and blackbirds.

This finding suggests that some damage sustained in 1998 was predictable by producers, and perhaps systematically related to location and features which enhance local wildlife populations. Some landowners who undertook prevention may have done so because they had already experienced damage and expected to experience more. This is consistent with farmers' perceptions that where damage does occur, local wildlife populations are "too large." Moreover, since these farmers had already experienced costs from past damage—both in the form of direct crop loss and indirectly in the form of costs of prevention activities—it is likely their tolerance thresholds for damage in 1998 would be lower than for producers who did not report past prevention effort.

We hypothesize that landowners who had invested in prevention activities over the previous five years would be less likely to tolerate a given level of damage than those who have not. The cumulative sum of costs of past damage and prevention actions may erode a landowner's willingness to tolerate further damage. If some of the benefits of on-farm wildlife have already been offset, the tolerance threshold would likely be lower. Thus a dummy variable indicating past prevention activity would be expected to reveal this lower threshold.

Proximity of farmland to protected habitat is expected to influence a producer's tolerance threshold. A landowner who perceives that a nearby publicly owned protected area contributes to crop damage or reduces the effectiveness of on-farm prevention activities may have lower tolerance thresholds. Respondents are asked to indicate their proximity to publicly owned and privately owned natural areas. Distinguishing between ownership permits testing for the notion that landowners perceive private owners have greater discretion over land use, while public lands managers may not adequately account for wildlife impacts on nearby private lands.

The percentage of household income from farming potentially could affect willingness to tolerate wildlife damage. One hypothesis is that households who more heavily rely on farm income are also those for whom farming is a way of life which embraces appreciation for the relation between farm activities and stewardship of land resources. Thus one might expect tolerance to be increasing in the percentage of total household income from agriculture. A second variable, the percentage of total farm income from field crops alone, accounts for the relative importance of field crops in overall farm income. Landowners for whom field crops are a minor proportion of their overall farm income may be more tolerant of a given level of damage, relative to those for whom field crops represent a large proportion of farm income. Further, tolerance is postulated to be decreasing in acreage devoted to a given crop, since the damage as a proportion of farm income would be increasing.

Landowners were asked whether they believed local wildlife populations were increasing over the previous five years. Focus group results indicate a widespread belief among participants that increasing populations of problem wildlife is a direct result of wildlife management's failure to address their problems. If farmer dissatisfaction with wildlife management is correlated with increasing local populations, then damage tolerance could be expected to decrease with increasing local wildlife populations.

Other variables capture attitudinal differences among landowners that would be expected to affect tolerance thresholds. Respondents were asked a series of questions about the importance of on-farm wildlife for recreational hunting, insect control, and nonuse values. Landowners who indicate that nonuse values and insect control values are important to them would be expected to have higher tolerance thresholds. Similarly, individuals who hunt would likely have higher tolerance levels.

Consistent with the assumption that tolerance is driven in part by on-farm wildlife benefits, we expect landowners to be more tolerant of damage caused by wildlife species that provide more benefits. Thus producers would be more tolerant of damage from geese and deer, two game species, than damage from raccoons and blackbirds, widely considered to be nuisance species. The data include crop yield losses by wildlife species and crop type—allowing us to test for differences in tolerance thresholds by wildlife species. We accomplish this by organizing the data into a panel for which each observation includes a unique crop type and wildlife species pair for each producer. Four crop types (corn, wheat, silage and/or forage, and soybeans) are represented, with four species of wildlife (raccoons, blackbirds, deer, and geese). Therefore, each producer could be represented by up to a total of 16 observations. In reality, the panel is much smaller, because most farmers did not report growing all four crops or damage from every species. An example of the panel structure is given in table 3.

Table 4 provides a summary of variables included in the empirical model. The dependent variable is the binary response to the question of whether the level of damage that occurred was tolerable. The dollar value of damage is estimated as the market value of yield loss due to wildlife damage by crop and wildlife species for each producer.

The Random Effects Model

A random effects probit is used to account for farm-specific and wildlife species-specific effects. The dependent variable, *Tolerable*, is a binary variable indicating whether the individual farmer reported being willing to tolerate losses sustained in 1998. The data are arranged as an unbalanced panel in which relevant combinations of crops and wildlife species are given for each farm. The number of observations per farmer depends on the number of crops grown, and number of species causing damage. The 241 different farms (of which 108 reported damage) are thus represented by 1,206 observations. The number of observations without damage is 906 and the number with damage is 300. The random effects probit is expressed as follows:

$$Y^{*}_{ics} = \alpha + \mathbf{X}_{ics}\beta + \mu_i + \varepsilon_{ics}, \tag{7}$$

where Y^{*}_{ics} is the unobserved hidden variable (tolerance threshold) specific to producer i for damage to crop c ($c = 1, 2, 3, 4$) from species s ($s = 1, 2, 3, 4$) (Greene, 2000). $\mathbf{X}_{ics}$ is a $\{K \times 1\}$ vector of exogenous variables; α and β are $\{1 \times K\}$ vectors of variable coefficients; and μ_i is an error term that accounts for the variance across individuals. This error term is specific for each individual i and is constant across the $\{c \times a\}$ observations of each individual. The error term ε_{ics} accounts for systematic variation across crop and wildlife species. While Y^{*}_{ics} is not observable, we can observe the binary ("yes" or "no") variable Y_{ics}. Both error terms are assumed to be normally distributed with a zero mean, and respective variance of σ^2_{μ} and σ^2_{ε}. Let $\sigma^2 = \sigma^2_{\varepsilon} + \sigma^2_{\mu}$, $\rho = \sigma^2_{\mu}/\sigma^2$, and impose the

Table 3. Example of the Panel Data Structure

Farm I.D. No.	Species	Crop	Damage ($)	Willing to Tolerate Damage
1	Deer	Grain	124.50	Yes
1	Raccoons	Corn	1,023.56	No
2	Deer	Soybeans	859.36	No
2	Geese	Corn	22.77	No
3	Blackbirds	Soybeans	23.86	Yes
3	Raccoons	Soybeans	950.00	Yes
3	Raccoons	Corn	2,570.84	Yes

Table 4. Summary of Variables Included in the Empirical Model

Variable	Definition	Variable Type
Tolerable	Response to question of whether damage experienced was tolerable or not tolerable, by species of wildlife and crop type	Dependent/binary variable
$ Damage	Value of yield loss by crop type and wildlife species type	Continuous variable
Crop Acreage	Number of acres specific to each crop type	Continuous variable
Public Protected Area	Within 2 km proximity to public protected areas such as parks	1 = less than 2 km 0 = farther than 2 km
Private Protected Area	Within 2 km proximity to private protected areas	1 = less than 2 km 0 = farther than 2 km
% Farm Revenue	Percentage of household income from farming activities	Continuous variable between 1 and 100
% Crop Revenue	Percentage of farm income from field crops	Continuous variable between 1 and 100
Crop Type: *Corn* *Wheat* *Soybeans* *Forage/Silage*	Dummies for crop type, where *Corn* is the base	0 or 1
Wildlife Species: *Raccoons* *Blackbirds* *Deer* *Geese*	Dummies for wildlife species, where *Raccoons* is the base	0 or 1
Perceived Population Change	Respondent's perception of change in wildlife population over past 5 years	1 = increased 0 = not increased
Recreation Value	Respondent's rating of the importance of wildlife for recreational purposes	1 = important 0 = not important
Insect Control Value	Respondent's rating of the importance of wildlife for the control of insects or rodents	1 = important 0 = not important
Nonuse Value	Respondent's rating of the importance of wildlife for education and aesthetics	1 = important 0 = not important
Past Prevention Effort	Preventative action taken to control damage at least once during prior five years	1 = yes 0 = no

normalization that $\sigma^2 = 1$. Following Guilkey and Murphy (1983), the probability that $Y_{ics} = 1$ is therefore defined as:

$$(8) \qquad \Pr(Y_{ics}) = \int_{-\infty}^{\infty} \Phi\left(\left[\left(\frac{\mathbf{X}_{ics}\beta}{\sigma_\varepsilon}\right) + \mu_i\left(\frac{\rho}{1-\rho}\right)^{1/2}\right]\left[2Y_{ica} - 1\right]\right) * f(\nu_i)\, d\nu_i,$$

where $\Phi(\cdot)$ is the normal cumulative distribution function, $\nu_i = \mu_i/\sigma_i$, and ρ is the coefficient representing the level of correlation between the $\{c \times a\}$ responses of a given individual. If $\rho = 0$, then correlation does not exist and a simple pooled probit model can be used for estimation. If $\rho \neq 0$, there are systematic components of error that occur within groups. Failure to account for these errors results in biased standard errors of the coefficients. The test statistic for ρ is distributed χ^2 with one degree of freedom.

Results

The results of the random effects probit, summarized in table 5, reveal that the model is a significant predictor of the probability a farmer would be willing to tolerate a given level of wildlife damage.[7] Crop type and wildlife species are dummy variables for which corn and raccoons, respectively, are the bases. The log likelihood (−132.49) is significant at 1%.

As expected, farmers are least tolerant of damage by traditional nuisance species that provide for little in the way of wildlife use benefits. The parameter estimates for deer and geese are positive and significant, indicating a higher tolerance threshold for damage caused by these game species, relative to that for raccoons. Damage from raccoons is least tolerated, while the coefficient for blackbird damage is not different from that for raccoon damage. Although landowners don't encourage blackbird or raccoon populations, willingness to tolerate damage from these species is consistent with the conjecture that landowners receive utility from the knowledge they contribute to habitat stewardship.

The perception of the change in on-farm wildlife population size over time affects tolerance. Farmers who perceive an increase in their on-farm wildlife populations are less likely to be tolerant of a given level of damage. The positive *Nonuse Value* parameter estimate is consistent with the expectation that farmers who value wildlife for nonuse purposes have a higher tolerance threshold than those who do not hold these values.

Parameters on crop type are not significant individually. This finding is not entirely surprising since damage is the market value of the crop, and the parameter on damage is significant. This implies that the dollar loss in income captures the loss: crop type adds nothing to the model. The parameters for the percentages of household income from farming and farm income from field crops were significant with opposite signs. As the percentage of damage for a given crop increases, the probability that the damage is tolerable declines. On the other hand, the probability that a given level of damage is tolerable increases as the overall household income from farming increases. This latter result suggests that producers for whom agriculture is a smaller contribution of household income are less tolerant of wildlife damage. Consequently, producers who are "part-time" farmers may be less invested with the stewardship role, while those who are "full-time" farmers are more invested with the stewardship role. However, all landowners are less likely to tolerate a given level of damage as it represents larger proportions of a particular crop by a particular wildlife species.

[7] The model was estimated using STATA, Release 6.0.

Table 5. Random Effects Probit Model Results: Willingness to Tolerate Damage (N = 1,206)

Variable	Coefficient	Std. Error	z	P > |z|
ln(*Damage*)	-0.6909555	0.0991688	-6.967	0.000
Crop Acreage	0.0025234	0.0008053	3.134	0.002
Public Protected Area	-0.4880142	0.3689356	-1.323	0.186
Private Protected Area	-0.1901989	0.3519856	-0.540	0.589
% Farm Revenue	0.0133577	0.0056501	2.364	0.018
% Crop Revenue	-0.0112881	0.0052049	-2.169	0.030
Forage / Silage [a]	-0.0832003	0.3437428	-0.242	0.809
Soybeans	0.2803119	0.3703238	0.757	0.449
Wheat	0.0639850	0.4294650	0.149	0.882
Blackbirds [a]	0.1350485	0.3677928	0.367	0.713
Deer	0.9301151	0.2920575	3.185	0.001
Geese	0.7745807	0.3749854	2.066	0.039
Recreation Value	-0.6862118	0.3161651	-2.170	0.030
Insect Control Value	0.0353223	0.4226714	0.084	0.933
Nonuse Value	0.6642093	0.3452026	1.924	0.054
Perceived Population Change	-0.6804137	0.3426990	-1.985	0.047
Past Prevention Effort	-0.6379280	0.2630459	-2.425	0.015
Constant	3.7385070	0.8716673	4.289	0.000
Log Likelihood	-132.49248			
Rho	0.4223979	0.1184475		

[a] Crop type and wildlife species are dummy variables, where the respective base is *Corn* and *Raccoons*.

The parameter estimates for the variables indicating proximity to protected areas containing wildlife habitat—*Public Protected Area* and *Private Protected Area*—are both negative as expected. But it was not possible to reject the null hypothesis that these were not different from zero.

The parameter for *Recreation Value* is significant at the 1% level, with a negative sign. This result is unexpected, since it implies farmers who value hunting have lower tolerance for damage. Upon further consideration, however, there is a plausible explanation. Another part of the survey asked farmers to rank the effectiveness of various forms of prevention activities. The majority of landowners ranked hunting as the most effective. However, many noted that barriers to the effective use of hunting pressure, such as no-shooting and/or no-trapping zones near municipal borders, the desirability of allowing unknown people with firearms on their land, limited availability of permits, and lack of wildlife management agency support, limit the use of hunting as an effective damage prevention strategy. Based on focus group results, some Ontario farmers believe that where wildlife damage is problematic, effort to localize hunting pressure to reduce these populations should be considered as part of a solution. Therefore, landowners who responded that on-farm wildlife populations are important for hunting values may also believe damage is indicative of wildlife populations which are "too high" and could be brought back to reasonable levels with increased hunting pressure.

The negative sign on the value of damage suggests the probability of tolerance decreases as the dollar value of damage increases—i.e., the higher the dollar value of

damage, the more likely the disutility from damage will exceed the utility from benefits, as expected. Figure 3 illustrates the change in the probability of tolerance by the value of damage to corn, by each species.

The *Past Prevention Effort* dummy variable is significant and negative, indicating farmers who had attempted to prevent damage at least once during the previous five years have a lower tolerance threshold for wildlife damage. This result was expected, as discussed above.[8] Figure 4 illustrates graphically the differences in tolerance thresholds between those who did and did not attempt to prevent damage to corn in the past for geese. Table 6 summarizes differences in median tolerance thresholds by species (discussed in fuller detail below). Median thresholds are generally less than half for those producers who had reported past attempts at prevention.

These results reveal that for Ontario field crop producers, the following variables are significant predictors of tolerance: level of damage, species, perceived changes in local wildlife population sizes, past prevention effort (a proxy for past damage), nonuse values, recreation values, proportion of income derived from farming, and acreage of crop damaged. The type of wildlife species causing damage affected the tolerance threshold as expected, with damage by nuisance species being less tolerated than damage from more desirable species.

Calculation of Tolerance Thresholds

The probability that damage is tolerable is estimated over the range of damages in the sample according to equation (9):

$$\Pr(\textit{Tolerable}) = \frac{1}{1 + EXP^{(-(\beta_0+\beta_1*Avg+\ldots))}}. \tag{9}$$

These results were used to derive the probability curves graphed in figures 3 and 4.[9] Each parameter estimate from the tolerance function is multiplied by the corresponding average value for continuous variables, and 0 or 1 for dummy variables. Median values for tolerance thresholds (willingness to tolerate) are the dollar values of damage taken where the probability of a "yes" is equal to 50%.

Average tolerance thresholds are calculated for crop type and wildlife species, and median values are presented in table 6. These tolerance thresholds are lowest for raccoons and blackbirds, and highest for geese and deer. As noted previously, probabilities of tolerance by damage level for each species are illustrated graphically for corn in figure 3, and figure 4 illustrates the effect of past damage on tolerance thresholds for geese damage.

Net Utility Gains and Losses

Where damage is below farmers' maximum willingness to tolerate damage, marginal increases in wildlife populations imply marginal net welfare gains. These marginal net

[8] A modified Wu-Hausman test found no evidence that the dummy variable for past prevention action introduced simultaneity into the model due to its possible relationship with 1998 damages, a concern which was raised by a reviewer.

[9] The logit equation was used to estimate the probability curves using estimated probit coefficients according to Maddala (1983).

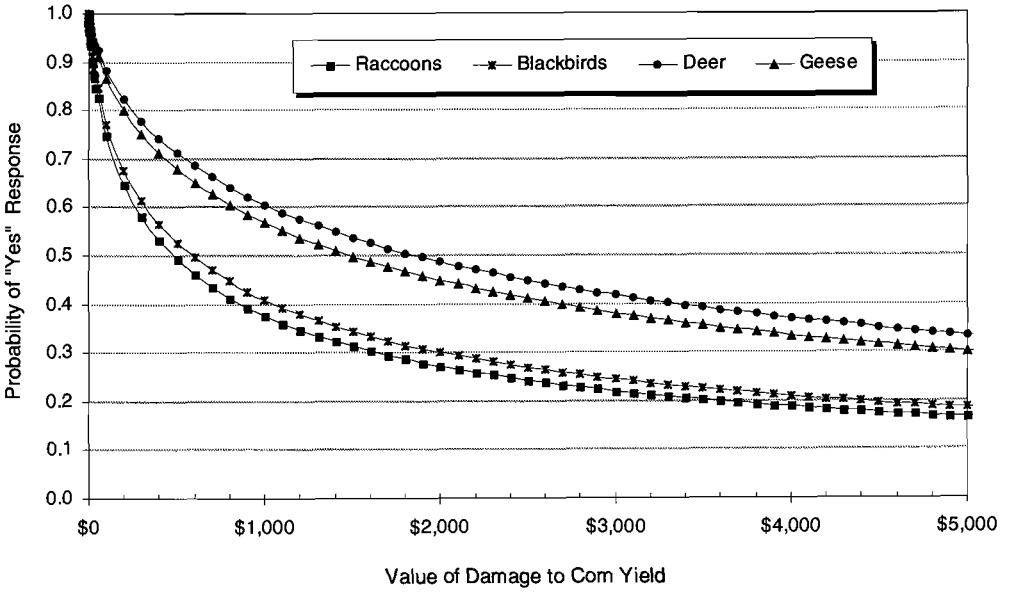

Figure 3. Willingness to tolerate corn damage, by wildlife species

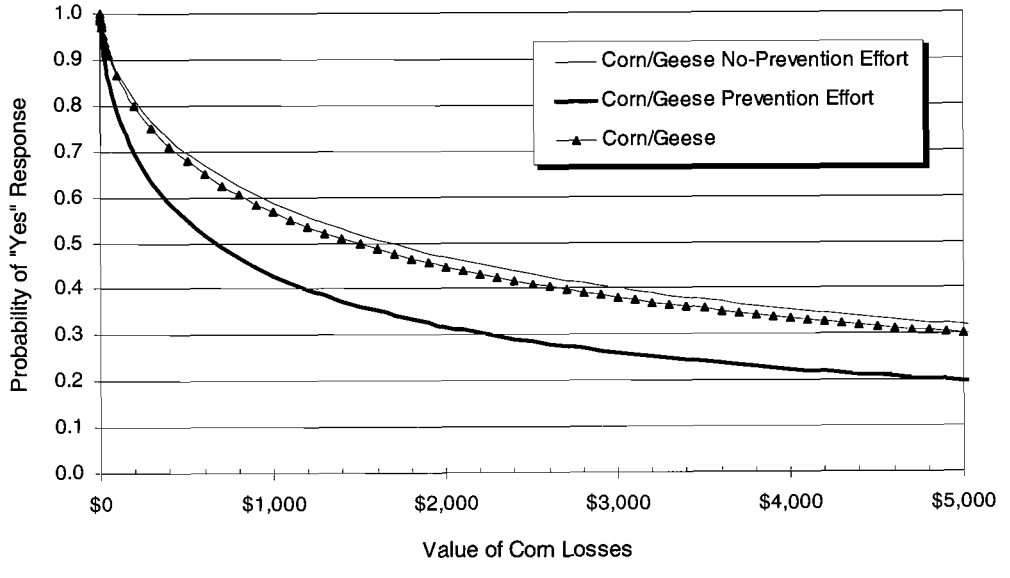

Figure 4. Willingness to tolerate corn losses from geese: Sensitivity to prevention effort

Table 6. Median Values of Willingness to Tolerate Damage, by Crop and Species ($)

	Wildlife Species			
Crop Type	Blackbirds	Deer	Raccoons	Geese
Corn	586	1,851	482	1,478
Forage/Silage	420	1,641	427	1,310
Soybeans	879	2,777	723	2,217
Wheat	642	2,030	528	1,621

Table 7. Yield Losses, and Net Costs and Benefits of On-Farm Wildlife for Survey Sample ($)

	Only Respondents Reporting Damage				All Respondents	
Crop Type	[1] Value of Yield Losses	[2] Losers' Net Losses	[3] Gainers' Net Gains	[4] Net Benefits	[5] Total Gains	[6] Total Net Benefits
Corn	145,135	66,201	112,366	46,165	404,518	338,317
Forage/Silage	60,184	41,032	30,016	-11,016	305,753	264,721
Soybeans	28,677	4,352	70,644	66,297	412,659	408,307
Wheat	4,198	0	37,795	37,795	270,991	270,991
Totals:	**238,194**	**111,585**	**250,821**	**139,241**	**1,393,921**	**1,282,336**

gains decrease to zero as wildlife populations increase to $\overline{W}$, due to marginal damage costs. Conversely, farmers with damages greater than their threshold would experience net marginal welfare losses with increases in wildlife. Using the damage tolerance thresholds derived above, both the net gains and net losses can be calculated for the sample. Table 7 summarizes these net marginal gains and losses. The first column indicates values of reported yield losses for each field crop. Column 2 is the net cost to only those respondents who reported damage in excess of their tolerance thresholds (maximum willingness to pay for on-farm wildlife). The median tolerance threshold is subtracted from actual damage for each respondent to arrive at individual net loss. Individual net losses are summed to give losses for the sample.

The third column indicates the net gain to those who reported damage at levels below the calculated tolerance thresholds. Column 4, net benefits, is the difference between the previous two. Except for forage/silage, on-farm wildlife is a net marginal gain, in aggregate, for those with damage. We interpret these results to be consistent with anecdotal reports from focus groups. Specifically, damage from wildlife is not a widespread problem for most farmers; the hardship is generated by the uneven distribution of costs.

Columns 5 and 6 of table 7 extrapolate these results over all respondents to include those who reported no damage. Total gains are the total benefits to landowners from on-farm wildlife for the sample. Total net benefits (column 6) are the difference between total gains (column 5) and total losses (column 2). Benefits for those with no damage are assumed to be the estimated values of the tolerance thresholds. Thus, over the entire sample, the net benefit from on-farm wildlife is $1,282,336, or almost 10 times as great as the value of the yield losses.

Table 8. Tolerance Thresholds for Damage to Corn and Decisions to Undertake Prevention Effort over the Previous Five Years ($)

Wildlife Species	No Prevention Effort During Previous Five Years	Prevention Effort During Previous Five Years
Blackbirds	660	262
Deer	2,080	829
Raccoons	543	215
Geese	1,660	662

Table 8 shows the differences in willingness to tolerate corn damage from each wildlife species, broken down by whether or not farmers undertook past prevention activities during the previous five years. In each case, the tolerance thresholds for those who had tried to prevent damage in the past five years was less than half of those who did not, as hypothesized. For example, the median tolerance threshold damage from geese is about $1,000 per year lower for farmers who attempted to prevent damage previously than for those who did not. (Figure 4 illustrates these differences graphically for geese.)

Implications

This study demonstrates that farmers' tolerance thresholds, as defined in the wildlife management literature, can be interpreted as their maximum net marginal willingness to pay for on-farm wildlife. Tolerance thresholds can be measured empirically and used to approximate the net welfare impacts of on-farm wildlife populations. The marginal net welfare effect of on-farm wildlife can be positive or negative, depending on the size of the population, marginal damage costs, and net marginal utility generated by the wildlife for the landowner. Because they are derived from preferences and marginal damage costs, tolerance thresholds vary with landowner and farm characteristics.

As indicated by data from Ontario, overall, the net welfare impact from the four wildlife species on field crop producers in the sample was positive, due to on-farm utility gains that outweigh damage costs in aggregate. When focusing exclusively on those who bear damage in excess of their gains, however, the net welfare loss ($111,585) is less than half of the financial value of the yield losses ($238,194). The results obtained from this approach using the Ontario data suggest that the economic problem for these field crop producers is not simply the financial cost of damage, which may be inevitable given the presence of on-farm wildlife. Rather, the economic problem is how the net costs of damage are distributed. A small number of producers appear to sustain a large proportion of damages, while the utility gains from on-farm wildlife are distributed widely over all producers and nonproducers. Indeed, the overall net impact over the sample is a dollar-valued utility gain of more than 10 times the damage costs. These results emphasize that focusing solely on the financial value of crop losses from wildlife may lead to an incomplete evaluation of the marginal welfare effects of on-farm wildlife on landowners.

This research demonstrates that not all crop yield loss resulting from on-farm wildlife activity should be interpreted as indicative of a net economic loss to farmers. This finding is consistent with opinions voiced in focus groups conducted as part of the study, in which farmers state they consider themselves to be good stewards of wildlife habitat and

affirm they take into account wildlife needs in assessing the productivity of their lands. Many assert, however that they object to localized wildlife populations which are allowed to increase to levels where damage sustained is in excess of what they believe to be reasonable. This implies that landowners believe they are able to assess what "reasonable" on-farm wildlife populations should look like, and what constitutes "reasonable" levels of wildlife damage due to forage and habitat needs on their farmland. A "reasonable" level of damage is, nevertheless, as perceived by the individual and estimable as indicated in this study.

Given these results, it is safe to conclude that wildlife damage policies in general which are based on the value of yield loss are likely to overstate economic damage, and thus lead to suboptimal wildlife management and damage policy. Full compensation for yield losses, for example, would overvalue the net value of on-farm wildlife damage and undervalue wildlife. Many focus group participants for this study expressed concern that compensation for yield loss would leave the public with the perception that farmers were not supportive of wildlife and habitat—when in reality their objection was with wildlife populations which were "too large."

To address distributional issues, an appropriate policy may target areas for wildlife removal/dispersal effort where farmers report on-farm damages over their tolerance thresholds, and where excessive damage has already occurred, to redistribute wildlife benefits. Programs that provide special wildlife hunting permits to reduce local problem wildlife populations are examples of this approach. Another policy option is to identify ways to increase tolerance thresholds, where damages are not severe. The approach developed in this study can be used to determine the impacts of factors such as proximity to protected areas, wildlife species, and farm characteristics on landowner tolerance thresholds, thereby allowing wildlife managers to better predict when and where problems may arise.

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Appendix: Example of the Survey Question Format Used to Elicit the Dependent Variable

The survey was organized into sections that pertained to individual wildlife species. Participants were asked about both positive and negative aspects of wildlife presence. They were asked to estimate the percentage of yield loss, by crop type, at time of harvest that they believed was attributable to the wildlife species in question. They were not asked to apply a dollar value to this loss. Rather, the researchers used the respondents' total acreage, along with county data for expected crop yields, to convert the percentage loss to crop units. The number of units lost was then multiplied by the market price for that crop type. Thus, for the empirical model, the damage estimate was in dollar units, while the sample question below was posed in terms of the percentage yield losses by species and crop type.

For the survey section that dealt with Canada geese presence on private lands, the tolerance question read as follows:

How would you rate the losses by *geese* to your field crops in 1998?

	Tolerable	**Not Tolerable**
Corn	❑	❑
Soybeans	❑	❑
Wheat	❑	❑
Grain Silage	❑	❑
Forages	❑	❑