

Cholinesterase-Inhibiting Pesticides

LETHAL RISK TO BIRDS FROM INSECTICIDE USE IN THE UNITED STATES— A SPATIAL AND TEMPORAL ANALYSIS

PIERRE MINEAU* and MÉLANIE WHITESIDE

National Wildlife Research Centre, Canadian Wildlife Service, Carleton University Campus, Ottawa, Ontario K1A 0H3, Canada

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Abstract—We used pesticide use data and previously published models to estimate the lethal risk to birds from insecticides used in U.S. agriculture. Data from the U.S. Department of Agriculture's National Agricultural Statistical Service (NASS, Washington, D.C.) were used to assess how the lethal risk to birds has changed over the period 1991 to 2003 and to compare risk among crop types according to the most recently available surveys. Because the NASS data coverage is incomplete, both with respect to crop and state, we also used a database assembled by the National Center for Food and Agriculture Policy (NCFAP, Washington, D.C.) for the 1997 reference year, to which we added state-specific average application rates for crop/insecticide combinations. For each state/crop/insecticide combination (>6,000 entries), we assessed the proportion of crop area on which avian mortality was deemed probable, as well as the extended number of hectares this represented. The crops responsible for most potential bird mortality in the United States were corn and cotton, followed more distantly by alfalfa, wheat, potato, peanut, sugar beet, sorghum, tobacco, and citrus. Other crops represented a higher risk to birds on a per hectare basis. The southeast United States generally had the highest proportion of farmland with a lethal risk to birds. On a positive note, the lethal risk to birds has generally declined over the last decade in most crops, although there are exceptions such as small fruit crops. The reasons for this improvement vary from crop to crop, but usually entail the replacement of older more hazardous products with newer ones with lower acute toxicity to birds.

Keywords—Birds Agriculture Pesticides Lethal risk United States

INTRODUCTION

Most bird species associated with farmland are in decline in Europe as well as in North America. The exact reasons for these declines are complex and often species specific, but most declines can be related to features of industrialized modern agriculture. In the United Kingdom, the intensive use of pesticides, especially herbicides, has been shown to contribute to those declines [1]. The main mechanism is through indirect effects, notably the loss of cover and invertebrate biomass, leading to reduced feeding opportunities and reduced breeding success. Outright loss of birds as a result of acute toxicity is not considered a factor leading to population declines in the United Kingdom. However, that country has been much more proactive at removing or minimizing the use of those products shown to give rise to avian mortality [2]. In North America, regulatory authorities have been much slower at removing insecticides of high avian toxicity, even when it could be shown that these products were giving rise to frequent and largely unavoidable mortality [3]. Borg et al. [4] first cautioned that birds killed or debilitated by mercury seed dressings were merely the “tip of the iceberg.” For every bird detected, there are several that go undetected. Although pesticide bird kills have often been compiled, there has always been uncertainty and controversy about the extent to which those visible incidents represent unusual events, or rather the tip of the iceberg. According to a recent analysis of pesticide field studies [5],

many of the insecticides in current use in North America give rise to regular bird mortality in a measurable proportion of treated fields. The bulk of bird losses is diffuse and goes undetected, so the iceberg analogy is quite apt. Given the sheer scale of use of a popular pesticide in today's global village, the loss of even a few breeding songbirds per hectare can amount to a large yearly take from potentially the same population. Rough calculations for some of the more notorious chemicals have shown that the extended mortality from a popular product can be very extensive. For example, Mineau [6], on the basis of field studies, calculated that a granular formulation of carbofuran, at the height of its popularity, was conservatively taking an estimated 17 to 91 million birds annually from the U.S. Midwest corn belt alone.

Mineau [5] amassed a sample of 181 avian field studies meeting minimum criteria of acceptability for 35 cholinesterase-inhibiting insecticides applied as liquids to a number of crops or pasture. Studies were further divided into pesticide use categories/bird guild combinations that might be expected to result in different exposure values for equivalent application rates (e.g., insectivore/granivore species in field crops, insectivore/granivore species in orchards, grazing herbivores in field crops and pasture, etc.). For each field study, the presence of compound-related avian mortality was assessed. Logistic regression models were constructed to relate mortality to a number of predictor variables. Not surprisingly, the most important predictor was a variable combining application rate and toxicity. Toxicity was expressed as the hazardous dose (HD5), or the 5% tail of the species acute toxicity distribution curve corrected for body weight according to the methods described by Mineau and colleagues [7,8]. A second predictor variable

* To whom correspondence may be addressed (pierre.mineau@ec.gc.ca).

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was the estimated relative dermal toxicity of the pesticides to birds (a simple ratio of dermal to oral toxicity). This ratio in turn was approximated through an empirical model constructed from published data comparing the oral and dermal toxicity of a number of pesticides to a few bird species. Finally, a third (albeit weaker) predictor was Henry's law constant, largely on account of a few insecticides with high vapor pressure and, presumably, high inhalation exposure.

Here, we look at the toxicity of insecticides to birds over time and use those logistic models to assess the actual lethal risk to birds from insecticide use. We ask the following questions: Which crops carry the highest probability of mortality for birds that might frequent them? How has the risk to birds changed in recent years? How does the risk to birds vary geographically in the conterminous United States?

METHODS

Toxicity of insecticides to birds

As a component of the risk of pesticide poisoning in birds, we decided to first see how the acute toxicity of insecticides had changed over time. We restricted our analysis to insecticides (including nematocides and acaricides) because few herbicides or fungicides are of comparable toxicity. Several editions of *The Pesticide Manual* [9] and previous editions, published by the British Crop Protection Council, were consulted to find the year of market introduction for as many products as possible. Also, their toxicity to birds in the form of their HD5 was obtained from Mineau et al. [10]. The HD5 is the amount of pesticide (mg/kg body weight) estimated to lead to 50% mortality in a species more sensitive than 95% of all bird species, calculated with a 50% probability of over- or underestimation. The HD5 can be calculated mathematically where several toxicity values exist, or extrapolation factors can be applied to single or multiple combinations of species-specific toxicity values (see table 1 in Mineau et al. [10]). Because of the influence of body weight on sensitivity [7], computed HD5 values are adjusted to reflect the most sensitive of species ranging from 20 to 1,000 g in weight. Mineau and colleagues argue that the resulting value is the most unbiased and predictive measure of the toxicity of pesticides to birds at large.

Validation of the avian risk models

One weakness of the field-based risk models developed in Mineau [5] is that they were not validated against a set of independent data points. Too few studies were available to be able to split the sample into a training and validation set. Because we considered it unlikely that a sufficient number of new field studies would be available for this purpose any time soon, we used "leave one out cross validation" as an alternative strategy. For the principal data set of interest here (field studies looking at the risk of mortality for the insectivore/granivore guild in field crops), 88 separate logistic regression models were constructed, each with 87 data points. This allowed us to test independently the classification accuracy of the 88 field studies.

Pesticide use data for time trend analyses

Our main source of pesticide use information was the Agricultural Chemical Usage Surveys of the U.S. Department of Agriculture's National Agricultural Statistics Service (NASS). The NASS reports annually (1990–present) on major crops such as wheat, cotton, soybean, potato, and corn, and in al-

ternate years for selected fruit and vegetable crops (<http://www.pestmanagement.info/nass>). Data include the proportion of a crop's acreage that is treated with any given pesticide, the average one-time rate of application, and the average number of applications. It is important to note that the same states are not always represented in the sample, the latter being chosen to represent at least 75%, but typically more than 90%, of the national total area for the surveyed crop. We used a compilation (1991–2003) of NASS data provided by Benbrook Consulting Services (Sandpoint, ID, USA). For this compilation, original paper versions of annual reports were obtained from NASS, and more information was captured than available electronically. In addition, information on area planted, also obtained from original NASS reports (see <http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/>) was matched to the pesticide information.

Pesticide use data for crop-by-crop comparisons and geographical analyses

As mentioned previously, the NASS data do not provide a geographically complete survey of pesticide use. For example, pesticide use in corn (maize) was surveyed in 16 states only in 2003, whereas corn is grown in all 48 conterminous states. Even though many states have a relatively small area devoted to agriculture and are therefore never included in NASS surveys, we felt it was important to consider the risks to grassland bird species in those states also. In addition, some crops (including some of the crops most important to wildlife; e.g., alfalfa) are not covered by the surveys. Because of these limitations with NASS data, we used also a more comprehensive database assembled by the National Center for Food and Agriculture Policy (NCFAP) (<http://www.ncfap.org>). For years circa 1992 (1990–1993) and circa 1997 (1994–1998), NCFAP collated information relative to pesticide use in U.S. cropland from a variety of sources such as surveys (including the aforementioned NASS surveys, as well as statewide efforts), crop profiles, and expert opinions [11]. Only the data for the 1997 reference year were used here. To our knowledge, these efforts were unique in attempting to capture the totality of agricultural pesticide use in the United States. No more recent comparable survey exists, at least any available publicly. The NCFAP reported crop acreage and percentage of crop treated with a given active ingredient but, unfortunately, reported only the quantity of active ingredient applied annually per treated acre. To use the avian risk models described here, annual application rates had to be converted back to their component data—average one-time application rates and frequency of treatment. We recovered one-time application rates from either NASS, the California Department of Pesticide Regulation (<http://www.cdpr.ca.gov/docs/pur/purmain.htm>), or other sources cited by NCFAP (a number of cited reports are available free of charge on disk from NCFAP). Where the above sources of information were insufficient to determine average one-time application rates for the complete state–crop–insecticide matrix, we followed a set of rules that entailed the use of either the median or average rate of application determined from other states, other years, or, rarely, other crops. The detailed data manipulations, as well as the resulting database of insecticide use for the 1997 reference year, are available on the *Environmental Toxicology and Chemistry* website (SETAC Supplemental Data Archive, Item ETC-25-05-001; <http://etc.allenpress.com>). The only other alternative to these methods of deriving best estimates of average application rates would have been to use

maximum labeled rates for all applications—clearly overestimating avian risk. Our choice of application rate values, on the contrary, had the effect of pushing state–crop–insecticide application rates in the direction of the median application rate already documented for this particular pesticide/crop combination.

Formulation and application method issues

The risk models developed by Mineau [5] were based entirely on foliar applications of the various insecticides. However, some insecticides can be applied as alternate formulations (e.g., granulars), and even the liquid applications can be applied in different ways expected to alter the risk to birds (e.g., subsurface injection). Available pesticide use data do not distinguish between application types or formulations. Therefore, for the purpose of the analyses presented here, we were forced to ignore this potential source of error. Because of the attractiveness of granular formulations to birds, it is likely that the risk of a granular application is at least as high as that from an equivalent foliar application of the same insecticide.

Developing an index of lethal risk

The avian risk models provide an estimated probability that a given pesticide application will result in avian mortality, or at least enough mortality that it should be detectable through a careful search of the affected area, as was done in the sample of field or orchard studies that formed the basis of the models [5]. If for example, 100 farmers applied the same treatment and the treatment carried a 0.2 risk of mortality, then we would expect to find some level of bird mortality following 20 of those applications. By extension of this logic, if the combined treatment area was 1,000 ha, we would expect to find avian mortality on some of 200 ha on average. We defined this area as the number of “bird kill hectares.” This derived measure of risk allows us to combine, through summation, the risk of different applications either on the same or different acreages. The overall number of bird kill hectares can then be expressed as a proportion of the total crop area to compare the relative risk of different crops to birds; it can be expressed as a proportion of total farmland, or it can be left as is to rank the magnitude of the bird risk, taking into account actual crop acreages.

Validating the use of a state-averaged rate of application in the risk models

The logistic regression models developed by Mineau [5] estimate the likelihood of avian mortality on the basis of the toxicity and physicochemical characteristics of each pesticide and a precise application rate. Because of the variation in application rates often encountered for a given insecticide, the lethal risk to birds should be ideally assessed on a field-by-field basis. Such an approach is only possible in one U.S. jurisdiction: California. Since 1990, the California Department of Pesticide Regulation (DPR) has required full pesticide use reporting (<http://www.cdpr.ca.gov/docs/pur/purmain.htm>). Every single application of a pesticide active ingredient applied by either a commercial applicator or a farmer has to be reported and situated to the nearest square mile. For 1997, we compared our avian risk estimates when risk was calculated independently for each single pesticide application and then summed for the entire area to the risk estimate calculated on the basis of an average one-time rate of application for each crop/pesticide combination. We extracted from the DPR database over

17,000 insecticide use records, comprising an extended treated crop area of 350,000 ha from the Central Valley of California. Treatments represented 58 different crops and 83 different insecticides. Therefore, avian risk models were run for the 17,000 records separately or for each unique crop/pesticide entry and the results compared.

RESULTS

Toxicity of insecticides to birds over time

Figure 1a, b, and c show the toxicity of insecticides to birds against the year of product introduction into the marketplace. It is clear that most of the insecticides of extreme high acute toxicity to birds (e.g., those with HD5 values <1 mg/kg body wt) were cholinesterase inhibitors (Fig. 1a). The average toxicity of cholinesterase inhibitors has had no apparent reduction over time, leading one to conclude that the gradual introduction of products of lower acute toxicity to mammals (e.g., diazinon replacing many older uses of ethyl parathion) did not benefit birds to any significant extent. Only the advent of alternative chemistry (such as the synthetic pyrethroids) resulted in the introduction of products of reduced acute toxicity to birds (Fig. 1b). On the basis of our experience with the risk models reviewed above and for the benefit of this paper, we will define products with HD5 values higher than 100 mg/kg as products of negligible risk. The models do not usually predict any avian mortality with these pesticides, regardless of the exact application rate or the physicochemical characteristics of the product. It is clear from Figure 1b that negligible-risk products were made available in increasing numbers from the mid-1970s onward. By the 1990s (the period covered by analyses presented here), many negligible-risk products were available for use. Overall then, there has been a net reduction in the average acute toxicity of insecticides over time (Fig. 1c). This trend has notable exceptions. One such exception (chlorfenapyr) is indicated in Figure 1c. This insecticide was denied registration in the United States largely because of its avian toxicity (<http://www.epa.gov/opprd001/chlorfenapyr/chlorfenapyr.pdf>), although it has been registered in a number of countries already.

Validation of the avian risk models

Overall classification success for the 88 field studies was 81%, with a higher proportion of false positives than false negatives (Table 1), which was expected given that mortality could have easily been overlooked in some of the field studies that were used to construct the model.

Validating the use of a state-averaged rate of application in the risk models

For the Central Valley of California, the computed area over which birds were deemed to be at lethal risk was almost identical, whether based on a state average application rate for each crop/insecticide combination or based on the exact application rates specified for each insecticide application. The number of bird kill hectares was 58,425 ha with the use of average application rates for each crop/insecticide combination versus 58,176 ha—or a difference of 0.4%—when risk was calculated separately for each of the 17,000+ applications. This comparison gives us confidence that the pesticide-specific estimates of risk derived from insecticide-specific state-averaged application rates are a reasonable proxy for a more rigorous field-by-field assessment.

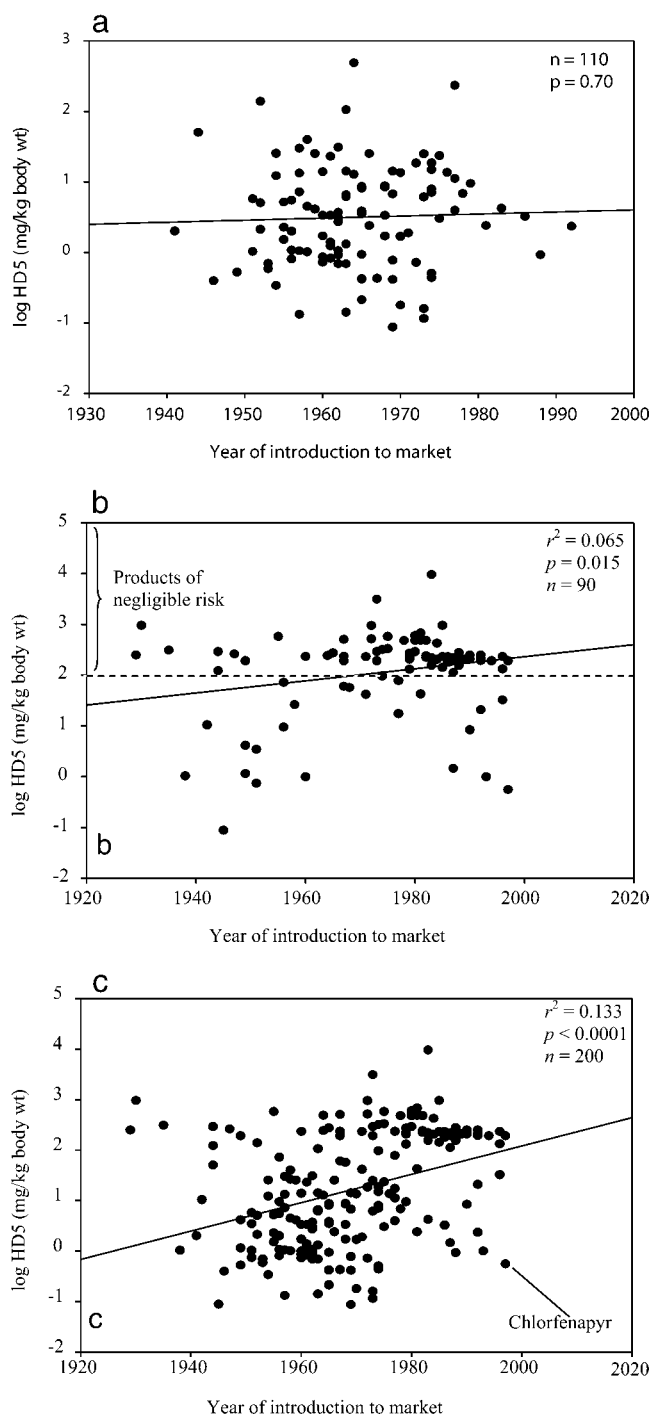


Fig. 1. Plot of the avian hazardous dose (HD5) (LD50—or the dose predicted to cause mortality in half of the individuals tested—for birds calculated to be at the 5% sensitivity tail of the species distribution) against the year of introduction in the marketplace according to several editions of *The Pesticide Manual* [9] for (a) cholinesterase-inhibiting insecticides and acaricides, (b) noninhibitors, and (c) all insecticides and acaricides combined. Map of the United States; abbreviations indicate zip code letter abbreviations for the states.

Time trends

By and large, time trends between 1991 and 2003 show a decreasing risk of lethality for birds. Representative crops are illustrated in Figure 2. Corn and cotton, potentially the two most important contributors to farmland bird mortality, both showed a net reduction in risk over time. An in-depth ex-

Table 1. Validation of the field crop and pasture model developed by Mineau [5] with the “leave one out cross validation” strategy for 88 separate pesticide field studies. The 0 indicates that no avian mortality was either predicted or observed. The 1 indicates predicted or observed avian mortality in the sample of field studies

Predicted	Observed		Total	Classification accuracy (%)
	0	1		
0	42	8	50	84
1	9	29	38	76
Total	51	37	88	81

amination of the NASS data reveals that, for corn, the proportion of the crop treated with insecticides of negligible risk increased sixfold from 1991 to 2003. Contrary to expectation, the NASS data did not indicate a decreased reliance on insecticides, as might have been expected with the introduction of transgenic Bt corn (containing a gene for the expression of *Bacillus thuringiensis* toxin). The proportion of the cotton acreage treated with negligible-risk products also increased, but not as dramatically. It appears that the main driver behind risk reduction in cotton has been the reduction in the proportion of the crop that is treated with any insecticide from 1995 onward. This is likely a direct result of the introduction of Bt cotton in the same year (<http://www.ers.usda.gov/data/biotechcrops/>). It is important, however, to note that the risk to birds is still high in cotton (i.e., currently over 40% of the total crop area) and that much more effort is needed to make this crop more bird friendly given its large spatial footprint.

The risk in vegetable crops (the summation of beans, peas, cole crops, celery, carrots, cucurbits, the potato family, lettuce, spinach, and onions) dropped from approximately 5 to 1% of the crop area over the period 1991 to 2003. The trends for most crops within that cluster were consistent, with the exception of asparagus, which showed a clear increase in risk over time, and spinach and bulb onions, which did not show any convincing trend either way (data not shown). Again, detailed examination of the data indicates that the overall improvement in vegetable crops is not a result of reduced pesticide use but, rather, a shift to products of negligible risk. For example, the proportion of the vegetable crop area treated with negligible-risk products has increased more than threefold between 1992 and 2002. For asparagus, even though negligible-risk products were also used on an increasing proportion of the acreage, the increasing use of a few insecticides of high acute toxicity to birds such as disulfoton and chlorpyrifos nullified these potential gains. At the rates of application used, the risk of mortality following an application can reach upward of 75 and 65% for these two pesticides, respectively.

Cereal crops, including wheat, rice, and sorghum, did not show much of a trend; but rather showed a high degree of year-to-year variability, most probably a result of irruptive pest problems (data not shown). The risk in rice (data not shown) remained stable and high at roughly 10% of the cultivated crop.

Of all the orchard crops, citrus showed the most evident decrease in bird risk over time. Apple, pear, and stone fruit crops also showed a decreasing risk to birds over time, but improvements came in the early 1990s, with no noticeable change since (data not shown). These improvements appear to be a result of the early removal of such acutely toxic insecticides as ethyl parathion and phosphamidon. For all these

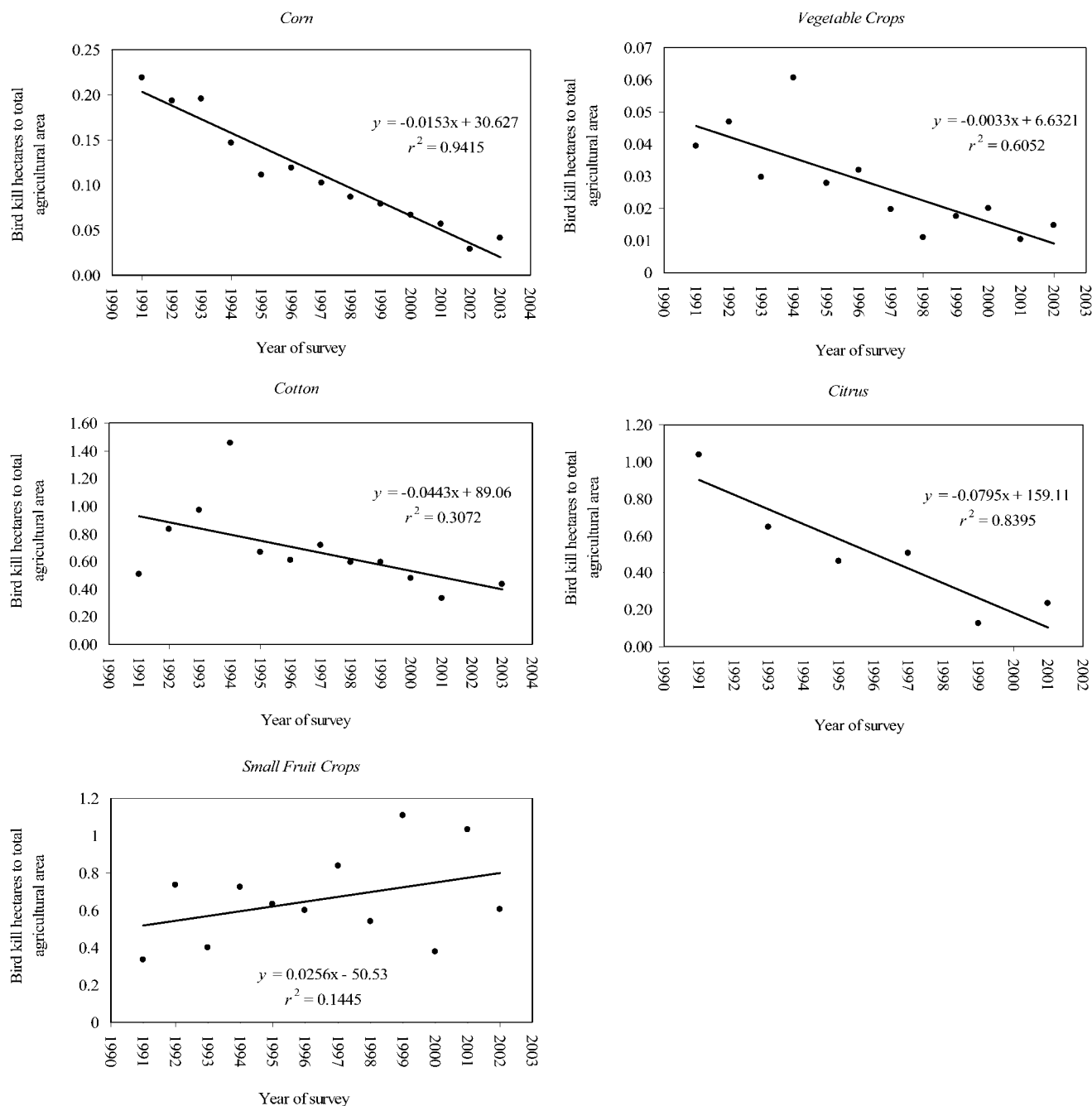


Fig. 2. Time trends in avian risk for main crops or crop clusters (corn, cotton, vegetable, citrus and small fruit crops) from data of the U.S. Department of Agriculture's National Agricultural Statistical Service (Washington, DC). Regression equations and r^2 values are provided where appropriate.

orchard crops, the risk to birds still is considered to be high—over 20% of the crop area for citrus and plums but between 50 and 170% of the crop area for the others. It should be noted, however, that the risk models developed for orchard crops [5] are not as robust as for field crops because of a much reduced sample of field studies available for modeling. Grapes (wine and table combined) showed a marked improvement, with the area of bird kill dropping from approximately half of the crop area in 1991 to approximately 5% of the crop area in 2001; but again, the main improvement was recorded between 1991 and 1993, with little gain since (data not shown).

A notable exception to the generally improving situation

over the last decade is the small fruit crops. Treatments on strawberries show a reduction in bird risk, but the other crops in the group (raspberry, blackberry, and blueberry) all show an increasing risk. Most of the increasing lethal risk to birds appears to be a result of an increasing intensity of treatment on blueberries; the proportion of the area that was treated with negligible-risk products actually dropped by half. Over the last decade, there has been a net increase in the use of products that carry a significant risk to birds, such as phosmet, diazinon, and azinphos-methyl. Given the attraction of small fruits to birds, this is an issue worthy of further investigation.

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Crop-by-crop and geographical variation in avian risk

The NCFAP included in its database 87 main crop types (this includes pasture, sod, and other uses that are not crops in the strict sense of the word). An updated data matrix for the 1997 reference year includes the 48 conterminous states and 67 separate insecticides. More recent information (post-2000) from NASS allows for a risk ranking of 50 of those crops for a much more restricted number of states. Table 2 lists the relative risk of crops to birds both on the basis of the complete 1997 matrix and the more recent NASS data. Risk can be assessed independent of total crop area or as the cumulative number of hectares over which there was risk of mortality. For example, on the basis of the 1997 complete data matrix, Brussels sprout represented the highest risk to birds on a per hectare basis. Indeed, because of repeat insecticide applications, the area of Brussels sprout showing a lethal risk to birds was more than four times the total crop area. However, because Brussels sprout was a very minor crop grown in a single state, they only ranked 60 out of 87 in terms of cumulated bird kill area. Celery, cranberry, cabbage, potato, sweet potato, and sweet and hot peppers were other crops with risk areas that exceeded planted areas in 1997. Several of these crops are not routinely surveyed by NASS, so it is not possible to see how this relative risk ranking has changed over time. On the basis of the NASS data, however, Brussels sprout, peach, and blueberry were crops in which the area at risk still exceeded the planted acreage when last surveyed.

However, in terms of overall probable effect on birds, by virtue of both the risk per hectare and the total planted area in the United States in 1997, the 10 crops of most concern in descending order were: corn, cotton, alfalfa, wheat, potato, peanut, sugar beet, sorghum, tobacco, and citrus. A look at the more recent NASS data would still place all of these, with the exception of sorghum, in the worst 10 crops. Rice, apple, soybean, and sweet corn would complete a more recent list of the 10 crops with the highest cumulated risk to birds. What is missing from this analysis is the extent to which the various crops are used by birds. Intuitively, the very high risk associated with alfalfa and wheat is of great concern, because these crops are well known to be heavily frequented by many bird species. Most bird mortality is associated with field edges, however; therefore, even the most inhospitable crop for birds could have a lot of avian mortality associated with it. This is the case with cotton, for example, where a large number of species have been found dead in association with toxic organophosphorus pesticides (<http://www.epa.gov/scipoly/sap/1999/july/finlrpt3.pdf>, p. 83). Field crops grown on large surfaces typically have less edge-to-surface ratio that could alter the relative risk ranking of different crops. Also, there is no information on when the insecticides were applied. Although it is reasonable to expect that most insecticide use is in the summer growing season, winter applications in the southern states have the potential to be extremely damaging because of the presence of large numbers of wintering or staging migrants.

Table 2 provides yet more information as to where attempts to make crops more bird friendly are most likely to be successful. By comparing the range of state-wide ratios of bird kill area to total crop area, it is possible to gauge whether the lethal risk to birds could be brought down. Of course, it is possible that states with a particularly high bird risk for a given crop are subject to a particularly problematic pest issue; on the other hand, the higher risk rating might simply reflect a poor choice of available insecticides.

We need to turn to the NCFAP 1997 data once again to visualize the complete extent of avian risk in the conterminous United States. The cumulated number of bird kill hectares per state as a proportion of the total cropland, pasture, and fallow area is shown in Figure 3. The risk to a grassland bird species is highest in the southeast—the Carolinas, Georgia, Mississippi, and Louisiana—as well as Massachusetts. In those states, we estimate that between 20 and 50% of the total extended agricultural area presents a lethal risk to birds. The risk drops to 15 to 20% for California. States showing the least risk to birds are predictably the Central Mountain and Great Basin states, where pasture predominates.

DISCUSSION

Overall, there has been a net reduction in the average avian acute toxicity of insecticides over time, and the analyses carried out for this paper confirm that most of our current problems with high acute risks to birds in farmland stem from our failure to remove in a timely fashion old dangerous products from the market. Available agricultural pesticide use statistics, coupled with empirically derived field-based avian risk models, suggest that the lethal risk to birds in our farmland has been generally decreasing over the last decade, with a few notable exceptions, such as at least one vegetable crop (asparagus) and small fruit crops (especially blueberry). Geographically, the risk appears highest in the southeastern United States. This is an area heavily used by birds as a breeding, stopover, and wintering area. We were unable to distinguish between seasons to separate the risk to breeders and migrants. Historically, one of the largest kills recorded in the United States was from treatment of a few Florida, USA, potato fields that killed more than 10,000 wintering American robins [12,13], so the use of toxic insecticides at a time when wintering migrants are present needs to be assessed carefully. Massachusetts also stands out because of the high proportion of its farmland with lethal risk to birds. This appears to be largely driven by the large acreage of cranberry treated with diazinon, an organophosphorus insecticide of extreme toxicity to birds.

Exploratory analyses of the data suggest that, with the possible exception of cotton, improvements in the overall risk picture over the last decade have not stemmed from a reduced dependency on insecticide use, but rather from a replacement of the more toxic insecticides, largely organophosphorus and carbamate products with insecticides of novel chemistry and reduced toxicity. These changes have been a long time in coming [3], but they are certainly welcome. There is increasing evidence that mortality of birds resulting from the use of highly toxic insecticides has been contributing to farmland bird declines in North America. Beyond the sheer number of birds calculated to be killed (e.g., [6]), emerging analyses link acute toxicity to regional population declines. For example, Mineau et al. [14] linked the reduced abundance or declining trends on the Canadian prairies of such common agricultural species as horned lark (*Eremophila alpestris*), house sparrow (*Passer domesticus*), western meadowlark (*Sturnella neglecta*), American robin (*Turdus migratorius*), and mourning dove (*Zenaidura macroura*) to the use of toxic granular insecticides (carbofuran and terbufos) applied at seeding in canola (edible oilseed rape). Analysis of the state-by-state risk indices calculated here suggests that these indices provide a better correlate of state-wide agricultural species declines than do other measures of agricultural intensification (P. Mineau, unpublished data). Most

Table 2. Crop-by-crop comparison of the lethal risk to birds on the basis either of pesticide use data from the National Center for Food and Agriculture Policy (NCFAP) for the 1997 reference year or on more recent data from the U.S. Department of Agriculture's National Agricultural Statistical Service (NASS). The crops are ranked by the cumulative area over which avian mortality is deemed to have occurred on the basis of the NCFAP survey. For both datasets, the minimum (min) and maximum (max) state-wide proportion of the crop area deemed to be at risk of suffering avian mortality is given, as well as the state average weighted by the crop acreage for each state

Crop	NCFAP (years circa 1997)					NASS (most recent of 2000–2003) ^a					
	No. of states in the database	Ratio of bird kill area		Cumulative bird kill hectares	Rank	No. of states surveyed	Year of survey	Ratio of bird kill area		Cumulative bird kill hectares	Rank
		Range	Weighted average					Range	Weighted average		
Corn	48	0.006–0.840	0.190	5,820,058	1	16	2003	0.000–0.229	0.045	1,221,863	2
Cotton	16	0.319–3.203	0.939	5,024,835	2	12	2003	0.084–1.498	0.435	2,250,435	1
Alfalfa	47	0.005–0.574	0.089	764,137	3	NA	NA	NA	NA	NA	NA
Wheat	42	0.000–0.105	0.035	701,088	4	3	2002	0.000–0.048	0.019	112,311	7
Potato	44	0.000–2.519	1.241	679,466	5	10	2003	0.003–1.591	0.637	263,808	4
Peanut	9	0.246–1.596	0.960	522,874	6	NA	NA	NA	NA	NA	NA
Sugar beet	12	0.014–1.397	0.734	425,892	7	9	2000	0.147–0.850	0.642	349,810	3
Sorghum	22	<0.001–0.259	0.084	300,479	8	1	2003	0.023–0.023	0.023	6,027	26
Tobacco	16	0.078–1.728	0.826	280,179	9	NA	NA	NA	NA	NA	NA
Citrus	4	0.001–1.146	0.485	263,815	10	2	2001	0.116–0.297	0.233	110,517	8
Rice	6	0.042–0.544	0.208	262,049	11	4	2000	0.000–0.897	0.193	115,097	6
Apple	35	0.000–6.945	0.898	204,770	12	8	2001	0.096–4.312	0.684	93,487	10
Soybean	31	0.000–0.228	0.021	161,344	13	8	2002	0.000–0.483	0.019	189,426	5
Lettuce	12	0.008–1.327	0.989	122,868	14	2	2002	0.274–0.725	0.615	72,417	12
Tomato	30	0.000–2.480	0.716	120,846	15	5	2002	0.000–2.092	0.185	29,493	15
Sweet corn	38	0.002–2.269	0.392	113,203	16	12	2002	0.000–1.636	0.256	96,289	9
Grape	19	0.003–2.146	0.252	102,033	17	5	2001	0.003–0.721	0.042	19,974	16
Sugarcane	3	0.000–0.241	0.227	81,237	18	NA	NA	NA	NA	NA	NA
Sunflower	9	0.015–0.737	0.072	73,320	19	NA	NA	NA	NA	NA	NA
Almond	1	0.328–0.328	0.328	71,801	20	NA	NA	NA	NA	NA	NA
Green bean	28	0.006–1.574	0.459	58,845	21	9	2002	0.000–0.460	0.156	15,216	21
Barley	30	0.000–0.086	0.031	57,515	22	2	2003	0.000–0.005	0.003	372	42
Onion	17	0.000–2.921	0.809	53,686	23	6	2002	0.253–1.502	0.694	35,541	13
Broccoli	12	0.000–2.026	0.850	48,200	24	1	2002	0.719–0.719	0.719	33,464	14
Peach	25	0.067–2.793	0.651	45,556	25	5	2001	0.622–6.445	1.783	86,219	11
Pecan	13	0.000–0.395	0.200	41,136	26	NA	NA	NA	NA	NA	NA
Cabbage	22	0.000–4.533	1.304	40,892	27	9	2002	0.000–0.419	0.181	5,062	29
Sweet potato	14	0.280–2.921	1.168	36,387	28	NA	NA	NA	NA	NA	NA
Dry bean	17	0.000–0.304	0.057	36,298	29	NA	NA	NA	NA	NA	NA
Plum/prune	6	0.001–0.592	0.577	35,957	30	1	2001	0.236–0.236	0.236	13,376	22
Walnut	2	0.140–0.363	0.361	34,216	31	NA	NA	NA	NA	NA	NA
Mint	9	0.000–1.155	0.472	31,845	32	NA	NA	NA	NA	NA	NA
Celery	3	0.979–2.776	2.393	30,791	33	1	2002	0.328–0.328	0.328	3,386	31
Cranberry	5	0.681–2.575	2.119	30,086	34	NA	NA	NA	NA	NA	NA
Dry pea	5	0.095–0.722	0.297	28,019	35	NA	NA	NA	NA	NA	NA
Sweet pepper	21	0.017–2.338	1.146	27,284	36	4	2002	0.009–1.375	0.581	11,278	24
Seed crops	21	0.045–0.108	0.101	24,717	37	NA	NA	NA	NA	NA	NA
Asparagus	9	0.000–1.154	0.767	23,356	38	3	2002	0.327–0.724	0.613	17,493	18
Cherry	11	0.090–0.623	0.412	19,848	39	5	2001	0.082–1.825	0.461	17,337	19
Blueberry	13	0.019–2.633	0.699	17,758	40	4	2001	0.303–2.238	1.433	18,675	17
Watermelon	20	0.007–0.735	0.258	17,717	41	5	2002	0.000–0.154	0.084	3,649	30
Cucumber	23	0.000–1.089	0.314	17,001	42	6	2002	0.000–0.526	0.070	2,761	34
Squash	24	0.000–1.429	0.694	16,869	43	6	2002	0.000–0.666	0.285	5,130	28

Table 2. Continued.

Crop	NCFAP (years circa 1997)					NASS (most recent of 2000–2003) ^a					
	No. of states in the database	Ratio of bird kill area		Cumulative bird kill hectares	Rank	No. of states surveyed	Year of survey	Ratio of bird kill area		Cumulative bird kill hectares	Rank
		Range	Weighted average					Range	Weighted average		
Strawberry	26	0.205–2.070	0.782	16,551	44	3	2002	0.210–0.667	0.605	9,528	25
Cauliflower	7	0.066–4.727	0.885	16,338	45	1	2002	0.394–0.394	0.394	5,905	27
Cantaloupe	16	0.057–1.289	0.397	16,228	46	4	2002	0.053–0.203	0.072	2,380	36
Pear	8	0.242–1.789	0.524	15,896	47	3	2001	0.336–0.707	0.501	12,339	23
Safflower	2	0.291–0.291	0.291	15,886	48	NA	NA	NA	NA	NA	NA
Green pea	23	0.000–0.658	0.143	14,774	49	4	2002	0.000–0.034	0.008	588	40
Nectarine	1	0.899–0.899	0.899	14,706	50	1	2001	0.946–0.946	0.946	15,882	20
Hot pepper	4	0.010–1.384	1.000	13,224	51	NA	NA	NA	NA	NA	NA
Carrot	13	0.000–1.107	0.185	9,988	52	4	2002	0.000–0.941	0.032	1,143	39
Pistachio	1	0.243–0.243	0.243	8,969	53	NA	NA	NA	NA	NA	NA
Apricot	1	0.779–0.779	0.779	7,397	54	1	2001	0.208–0.208	0.208	1,598	38
Melon	3	0.116–1.061	0.475	7,130	55	5	2002	0.000–0.154	0.086	2,936	32
Hops	3	0.296–1.057	0.391	6,962	56	NA	NA	NA	NA	NA	NA
Spinach	10	0.000–2.654	0.453	6,579	57	2	2002	0.000–0.241	0.214	1,953	37
Pumpkin	20	0.000–0.704	0.258	5,892	58	3	2002	0.000–0.049	0.013	120	45
Canola	8	0.025–0.380	0.033	5,479	59	NA	NA	NA	NA	NA	NA
Brussels sprout	1	4.084–4.084	4.084	5,264	60	1	2000	2.383–2.383	2.383	2,797	33
Raspberry	6	0.027–1.011	0.679	4,208	61	2	2001	0.365–0.494	0.457	2,477	35
Artichoke	1	0.883–0.883	0.883	3,816	62	1	2000	0.000–0.000	0.000	0	47
Sod	23	0.001–0.052	0.050	3,051	63	NA	NA	NA	NA	NA	NA
Radish	7	0.002–1.230	0.351	2,945	64	NA	NA	NA	NA	NA	NA
Oat	37	0.000–0.034	0.005	1,940	65	NA	NA	NA	NA	NA	NA
Eggplant	3	0.471–0.867	0.567	1,148	66	2	2000	0.076–0.215	0.172	181	44
Green onion	2	0.214–0.272	0.233	860	67	NA	NA	NA	NA	NA	NA
Collard	9	0.000–0.512	0.160	752	68	5	2000	0.000–0.62	0.033	188	43
Blackberry	2	0.200–0.503	0.227	516	69	1	2001	0.175–0.175	0.175	437	41
Other hay	33	0.000–<0.001	<0.001	344	70	NA	NA	NA	NA	NA	NA
Beet	6	0.003–0.505	0.134	304	71	NA	NA	NA	NA	NA	NA
Kiwi	1	0.111–0.111	0.111	263	72	NA	NA	NA	NA	NA	NA
Parsley	1	0.099–0.099	0.099	123	73	NA	NA	NA	NA	NA	NA
Olive	1	0.002–0.002	0.002	23	74	1	2001	0.000–0.000	0.000	0	47
Garlic	3	0.000–<0.001	<0.001	4	75	NA	NA	NA	NA	NA	NA
Okra	3	0.001–0.001	0.001	1	76	4	2000	0.000–0.071	0.015	20	46
Avocado	2	0.000–0.000	0.000	0	77	1	2001	0.000–0.000	0.000	0	47
Date	1	0.000–0.000	0.000	0	77	1	2001	0.000–0.000	0.000	0	47
Fallow land	46	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Fig	1	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Flax	3	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Hazelnut	1	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Millet	5	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Pasture	48	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Pomegranate	1	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Rye	15	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA
Wild rice	2	0.000–0.000	0.000	0	77	NA	NA	NA	NA	NA	NA

^a NA = this crop was not surveyed by NASS for pesticide use.

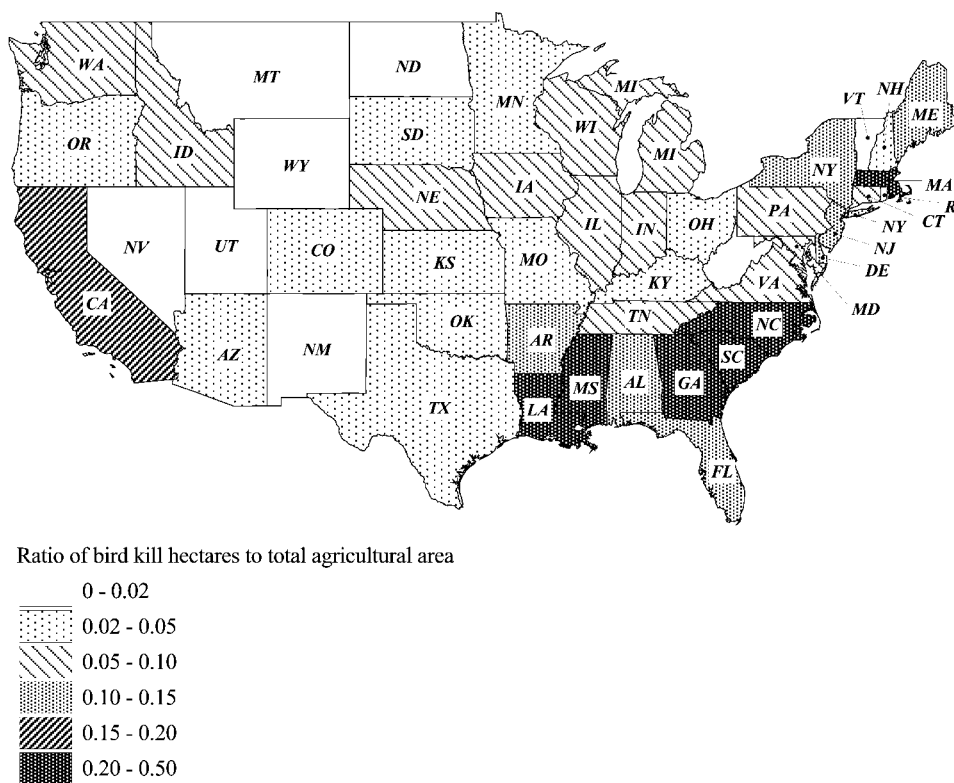


Fig. 3. A map of the state-by-state (United States) risk of bird lethality for the 1997 reference year. This is based on the proportion of total farmland (including fallow and pasture) over which avian mortality is expected once the risk from all insecticide treatments has been summed for that state.

importantly, the analyses presented here can be applied to any regional scale provided the pesticide use data are available. This allows for an objective assessment of the acute risk to birds at the local level and provides the means to identify possible risk reduction measures. Of course, the lethal effect of toxic insecticides on birds will be dependent on a host of biotic and abiotic factors unrelated to the pesticide itself. At smaller regional scales, some of these factors could moderate or confound predicted effects.

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