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IMPACT OF BLACKBIRD DAMAGE TO SUNFLOWER: BIOENERGETIC AND ECONOMIC MODELS

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Abstract. We constructed bioenergetic and economic models to estimate the potential impact of Red-winged Blackbirds (*Agelaius phoeniceus*), Common Grackles (*Quiscalus quiscula*), and Yellow-headed Blackbirds (*Xanthocephalus xanthocephalus*) on production yields of sunflower in the northern Great Plains of North America. The amount of sunflower consumed annually by males and females, after considering field metabolic rates, energy value and moisture content of achenes, and percentage of sunflower in diets was, respectively: Red-winged Blackbirds 277 g and 168 g; Common Grackles 267 g and 230 g; and Yellow-headed Blackbirds 248 g and 139 g. The per capita annual economic damage was: male Red-winged Blackbirds $0.09 (U.S. dollars), females $0.05; male Common Grackles $0.09, females $0.07; and male Yellow-headed Blackbirds $0.08, females $0.05. Annual loss was $5.4 ± 1.3 × 10^6$ for all three species in aggregate, with Red-winged Blackbirds accounting for 52% of the loss. Blackbird damage represented 1.7% of the dollar value of the 1999 sunflower harvest in the northern Great Plains. This loss would be inconsequential if damage were distributed evenly; however, bird damage is often localized around wetlands and can be economically debilitating to individual producers. Although our model was based on regional population estimates, it should perform well at local scales, provided that a local population can be defined, accurately estimated, and remains stable in size over the six-week length of the damage period. Because of the large numbers of blackbirds that congregate in the region during August and September prior to migration, sunflower producers should expect some crop losses. The solution to the conflict appears to be one that focuses not on eliminating all damage, but on preventing it from exceeding 5% per field.

Key words: bioenergetics; Common Grackle; crop damage; economic valuation; modeling; Red-winged Blackbird; sunflower; Yellow-headed Blackbird.

INTRODUCTION

Indices from the North American Breeding Bird Survey (BBS) show that Red-winged Blackbirds (*Agelaius phoeniceus*), Yellow-headed Blackbirds (*Xanthocephalus xanthocephalus*), and Common Grackles (*Quiscalus quiscula*) may attain some of their highest densities in the northern Great Plains in Minnesota, South Dakota, and North Dakota. For all three species of blackbirds (Icteridae), there are areas within these states with BBS routes that average >100 birds per route (Sauer et al. 2001). Numbers of blackbirds were notably high in North Dakota, where average route counts of Red-winged Blackbirds and Yellow-headed Blackbirds exceeded all other states and provinces in the BBS from 1996–2001 (USGS 2002). During the post-reproductive period, blackbirds start congregating at roosting sites in cattail-dominated (*Typha* spp.) wetlands, and by mid-August, large mixed-species flocks have formed, numbering up to 500 000 birds at favorite sites. Resident blackbirds and northern migrants will stage in the northern Great Plains until migration in September and October. Prior to departure, they feed disproportionately on sunflower achenes, accumulating the energy reserves needed for migration (Homan et al. 1994*a*). This can result in extensive damage to sunflower fields located near preferred roosting and loafing sites.

Complaints about blackbird depredation of sunflower began shortly after the crop became economically viable in the northern Great Plains in the late 1960s (Linz and Hanzel 1997). Blackbirds are opportunistic granivores throughout most of their life cycle and thus were quick to exploit this new high calorie food source. Region-wide field estimates of blackbird damage in 1979 and 1980 showed economic losses totaling $5.1 and $7.9 × 10^6$ (U.S. dollars), respectively (Hothem et al. 1988). Although sunflower is planted as a rotation crop between plantings of small grains and other crops, it can be a highly profitable crop of considerable economic importance in the northern Great Plains. In 1999, 1.4×10^6 ha (~80% of total U.S. production) were planted in North Dakota, South Dakota, and Minnesota with a total market value of $315 × 10^6$ (USDA 2000).

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Total economic impact in the three states was estimated at 1×10^9 (Bangsund and Leistritz 1995).

When blackbirds reach their highest densities in the northern Great Plains during late August and September, sunflower is near maturity. From the perspective of sunflower producers, blackbirds are overabundant and pose a threat to their livelihoods (Caughley 1981). Sunflower producers in South Dakota cited blackbirds as their number one production problem (Lamey and Luecke 1994); whereas, producers in North Dakota cited the likelihood of blackbird damage as a significant factor influencing their decision not to plant the crop (North Dakota Agricultural Statistics Service 1990). Of 601 sunflower producers surveyed in North Dakota and South Dakota, 82% agreed that lethal control measures should be employed to reduce blackbird populations (North Dakota Agricultural Statistics Service 1995). The concept of overabundance is a difficult one to define and controversial (see Garrott et al. 1993). The controversy lies in the subjectivity of the definition, as it is based on the nature of one's interests, likes, and dislikes. It has been generally defined as that point of abundance where all positive values of the species have been overwhelmed by the negative values created by the sheer numbers of individuals (Conover 2001).

In response to importunate requests from sunflower producers for an effective solution to the 30-yr conflict with blackbirds (Linz and Hanzel 1997), the U.S. Department of Agriculture began preparation of an Environmental Impact Statement (EIS) to analyze various alternatives for managing blackbird damage to sunflower. A critical component of the EIS will be an accurate analysis of the economic losses caused by blackbirds. Accurate estimates of damage are not only necessary for making sound decisions on management strategies but are also the baseline value upon which efficacy (e.g., cost : benefit ratios) of a program can be quantified (Wywialowski 1996, Leitch et al. 1997, Newton 1998).

Improvements in allometric formulas used to estimate metabolic rates of free-ranging birds and new information on metabolizable energy contents of foods have now made bioenergetic modeling a useful tool for estimating crop damage caused by birds. Bioenergetic models provide estimates of damage that are derived independently from those obtained through direct measuring of crop losses by field surveys and can help in validating the reliability of the latter, which often have variances so large that their confidence intervals cross into negative values (Wiens and Dyer 1975). For resource managers, who must decide on the most effective and environmentally sound course of management to lessen conflicts between society and wildlife, objectivity must be maintained. Our goal was to develop accurate and objective bioenergetic and economic models by combining elements of blackbird biology, population dynamics, and metabolism with energetic and economic components of sunflower. Basili and Temple (1999) conducted a similar analysis to examine the conflict between Dickcissels (*Spiza americana*) and rice farmers in Venezuela. To date, no such analysis has been conducted on the economic impact resulting from blackbird depredation of the sunflower crop.

Methods

Study area

Approximately 70% of U.S. sunflower production occurs in North Dakota and South Dakota between 44–48° N and 98–101° W (~472 000 km²). North Dakota leads all U.S. states in sunflower production, accounting for 44% of U.S. production; South Dakota is second with 26% (USDA 2002). In the Dakotas, 90% of the crop is located in the Drift Prairie or Glaciated Missouri Plateau physiographic regions (Fig. 1). Field densities are greatest north of the 9th standard parallel (~46.5° N) in the Drift Prairie region of North Dakota, where 70% (550 000 ha) of the North Dakota crop was planted in 1998. The terrain here is flat to gently undulating, with numerous glacially carved wetlands formed during the Wisconsin Age of glaciation 10 000 BP. The vast expanse of Northern Mixed Grass Prairie vegetation that once covered the Drift Prairie has been replaced, mainly by crop system agriculture. Because of modest precipitation (46 cm) and cool temperatures (13°C) at the start of the growing season, small grains (e.g., wheat, barley, oats, and rye) have always predominated crop plantings in the northern Great Plains. In 1998, 3.5×10^6 ha of small grains (44% of all planted crops) were planted in the prime sunflower-producing area of the Dakotas.

Bioenergetic models of sunflower consumption by blackbirds

We constructed bioenergetic models to determine the amount of sunflower consumed independently for each sex of the three blackbird species (Table 1). To do this, we first calculated daily energy need using field metabolic rates (FMR) based on the following formula:

$$y = 10.4x^{0.68}$$

where y = FMR in kJ/day and x = mean body mass in grams. The formula has been modified for passerines from an allometric formula that encompassed several orders and body sizes of birds, ranging from the Ostrich (*Struthio camelus*) to hummingbirds (Williams et al. 1993, Nagy et al. 1999). It not only accounts for basal metabolic rate, but all other activities of free-living birds, including thermoregulation, foraging and digestion, predator avoidance, growth, and reproduction. Body masses were mean values recorded from 15 August to 15 September, the period of greatest damage in the Dakotas (Cummings et al. 1989).

To calculate the grams of achenes consumed per day, we divided the FMR values by metabolizable energy content (MBE) of sunflower achenes, then

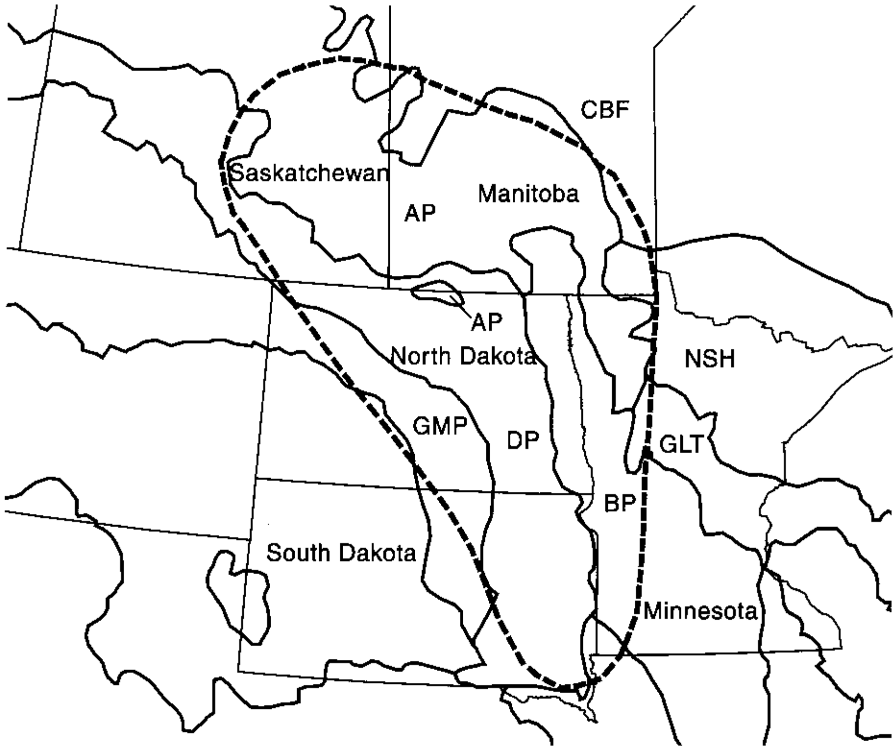

FIG. 1. The seven physiographic regions in the northern Great Plains of North America containing the populations of blackbirds (Icteridae) that cause damage to the commercial sunflower crop. The dashed line represents the area encompassing the populations most likely to cause the majority of sunflower damage (from Stehn 1989). Region abbreviations are: AP, Aspen Parkland; BP, Black Prairie; CBF, Closed Boreal Forest; DP, Drift Prairie; GLT, Great Lakes Transition; GMP, Glaciated Missouri Plateau; and NSH, Northern Spruce Hardwoods (from Robbins et al. 1986).

multiplied by the proportion of sunflower in the diet. The proportion of sunflower was based on analyses of esophageal contents of the three species collected in the Drift Prairie physiographic region during the period of sunflower maturation (Linz et al. 1984, Twedt et al. 1991, Homan et al. 1994*b*). All three species were consistent in their food choices across time, perhaps due to the similarities in availability of palatable foods in the Drift Prairie landscape (Homan et al. 1994*a*). The MBE value was based on dry mass (Park et al. 1997); we compensated for dry mass by multiplying the amount consumed by 1.225 (unity, plus midpoint of moisture range of achenes at harvest 0.20–0.25) (Weatherhead et al. 1982, Basili and Temple 1999). Our use of 1.225 represented a conservative approach toward assessing MBE because moisture content is greater during earlier stages of achene development (Hofman and Hellevang 1997). We considered this the best approach, however, because sunflower varies greatly in its stage of development within and among fields. The sunflower damage period lasts a minimum of 42 d, peaking before the achenes reach physiological maturity (Cummings et al. 1989). Because the MBE of immature achenes is about one-half (15.28 kJ/g) that of mature achenes (Conner and Hall 1997), more must be consumed to meet energetic demands early in the damage period. However, during the early stage of achene development, sunflower plants can redirect energy to the undamaged achenes, compensating for between 6% and 44% of the losses (Sedgwick et al. 1986). Following Baltezore et al. (1994), we divided the damage period into two periods to allow for damage compensation and changes in energetic quality of the achenes. The first damage period (Period 1) consisted of the 14 d that followed anthesis (petal drop). Sunflower consumption during this period was multiplied by 0.85 (Baltezore et al. 1994) to adjust for the compensatory ability of sunflower plants. Consumption during the second damage period (Period 2) was multiplied by 28 d (i.e., period length), with no correction for compensation. During Period 2, the FMR was divided by 30.56 kJ/g, the full MBE value calculated for hulled, mature, oil-type sunflower achenes (Park et al. 1997).

Economic models of blackbird damage

We calculated the economic value of blackbird damage by multiplying the amount of sunflower consumed by the late-summer population of blackbirds by the average market price of sunflower for the five-year period between 1993 and 1997 ($0.00026/g; North Dakota Agricultural Statistics Service 1999). This resulted

TABLE 1. Estimates of sunflower damage caused annually by three species of blackbirds in prime sunflower production areas in the northern Great Plains of North America.

Model components	Red-winged Blackbird		Yellow-headed Blackbird		Common Grackle		Total
	Male	Female	Male	Female	Male	Female	
A) Bioenergetic							
FMR (kJ/d)†	194	142	230	163	268	230	1227
B) Consumption (g)							
Period 1‡							
Daily	9	5	8	5	9	8	44
Total	127	77	114	64	123	106	611
Period 2§							
Daily	5	3	5	3	5	4	25
Total	150	91	134	75	144	124	718
Total	277	168	248	139	267	230	1329
Economic loss (U.S.$)							
Per bird	0.09	0.05	0.08	0.05	0.09	0.07	0.43
Per population‖	1 769 619	1 068 798	678 192	379 529	823 064	707 188	5 426 390
Per species	2 838 417		1 057 721		1 530 252		

Notes: The damage period was divided into two parts based on the maturation process of sunflower. Period 1 was a 14-day period of development during which the plant could partially compensate for loss of achenes. Period 2 consisted of a 28-day period when the plant was at or near maturity and not able to compensate for loss. The energy value of mature achenes during Period 2 (30.56 kJ/g) was estimated at twice that of immature achenes in Period 1.

† FMR (field metabolic rate) = 10.4 (body mass)$^{0.68}$. Masses (g) of Red-winged Blackbird: male 73.7, female 46.5 (Linz 1982); Yellow-headed Blackbird: male 94.7, female 57.2 (Twedt 1990); and Common Grackle: male 119, female 95.2 (H. J. Homan, *unpublished data*).

‡ Sunflower consumption Period 1 = FMR × (sunflower in diet) × (correction for moisture) × (correction for compensation) × 14 d/(energy value of sunflower). Corrections for moisture and compensation: 1.225 and 0.85, respectively. Energy value of sunflower achenes during Period 1: 15.28 kJ/g. Proportion (dry mass) of sunflower in diet of Red-winged Blackbirds: male 69%, female 57% (Linz et al. 1984); Common Grackle: male 48%, female 48% (Homan et al. 1994*b*); Yellow-headed Blackbird: male 52%, female 41% (Twedt et al. 1991).

§ Sunflower consumption Period 2 = FMR × (sunflower in diet) × (correction for moisture) × 28 d/(energy value of sunflower). Energy value of sunflower during Period 2: 30.56 kJ/g.

‖ Estimate was derived by multiplying population size in late summer by per-bird consumption after correcting for hull mass (correction term = 1.25). Damage values were based on the market price for oil sunflower from 1993 to 1997: $0.26/kg (North Dakota Agricultural Statistics Service 1999). Confidence intervals (95%) for economic damage: Red-winged Blackbirds, $637 847; Yellow-headed Blackbirds, $312 368; Common Grackles, $379 408; Total, $1 329 624. Confidence intervals were calculated using standard errors of populations estimates of the three species from 1996 to 1998 (see Table 2; Linz et al., *in press*).

in the amount of financial damage caused in one season. Our bioenergetic models included only the sunflower kernel because blackbirds do not eat hulls; however, the market price of sunflower includes hull mass. Sunflower hulls compose, by proportion, 0.22 to 0.28 of the total mass of sunflower achenes (Park et al. 1997). We used the midpoint of this range (0.25), added unity, and multiplied consumption by 1.25 to correct for hull mass. We calculated 95% confidence intervals (CI) for annual economic damage by using the population variance of the three species in late summer. This variance was obtained from annual estimates of breeding density in the Drift Prairie and Glaciated Missouri Plateau physiographic regions from 1996 through 1998 (Linz et al., *in press*). The formula for estimating economic damage per individual per period was as follows:

$$\text{damage} = (\text{FMR/MBE}) \times \text{diet} \times \text{moisture} \times \text{compensation} \times \text{hull} \times \text{days} \times \text{price}$$

where diet = proportion of sunflower in diet by sex by species, moisture = correction for wet mass of achene (1.225), compensation = ability of plant to recover from minor damage (0.85), hull = correction for discarded hull for which the producer is paid (1.25), days = days in the two damage periods (Period 1 = 14, Period 2 = 28), and price = market price of sunflower ($0.00026/g).

Blackbird population sizes

From banding data, Stehn (1989) determined that the majority of blackbirds responsible for sunflower depredation originated from North Dakota (except the southwest corner), the eastern third of South Dakota, far western Minnesota, southern Manitoba, and southeastern Saskatchewan (Fig. 1). This area encompassed seven different physiographic regions. We determined the areal extent of each region using Geographic Information System analysis of Stehn's figure of the area. Densities of territorial male breeding blackbirds were known for the Drift Prairie and Glaciated Missouri Plateau regions of North Dakota from counts conducted between 1996 and 1998 on randomly selected General

Land Office quarter sections (Linz et al., *in press*). To obtain the population size of breeding males for these regions, we multiplied average density per quarter section (0.65 km^2) by regional area. Based on models of demographic age structure, the number of territorial males was multiplied by 4.08 to adjust for females, nonbreeding males, and males that were missed during the counts (Stehn 1989). Late-summer population size was calculated by multiplying the inclusive spring population by 1.45 to allow for recruitment (Stehn 1989). In the remaining five physiographic regions, the only population measurements available were indices from the BBS. We used the average of the indices between 1996 and 1998 from each of the five physiographic regions and converted these to density estimates by using the proportional relationship established between density and index for the three blackbird species in the Drift Prairie and Glaciated Missouri Plateau (Robbins et al. 1986, Linz et al., *in press*). The proportional relationship indicated that on average one breeding male/km^2 was counted by Linz et al. (*in press*) for every seven birds tallied on BBS routes. For example, if the average number recorded on a BBS route was 70 birds, then we estimated that the density of breeding males was 10 males/km^2. The 1:7 ratio that we observed between the density estimates of Linz et al. (*in press*) and the BBS route indices in the Drift Prairie and Glaciated Missouri Plateau was nearly equal to the constant of 7.24 (in Model 2) derived by Clark et al. (1983) in their study in Quebec on the relationship between density of breeding male Red-winged Blackbirds and BBS indices. The main assumption used to estimate density from an index is that a nearly linear relationship must exist between both. Clark et al. (1983) validated this assumption in Quebec, and we believe that it was a reasonable assumption for the northern Great Plains as we were dealing with conspicuous species in fairly open landscapes. From 1996 to 1998, Linz et al. (*in press*) recorded the following numbers of male breeding blackbirds (per square kilometer) in the Drift Prairie and Glaciated Missouri Plateau regions of North Dakota, respectively: 16.23 $\pm$ 2.4 (SE) and 19.80 $\pm$ 4.5 Red-winged Blackbirds, 14.38 $\pm$ 3.0 and 3.63 $\pm$ 1.6 Yellow-headed Blackbirds, and 6.55 $\pm$ 0.7 and 11.23 $\pm$ 3.5 Common Grackles. We generated 95% CIs for each density estimate using standard errors of annual means (by species) between 1996 and 1998.

Results

Bioenergetic models

Field metabolic rates were $\geq$230 kJ/d for both sexes of Common Grackles and male Yellow-headed Blackbirds (Table 1). The smaller massed Red-winged Blackbirds and female Yellow-headed Blackbirds had FMRs <200 kJ/d. Because of the lower energy value of achenes during Period 1, twice the amount of sunflower was needed to meet energy requirements as was needed during Period 2. The total amount of annual sunflower damage was higher for males than females for all species. Male Red-winged Blackbirds consumed the most sunflower over the combined damage periods (277 g), followed in descending order by male Common Grackles, male Yellow-headed Blackbirds, female Common Grackles, female Red-winged Blackbirds, and female Yellow-headed Blackbirds (Table 1). Compared to male Red-winged Blackbirds, female Yellow-headed Blackbirds consumed about one-half the amount of sunflower over the two damage periods.

Economic models

The annual economic value of sunflower damage per bird ranged from \$0.05 for female Red-winged Blackbirds and female Yellow-headed Blackbirds to \$0.09 for male Red-winged Blackbirds and male Common Grackles (Table 1). Our model predicted a total annual economic impact of ~\$5.4 $\pm$ 1.33 $\times$ 10^6 for the three blackbirds species in aggregate. Total population size in late summer for all species combined was 75 $\pm$ 18 $\times$ 10^6 birds. The population size of Red-winged Blackbirds was twice as large (39 $\times$ 10^6 birds) as the populations of Common Grackles and Yellow-headed Blackbirds (Table 2). Because of their numerical dominance among the blackbird species in the sunflower-producing region, male and female Red-winged Blackbirds had the greatest economic impact; they each caused >\$1 $\times$ 10^6 in damage, and \$2.8 $\pm$ 0.64 $\times$ 10^6 combined. The least amount of economic damage was caused by female Yellow-headed Blackbirds (\$0.4 $\pm$ 0.11 $\times$ 10^6). Female Yellow-headed Blackbirds caused less than one-quarter of the economic damage of male Red-winged Blackbirds.

Discussion

Our bioenergetic and economic models can be viewed as supplemental tools that can be used to increase our understanding of the interaction between blackbird populations and sunflower damage in the northern Great Plains. The models provided estimates that were independent of field damage surveys and, when used in conjunction with the latter, may help strengthen the soundness of our management decisions. The sole use of field estimates of damage can lead to unnecessary or impractical management programs, because these estimates can be highly variable, subjective, and biased. For example, a bioenergetic model developed by Dyer and Ward (1977) showed that a subjective estimate of corn damage caused by Red-winged Blackbirds in Ohio exaggerated the true value by 15 times. Similarly, Weatherhead et al. (1982) found that a Canadian government estimate of corn damage by Red-winged Blackbirds was 59 times higher than their model estimate, which later was confirmed as accurate in field trials. Our model, because it was based on regional population estimates, can be used to reaffirm the region-wide field surveys of sunflower dam-

TABLE 2. Estimated breeding and fall blackbird population sizes (±95% confidence intervals [CI]), and the number of square kilometers of each physiographic region in the sunflower growing region as determined by Geographic Information System analysis.

Physiographic region	Area (km²)†	Red-winged Blackbird		Common Grackle		Yellow-headed Blackbird	
		No.	(CI)	No.	(CI)	No.	(CI)
Great Lakes	3 040	179 279	(42 705)	57 224	(15 447)	7 754	(3 170)
Northern Spruce Hardwoods	9 735	108 354	(25 810)	159 459	(43 045)	0	(0)
Closed Boreal	18 763	12 984	(3 093)	23 565	(6 361)	0	(0)
Aspen Parklands	177 179	6 157 881	(1 466 843)	307 140	(82 910)	956 616	(391 127)
Drift Prairie	163 502	10 828 773	(2 014 803)	4 368 602	(607 918)	9 592 378	(2 499 664)
Glaciated Missouri Plateau	47 360	3 826 050	(1 110 900)	2 169 687	(869 461)	701 343	(390 748)
Black Prairie	64 556	5 962 740	(1 420 360)	5 983 655	(1 615 250)	352 769	(144 235)
Total breeding population		27 076 061	(6 084 514)	13 069 332	(3 240 392)	11 610 860	(3 428 944)
Fall population‡		39 260 288	(8 822 545)	18 950 531	(4 698 568)	16 835 747	(4 971 969)

Notes: Confidence intervals were calculated from standard errors of annual means (by species) estimated between 1996 and 1998 from complete counts of 67 0.65-km² plots (Linz et al., *in press*).

† The total region sampled was 484 135 km².

‡ Fall population sizes were calculated by multiplying breeding population sizes by 1.45 (Stehn 1989).

age done in 1979 and 1980 (Hothem et al. 1988). Indeed, our point estimate of \$5.4 $\times$ 10^6 of damage was within the range of field estimates of \$5.1 $\times$ 10^6 in 1979 and \$7.9 $\times$ 10^6 in 1980. Despite the fact that regional estimates often fail to portray the true nature and impact of bird damage, these estimates may be necessary. They are important because the application and assessment of new management techniques sometimes can only be accomplished at the regional scale; e.g., implementation of regional-based population management programs. Second, because of the paucity of effective damage management methods and the relatively confined area in which major sunflower production occurs, newly introduced techniques often reach ubiquity in the sunflower-growing region (Linz and Hanzel 1997). For instance, cattail management is now so widely employed that it may have regional influence.

Region-wide estimates of damage do not convey the true nature of bird damage because it is usually locally distributed. The region-wide surveys conducted by Hothem et al. (1988) indicated that bird damage averaged 1–2% per field. Additionally, only 2% of the fields had damage ≥10%. When damage was estimated at more refined scales, the average field damage was much higher than 1–2%. In central North Dakota, field damage was estimated at 6% per field; perhaps more importantly, 20% of the fields had damage ≥10% (Linz and Hanzel 1997). Our models have the flexibility to estimate local damage provided that a local population can be defined, accurately estimated, and remains relatively stable in size over the six-week length of the damage period. Last, because predictions about effects of management programs are generally not amenable to direct field testing, our models can be used to assess the potential effects of differing management scenarios or adaptive management programs.

The value of all mathematical models depends on the accuracy of the inputs used. We may have underestimated the amount of sunflower eaten, if for example, the formula for FMR did not adequately account for the increased energy demands of molt and thermoregulation that could be imposed on birds molting in northern latitudes. The estimate of the geographic origin of the populations causing sunflower damage is another potential source of error that could significantly affect the output of the model by changing the size of the depredating population. Color-marking of Red-winged Blackbirds staging in eastern South Dakota has shown that 18% of the birds migrated northwest to breeding areas outside of the boundary polygon (in Fig. 1) used in our model (Homan et al. 2002). It is likely that these birds retraced their migration route and were present in the sunflower-growing region as early as late August, but this is not known for certain (Dolbeer 1978), and this population was not included in the model. Initiation of new research projects that would provide more knowledge on migrational timing and patterns (e.g., DNA or trace mineral analysis of subpopulations; color-marking of birds outside of the boundary polygon) should increase the accuracy of the model. Likewise, direct estimates of breeding male density in the physiographic regions where they are now lacking would be helpful, particularly in the large Aspen Parkland region.

Temporal and spatial differences in dietary intake of sunflower would also significantly alter the results of the model. However, research has provided evidence that use of sunflower by blackbirds will remain consistent over time within our modeled area, which lies outside the range of intense corn production, another preferred food item of blackbirds (Dolbeer 1990). Linz et al. (1984) conducted their study on food habits of Red-winged Blackbirds in southwestern Cass County (≅47° N), roughly 300 km south-southeast from where the dietary studies were done on Yellow-headed Blackbirds and Common Grackles (Benson County, ≅48° N). Although both of these North Dakota counties had corn crops, Cass County, because of its more southern location and longer growing season, produced more corn (6% of county area) than Benson County (0.8%). The results from Linz et al.'s study indicated that when given a choice between feeding on corn or sunflower, Red-winged Blackbirds chose sunflower. They consumed much more sunflower (males 69%, females 57%) than corn (males 3%, females 1%). The preference shown by blackbirds for sunflower adheres to the principle of maximum-efficiency foraging (Gill 1990): sunflower has an energy content 40% greater than corn.

Another source of model inaccuracy would arise from underestimating the collateral damage that results from the birds pulling the achenes from the heads of sunflower. Random samples of achenes taken from the ground in damaged sunflower fields indicated that only shelled hulls remained in most cases (G. M. Linz, *personal observation*). This type of damage does not appear to be a contributing factor in damage to sunflower, although for other types of crops (e.g., rice) it is so (Basili and Temple 1999).

A strong majority of sunflower producers surveyed by questionnaire believed that population reduction would solve their production problems with blackbirds. Despite the intuitive appeal of this approach, lethal programs generally are ineffective when the damage is caused by birds. For example, crop depredation by foraging Woodpigeons (*Columba palumbus*) was the most frequently cited reason for forcing English farmers out of canola production (Lane 1984). In response, ~60% of the Woodpigeon population was culled (Murton et al. 1974). Similarly, in one of the most ambitious population control programs ever, hundreds of millions of Red-billed Quelea (*Quelea quelea*) were killed annually in South Africa to reduce damage to grain crops (Bruggers and Elliott 1989). Neither of these lethal programs appeared to reduce crop damage or population density of the pest. Indeed, lethal programs can unnecessarily put target and nontarget species at risk, and in worst cases, possibly alter the integral dynamics of the ecosystem if keystone species are involved (Ward 1979, Feare 1991, Newton 1998). There are several reasons why lethal control efforts can fail: (1) the timing or place of the culling was inappropriate; (2) the wrong subpopulation, age group, or sex was targeted; (3) the culling did not exceed the annual natural mortality; and (4) the area was repopulated through immigration. Given the highly localized distribution of sunflower damage, alternatives such as regional population control (the scale at which most lethal programs are implemented because of cost and efficacy) would likely not have the desired effect because only a small proportion of the birds from the target population would be removed (Dolbeer 1990).

Why do producers continue to grow sunflower in areas where blackbird depredation is likely? Sunflower is a rotational crop, usually planted at three- to five-year intervals. Producers who may not have had bird damage during a previous planting may so in the next (and vice versa). This uncertainty can exist within and between growing seasons, with sites of severe damage seemingly located at random. The randomness may occur for several reasons, such as the chaotic movements of roosts and flocks, changes in local breeding population densities, and precipitation-induced changes in wetland quality or quantity. We note that the major area of sunflower production in the United States is the same area renown for its density of wetlands. The density here of semipermanent wetlands (the preferred roosting and loafing habitat of blackbirds) is 0.88 wetlands/km^2 (Reynolds et al. 1997). Blackbirds will foray up to 16 km from their wetland roosts to reach sunflower (Linz and Hanzel 1997); conversely, over 700 semipermanent wetlands may lie within a 16 km radius of a sunflower field at the above density of 0.88 wetlands/km^2. Under this scenario, the option of simply not planting sunflowers near blackbird roosts becomes a conundrum for the producer. Fortunately, an inverse relationship exists between the amount of damage incurred in a field and the distance it lies from wetlands. Otis and Kilburn (1988) found a strong relationship between the extent of bird damage and the number of wetlands within 810 m of sunflower fields. This relationship probably results from a combination of habitat preference for cattail-dominated wetlands, premigratory flocking behavior, and Optimal Foraging Theory's principle of maximizing nutrient gain while minimizing feeding costs (Orians and Pearson 1979, Pyke 1984).

Cattail management near sunflower may offer a cost-effective nonlethal method for reducing local cases of severe damage (Linz et al. 1995). However, to date we have no direct quantitative evidence that reduction in cattail densities actually lowers sunflower damage, either locally or regionally. The USDA's cattail management program has been a popular program among producers for over 10 years. This continued strong demand provides indirect evidence from the "marketplace" that perhaps cattail management may be helping to reduce bird damage (Homan et al. 2000). By splintering large roosts into smaller ones, it is possible that damage will become dispersed over a wider area. Cattail reduction may thus help fulfill our management objective of lowering the number of fields with damage >5% (Dolbeer 1990). High wetland densities and rapid colonization by cattail present obstacles to achieving this objective solely through cattail management, which has fairly high application costs.

The economic and bioenergetic analyses we have presented here provide a valuable baseline for defining the issue of blackbird damage and its impact on sunflower production. The model has provided a damage estimate falling within empirically derived estimates from field surveys, which indicates that the values we used may have some accuracy. Of course, it would be unreasonable to assume that there is not error in the model's variables and that they could not be improved upon. However, we believe the error in the models is probably small and thus provides more reliability than the field surveys with their large variances, a result of completely randomized designs being used to measure the localized distribution of sunflower damage. Because we are seeking to construct models that are both robust and broadly applicable for use by resource managers, our approach has been to stress generality and biological realism at some expense of precision (e.g., by pooling age classes). It is illogical to build complex and precise models based on imprecise data, even though this is often done. Our model is sufficiently flexible that other data inputs can be incorporated into it as they become known or better defined. Last, it is possible to adjust this model to make predictions at a more localized scale, similar to the approach used to predict corn damage near a large roost in Ohio (Wiens and Dyer 1975). Analyzing at localized scales requires new methods of data collection and the ability to predict and find the locations of large local roosts that are stable enough over time to conduct accurate population counts.

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