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ARTICLES

Field Deaths in Plant Agriculture

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Abstract
We know that animals are harmed in plant production. Unfortunately, though, we know very little about the scale of the problem. This matters for two reasons. First, we can't decide how many resources to devote to the problem without a better sense of its scope. Second, this information shortage throws a wrench in arguments for veganism, since it's always possible that a diet that contains animal products is complicit in fewer deaths than a diet that avoids them. In this paper, then, we have two aims: first, we want to collect and analyze all the available information about animal death associated with plant agriculture; second, we try to show just how difficult it's to come up with a plausible estimate of how many animals are killed by plant agriculture, and not just because of a lack of empirical information. Additionally, we show that there are significant philosophical questions associated with interpreting the available data—questions such that different answers generate dramatically different estimates of the scope of the problem. Finally, we document current trends in plant agriculture that cause little or no collateral harm to animals, trends which suggest that field animal deaths are a historically contingent problem that in future may be reduced or eliminated altogether.

Keywords Field animals · Plant agriculture · New omnivorism · Steven Davis · Mike Archer

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Introduction

There are familiar arguments for thinking that animals matter morally. And if they matter, then it's important to know just how humans affect them, including the scope of any harm we cause. In agricultural contexts, estimates of the total harm to animals tend to focus on *animal* agriculture. But we know that animals are harmed in plant production too: field mice are crushed by tractors, birds' nests are destroyed by combines, and fish are poisoned by fertilizer runoff. Unfortunately, though, while reasonably good numbers are available for the harms associated with animal agriculture (for terrestrial animals, see the USDA's most recent statistics, available on the web[1]; for fish, see Elder and Fischer 2017), we know very little about the scale of the problem in plant production.

This matters for two reasons. First, if we want to reduce this harm, but we have various other important problems to which to devote our resources, then we need more information to decide what deserves our attention. That is, if we want to engage in cause prioritization, the standard effective altruist framework says that we ought to consider three things: the scope of the problem, its tractability and the degree to which it's neglected. As we'll argue below, the harms to animals in plant agriculture are fairly tractable (there are some straightforward strategies to minimize the relevant harms, and farmers may well adopt some of them for independent reasons), and the problem is certainly neglected (as far as we know, there is no animal advocacy organization that has taken up this issue). But if the problem is relatively small when compared to the other causes that merit our attention, it may still be unwise—and perhaps even immoral—to focus on it when more pressing issues are on the horizon.

Second, this information shortage could throw a wrench in arguments for veganism.[2] If significant numbers of animals die in the cultivation of vegan food, then so much for the seemingly obvious link between animal protection and animal-free diets. Depending on exactly how many mice and other field animals are killed by threshers, harvesters and other aspects of crop cultivation, traditional veganism could potentially be implicated in more animal deaths than a diet that contains free-range beef and other carefully chosen meats. The animal ethics literature now contains numerous arguments for the view that meat-eating isn't only permitted, but *entailed* by philosophies of animal protection.[3] Such arguments endorse diets that we can collectively term *the new omnivorism*. New omnivore proposals differ in the particular types of meat-eating they defend and the rationales that they offer, but common to many is that they cite the harms done to animals in plant agriculture to make their case.[4]

[1] https://www.ers.usda.gov/topics/animal-products/.

[2] Singer (1975), Regan (1983), McMahan (2002), Cochrane (2012).

[3] Protection-based arguments for meat-eating not only flourish in the philosophical literature (Davis 2003; Schedler 2005; Meyers 2013; Bruckner 2015), but have been promulgated in *The New York Times* and other notable media outlets (Pollan 2002; Corliss 2002).

[4] For a discussion of new omnivorism, see Lamey (forthcoming).

Our goal isn't to settle the debates just mentioned; that project would take more space than we have here. Moreover, we should acknowledge at the outset that it's all but impossible to offer a meaningful estimate of all harms associated with plant agriculture, at least if a "harm" is understood as any way in which a being's welfare is negatively affected. Insofar as there are data, they are almost entirely about mortality. So, we have three relatively modest aims here: first, to collect and assess the available empirical claims about animal death associated with plant agriculture; second, to show just how difficult it's to come up with a plausible estimate of how many animals are killed by plant agriculture, and not just because of a lack of empirical information (though that's indeed a problem). Additionally, we show that there are significant philosophical questions associated with interpreting the available data—questions such that different answers generate dramatically different estimates of the scope of the problem. Among the many choice points here, there are questions about the appropriate metric for comparing the fatality rates in different agricultural systems, whether to include animals killed by nonhuman predators and whether unintended deaths are morally equivalent to intended ones. Finally, we point to many existing agricultural practices that cause minimal harm to field animals, and which might be further developed so as to reduce—or even eliminate—collateral damage to animals in plant and crop cultivation altogether.

The plan is as follows. In the next section, we pull together all the evidence that's been used to generate estimates of field animal deaths, and we add a number of sources that have been overlooked. Then, in the section after that, we provide empirical reasons to be skeptical about the estimate that all this evidence suggests. Next, we point out the various philosophical choice points in interpreting this evidence, where certain answers will reduce the estimate even further. Finally, we canvass some ways to make plant agriculture more animal-friendly.

Deaths in Plant Agriculture: A First Pass

To date, Steven Davis and Michael Archer have offered the most extensive empirical information about animal deaths in plant agriculture—which, as will soon become apparent, isn't saying much. Davis (2003) estimates that the various forms of plant agriculture kill, on average, 15 field animals per hectare per year. He reaches that number by averaging the mortality rates of two studies: one on mouse deaths during the harvesting of grain (Tew and Macdonald 1993), and the other on rat deaths during the harvest of sugarcane (Nass et al. 1971). The estimated mortality rate in the former study was 52%, and in the latter, 77%. Davis assumed a per-hectare population of 25 animals, as found in Tew and Macdonald's study, and an average mortality rate of 60%, which works out to 15 deaths per hectare.

Archer (2011a, b) offers a higher estimate. Based on data from Australian farms, he estimates that at least 100 mice are killed per hectare per year to grow grain there.[5] However, these deaths were not from tractors, but from poisons. Australian

[5] Singleton et al. note that while mouse plagues have been reported in China they occur primarily in Australia, particularly south and eastern Australia, and are rare in Western Australia and Tasmania (2005:

farms are periodically overrun by mouse plagues, and farmers use rodenticides that kill about 80% of the mice present to avoid excessive losses to the relevant commodity. As Archer (2011a) writes:

> Each area of grain production in eastern Australia is subject on average to a mouse plague every four years (Singleton et al. 2005; Caughley et al. 1998). Mouse numbers rise to at least 500–1000/ha or more during these plagues (Singleton et al. 2005). Poisons used to control these plagues kill at least 80% of the mice present (Caughley et al. 1998).

Archer employs the formula of 500/4 * 0.8 to arrive at his estimate of 100 mouse deaths per hectare of grain.

What should we say about this variation? And is Archer's estimate relevant to US farms? To begin, and as Lawrence Cahoone (2009, 81) notes, Davis's 15-deaths-per-hectare estimate is based on "the number of *one* species of rodent killed by *one* machinery pass over the fields, ignoring all other species and machinery passages, e.g. ploughing, harrowing, cultivating, planting, fertilising, etc." In other words, perhaps it's implausible that there are only 25 animals per hectare on US farms, and likewise that the *annual* death rate is only 60%; that may only be the rate for one instance of a particular activity. After all, many of the relevant animals reproduce rapidly: field mice, for example, have three to four litters per year, each of four to six young, and they're hardly exceptional. Jacob (2003) found common voles in bean and wheat fields at densities ranging from 90 individuals per hectare to 362 per hectare, depending on the crop and season. (Moreover, he found that disk plowing at the end of the season seemed to reduce the population by 75%, while other farming activities—such as mulching, harvesting, and mowing—had smaller but still significant effects on population density.) This high birth rate means that plagues of rodents are common in many agricultural contexts. Voles, for instance, go through population cycles every three to 6 years, and Fagerstone and Ramey (1996) report that they can reach densities of 7400 per hectare in peak years. Finally, we should note there is going to be variation by species. Surely some species will fare better, but others will fare worse: Bollinger et al. (1990), for example, found a 94% mortality rate among bobolink—a small North American blackbird—after mowing hay fields. The upshot: Davis may have lowballed both the number of animals per hectare and the annual death rate, so the variation may not be as significant as it first appears to be; and although we can't extrapolate directly from Archer's estimate due to geographic differences, it's possible that the average annual mortality rate is similar in US contexts, albeit for different reasons.

The case for a higher estimate is bolstered, if only slightly, by two other sources of animal death in agriculture for which there's data: first, avian deaths due to pesticides; second, fish kills due to pesticide and fertilizer runoff. Calvert et al.

Footnote 5 continued
619–20). According to the Australian Government, "The majority of Australian wheat is sold overseas with Western Australia the largest exporting state. The major export markets are in the Asian and Middle East regions… Wheat grown for domestic consumption and feedstock is predominantly produced on the east coast" (Australian Government: 2017). This suggests that Archer's analysis pertains primarily to Australians, but nevertheless remains important.

(2013) estimates that roughly 2.7 million birds are killed by pesticides each year in Canada, and the US devotes more than three and a half times as much land to plant agriculture. So, it seems reasonable to suppose that 9.5 million birds are killed per year in the US.[6] Fish kills are much harder to estimate, as the EPA stopped collecting and publishing data on them not long after it was created. From 1961 to 1975, however, the Environmental Protection Agency (EPA) reported that 31 million fish died per year due to pollution, 6% of which were directly tied to agriculture (EPA 1975).[7] What's more, the authors of the report include this at the outset:

> It should be stressed that pollution-caused fish kills reported in this publication probably represent only a fraction of the kills which actually occurred during the 1961-1975 period, partly because the reporting of fish kills is voluntary. Also, numerous small kills often go unnoticed or unreported, and significantly large kills are often not included due to lack of sufficient information to determine if the kills were caused by pollutants, or were due to natural causes. (EPA 1975, 1)

Agriculture has grown significantly since 1961: pesticide use has more than doubled (USDA 2014), and fertilizer use have tripled (USDA 2013). So, it's all but certain that fish have continued to be killed in substantial numbers since the EPA stopped issuing its reports. What's more, the EPA's hedging applies equally well to avian deaths caused by pesticides, and we should recall that these are only the sources of animal death for which data are available. We're still ignoring reptiles and amphibians; we're ignoring so-called "secondary" deaths (where animals die as a result of eating other animals that have been poisoned), and the usual mix of known and unknown unknowns.[8] Granted, these factors won't seriously change the per-hectare annual death estimate, simply because of the size of US agriculture. As of 2012, the US boasted 157.7 million hectares of cropland, of which 127.5 were harvested; so, the deaths just discussed may not even shift the annual estimate by a single death per hectare. Still, they serve as a reminder that many species are negatively affected by plant agriculture, and in many different ways.

Where does this leave us? If we were to average Davis and Archer's estimates, and limit the estimate to harvested cropland (which would be to ignore the other

[6] This study aggregates and generalizes from US data, so that's further reason to take the estimate seriously. It's, of course, a bit odd to take such a circuitous route to this number, but since we aren't aware of a paper that aggregates all this information for the US specifically, the circuitousness is unavoidable here.

[7] This 6% figure is high, but we don't know by how much. The report says that agricultural deaths were due to insecticides, fertilizers and "manure-silage" (9). The glossary clarifies that this third category should be understood as "manure drainage, ensilage liquors, or feedlot operations" (77). Both ensilage liquors (liquids that leak from silage; i.e., what's fed to cattle, sheep, etc.) and feedlot operations aren't part of plant agriculture, but just given their relative sizes, it seems implausible that they account for a significant portion of the harm footprint. So we need to hedge a bit here.

[8] Among the known unknowns, consider the death tolls associated with less prominent crops, such as pecans and leafy greens, consider the death tolls associated with alternative production environments, such as greenhouses, and consider the death tolls associated with parts of the farm other than the fields, such as rodent problems in barns, which are often managed using cats and sticky traps.

ways that animals might be killed on cropland left fallow), we would get a dramatic number: over 7.3 billion animals killed each year. That's remarkably more than the number of cattle or pigs slaughtered every year in the U.S. (roughly 40 and 120 million, respectively) and not too far from the number of broiler chickens killed there also (roughly 9 billion).[9]

Problems with the Data

We've offered the 7.3 billion number as though it's a hedge. Averaging Davis and Archer seems like a way to be conservative, discounting Archer's high estimate based on concerns about the degree to which his data is representative. However, as we'll now argue, we haven't hedged nearly enough. There are several reasons to question the accuracy of these calculations. In this section, we focus on empirical issues.

Generalization

The first problem is that the estimates above rest on a dubious assumption: namely, that we're in a position to generalize from the mortality rate of one field animal or crop to other animals or crops. On this approach—typified by Davis and, to a lesser degree, Archer—findings about mice deaths in grain production, for example, can be used to calculate a death rate for plant agriculture as a whole, even though it involves a wide variety of other animals and crops. But is this really the case?

One reason for doubt is specific to Davis's analysis. Globally, 60 percent of sugar cane has been harvested by hand, with regions that employ mechanical cultivation most commonly using combine harvesters (Elvers 2017: 968). Davis's sugarcane study however involved sugarcane cultivation in Hawaii, which traditionally used a distinctive local method, one that employed v-cutter harvesters and push rakes. Hawaii was thus historically unique in the particular machinery that it used. Recent years have seen a substantial decline in Hawaiian sugar cane production, due to increased labour costs and global competition, to the point that the last functioning Hawaiian sugar mill closed in 2016 (Solomon 2016; Wang 2016). As result, sugar cane is no longer industrially harvested in Hawaii. Given that Hawaiian sugar cane cultivation was historically practiced in a unique form that no longer exists, it's unclear what relevance the deaths of field animals under such a method have to determining field animal mortality rates for other forms of sugarcane production, let alone agriculture as a whole.

The Hawaiian sugarcane example illustrates the larger problem with generalizing field animal deaths across species and crops. The death rates of crop harvesting practices don't appear to follow a one-size-fits-all model. Rather, there appears to be wide variation in the effects particular crop harvesting practices have on particular

[9] These numbers are not meant to represent the total number of animals killed to provide meat. Plainly, to generate that estimate we would need to factor in all the animals that are killed in plant agriculture to produce feed crops for farmed animals. However, our goal here is simply to draw attention to the significance of over seven billion animals being killed in plant agriculture.

species. This can be seen by noting the findings of additional studies of the effect of harvest on field animals.

A 2004 study examined the effect of wheat and corn harvesting in central Argentina. It compared the population and distribution of grass mice (*Akodon azarae*) in three habitats: crop fields, regions bordering the fields and the wider surrounding area. While the number of mice found in fields substantially decreased after harvest their numbers substantially increased in the border regions. When it came to "disappearances," a category that included both mouse deaths and migration out of the study area, there was no significant difference between the three habitats. The study concluded that changes in the number of field animals were "the consequences of movement and not of high[er] mortality in crops" (Cavia et al. 2005: 98).

A second study tracked the presence of small mammals in and around cornfields in South Dakota. Snap traps set by the researchers caught short-tailed shrews, masked shrews, prairie voles, meadow voles and three species of mice. However, many of the species caught adjacent to cornfields were not found in the cornfields themselves. "With the exception of one grasshopper mouse, deer mice and white-footed mice were the only species captured in cornfields" (Pinkert et al. 2002: 41). The authors suggest that mice are the only permanent residents of corn fields because they don't require herbaceous plant cover to avoid predators, and can rely instead on underground burrows (2002: 43; Warburton and Klimstra 1984: 329; Johnson 1987: 128). The populations of deer and white-footed mice in the cornfields after harvest was unchanged in one of the two crop-field habitats the researchers examined, while in the other the number of both species increased slightly. (The same was true of grasshopper mice, the population of which increased from zero before to one after harvest.) The evidence suggests mice likely migrate into croplands after harvest to eat the seeds and crop waste available there.

The authors of the South Dakota study note that their findings may underreport the presence of shrews because they can avoid capture in snap traps more easily than other traps. Despite this limitation, their study and its Argentinian counterpart are in keeping with two common finding in the literature on field animal populations. One is that field-animal populations are species-specific. A cultivated area that supports large numbers of one local species can be home to zero members of another. This already makes generalizing mortality rates across species difficult. But the second finding is that crop cultivation often has no effect on whether field animals live or die.

Some studies do suggest that no-till agriculture has more positive outcomes than conventional tillage systems, such as larger and more stable population of small mammals, as well as greater species diversity (Warburton and Klimstra 1984; Johnson 1987; Young 1984). Other studies however suggest that the comparative disadvantage of conventional tillage is illusory, as there is "no adverse effect by tillage on resident small mammals" (Schwer 2011: 29; Albers et al. 1990; Wegner and Merriam 1990; Getz and Brighty 1986; Castrale 1985; Fleharty and Navo 1983). What all these studies have in common however is that they don't document animals being killed in crop cultivation. Indeed, it's relatively uncommon to find peer-reviewed research documenting such an outcome.

This absence of evidence poses a problem for any high estimate of the fatality rate that's driven by harvesting machinery. (Some deaths associated with harvest, such as increased predation enabled by reducing crop cover, are less clearly direct effects of harvest itself and raise questions about how to classify them. More on this below). It's worth underscoring the limits of our current understanding regarding the frequency of these deaths. In addition to the studies cited by Davis, we've only been able to find one further study documenting a field animal's death directly due to crop harvest. Jacob and Hempel (2003) examine four tracts of agricultural land that saw 12 voles die shortly after harvest. One of the voles was killed by farm machinery and another was removed by a buzzard. No cause of death could be identified in the other cases but the authors note that some may have been buried alive in their burrows due to soil compression caused by farm machinery (2003: 49). Davis originally cited two studies documenting the deaths of three mice and seventeen rats respectively (Tew and Macdonald 1993; Nass et al. 1971). We've additionally cited Jacob and Hempel (2003), which describes a vole unambiguously being killed by farm machinery as well as ten additional possible deaths. These three studies document a maximum of 31 field animal deaths due to agricultural machinery. If the Hawaiian rat deaths are removed from the 31 total that leaves 14 (only four of which were confirmed to be due to agriculture). Whether we've the maximum or the minimum figure in mind, and even if it were possible to generalize across crops and species, the sample size of either figure would seem too small to support the large-scale generalizations about agricultural practices that we saw above.

Things are no better when we turn to the insecticide and pesticide data. Many pesticides that have historically killed birds and fish are now banned. When it comes to bird kills, for example, Action by the American Bird Conservancy has resulted in an end of the use of carbofuran and a phase out of insecticides treated with neonicotinoids in U.S. stores such as Home Depot and Lowe's. The Conservancy also takes credit for include being "instrumental in the cancellation of more than a dozen pesticides that are particularly harmful to birds, including carbofuran, fenthion, chlorfenapyr, ethyl parathion, and a suite of rodent poisons" (American Bird Conservancy 2017).

Of course, this doesn't show that avian deaths don't happen, and there is no reason to suppose that fish kills have ended. Still, they should moderate any estimates we make. What's more, it's worth bearing in mind the remark of a researcher whose findings informed the above-mentioned study on Canadian bird deaths due to pesticides: "Mitigation of kills is relatively easy. The products that have a high probability of causing avian mortality have been identified. In most cases, substitution products of lower toxicity to birds already exist. Regulatory inaction is the only impediment to a reduction of the direct incidental take (Mineau 2010: 1)." In short, it looks like these are fixable problems: we just need better regulation and further efforts on the part of animal advocacy groups.

Calculation Errors

A second problem is that the estimates above appear to contain calculation errors. For instance, as one of us has already pointed out, Davis misread the sugarcane study he cites, as he ignored the longer growing time: sugarcane has a 2-year growing season, so the annual mortality rate is only 38.5%, not 77% (Lamey 2007).

Archer's analysis offers a similar example. It inadvertently exaggerates the scope of mouse plagues.[10] Archer writes that "each area of grain production in eastern Australia is subject on average to a mouse plague every 4 years" (2011: 980). The sources Archer cites support this statement insofar as "each area" is understood to refer to large geographic regions such as states or parts of states (Victoria, southern Queensland, etc.) (Singleton et al. 2005: 618; Caughley et al. 1998: 11). But Archer's calculations take "each area" to refer to every hectare of grain cropland in Australia. The difference here is between a quadrennial mouse plague happening somewhere in all of Victoria and such a plague happening on every last Victorian farm. This innocent mistake undermines Archer's calculation of mouse poisoning deaths. A more accurate picture is suggested by the Cooperative Research Centre for Pest Animal Control, which notes that each year between 100,000 and 500,000 ha of grain crops in Australia are subject to mouse plagues (McLeod 2004: 9). Australia plants approximately 22 million hectares of grain crops annually (Australian Export Grains Innovation Centre 2016). These figures suggest that in an average year 2.3% of Australian grain cropland is hit by plague. When Archer's figure of 55 deaths per hectare of grain is recalculated to only apply to 2.3% of crop land the mortality rate for grain becomes 1.27 animal per hectare.

What's more, mouse plagues aren't confined to crop fields. Although the plagues are particular to Australia's grain belt, the mice's spawning grounds extend beyond individual wheat fields. That's why models for predicting mice plagues are based on the food available to mice not only in fields but also in grazed pasture (Pech et al. 1999: 81). As the Government of New South Wales explains, "in the field, mice are always present, but mostly in low numbers. Refuge areas such as channel banks and the more densely vegetated pastures are ideal habitats, where detection is difficult" (2017: 3). If mice are not confined to crops when they spawn, the same is true when it comes to overrunning farms. Upon reaching plague proportions they attack agricultural operations indiscriminately, as the Cooperative Research Centre report describes:

> Mice invade intensive farming enterprises such as poultry housing and piggeries causing damage to infrastructure, spoiling feed and, in some cases, causing damage to animals (Caughley et al. 1998). In addition to intensive farming, the grazing industry is impacted through mice consuming pastures, destroying feed grain and damaging stored hay. Similarly to grain producers, farm equipment and buildings are damaged as a result of a plague (McLeod 2004: 11)

[10] We owe this point to Animal Liberation South Australia (2014c). For additional empirical criticisms of Archer by Australian animal rights advocates see Animal Liberation South Australia (2014a, b) and All Animals Australia (2014).

The point to note here is that mouse plagues also damage grazing land. A primary reason farmers resort to poison is to avoid the extensive economic losses mouse plagues cause. Insofar as mouse plagues damage farms indiscriminately, it's incorrect to argue that farmers poison mice "to grow grain" (Archer 2011a: 980). The poisoning that occurs in Australia is done to protect all aspects of affected farming operations, including pastures. Archer's analysis is thus misleading in failing to associate mouse poisoning with animal agriculture, and this undermines his attempt to use mouse poison deaths as grounds to prefer pasture-raised meat over plant foods.

Choice Points

The above should make us quite wary of the number we mentioned earlier: 7.3 billion deaths each year in the U.S. It's difficult to know just how much we ought to reduce the estimate based on the above considerations alone, but two things are clear. First, the estimate should be reduced: 7.3 billion is clearly too high. Second, we should have a fairly low level of confidence in whatever number we propose. There are too many reasons to be skeptical about generalizing from the available data, which is obviously quite limited in its own right.

Additionally, we need to recognize that the 7.3 billion estimate rests on a number of philosophical assumptions, which are quite controversial. Our aim here isn't to argue that these assumptions should be rejected, but rather to identify them and explain their significance. In so doing, we hope to show that before anyone can put an estimate to use in the context of an argument—whether for prioritizing a particular cause or against veganism—she needs to be sure that her interlocutors are on board with the philosophical assumptions that lead to that particular number. If they aren't, her argument won't get very far.

Predation

The first question concerns the moral significance of predation. It turns out that many of the deaths associated with plant agriculture are not directly caused by machinery, poisons, or other direct human interventions. In the majority of cases, rather, what happens is that human activity exposes animals to predators, and those predators are the ones directly responsible for the deaths. Take, for instance, the field mouse study that Davis relies on in generating his estimate. As the authors of that study indicate, of 33 mice tracked with radio collars, 17 died as a result of harvest. However, only one of those deaths came directly from machinery (a combine harvester); the other 16 came from tawny owls, weasels, and the like. Suppose you take the view that human beings are only responsible for the deaths that we directly cause, having no responsibility to prevent predation. Then, insofar as we can generalize from this study, we should divide our estimate of the *morally relevant* field animal deaths by 17.

That said, it isn't automatic that this move will work. Whether it does depends on what conditions need to be met in order for predation to generate moral obligations.

After all, it may be the case that the reason why we don't have an obligation to prevent the lion from killing the gazelle is because that killing occurs entirely independently of human action: nothing we do puts the gazelle at special risk, and so we've no obligation to intervene. In these cases, however, field animals die because we remove the cover that formerly protected them. Insofar as farming exposes field animals to mortal risk, it seems possible that we've some responsibility for their fate.[11]

At this point, it might be possible to invoke the doctrine of double effect (Lamey, forthcoming). According to that principle, you may do something good (e.g., consume plants) even if it has a bad side effect (e.g., significantly increasing the likelihood that field animals will be eaten by predators) as long as several conditions are met, including that you don't intend that the bad side effect. And that might be what's going on here: field animal deaths are foreseen but unintended side effects of an otherwise morally legitimate practice.

Of course, it would take much more work to show that this sort of strategy succeeds. One question, for example, is whether we can apply the doctrine of double effect to the action of farmers who actually kill animals (since they want predators to reduce field animal populations based on concerns about crop loss; see, e.g., Witmer 2007), or only to the vegans who consume their crops. Again, we make no claim to resolve such issues here. Our goal is only to draw attention to them, as evidence that we can't calculate the number of morally relevant deaths just by looking at the number of lives lost: we need to consider puzzles that are squarely philosophical.

The Line-Drawing Problem

A further significant issue concerns where we draw the line of moral considerability. Suppose (implausibly) that only mammals are morally significant. Given that assumption, we could write off all the avian and fish deaths, as well as the reptile and amphibian deaths for which we don't have data. This wouldn't reduce our estimate very much, but it would reduce it some, and it would certainly allow us to have a higher degree of confidence in whatever number we proposed, as much of the uncertainty concerns deaths that fall into these other categories.

However, suppose that rather than restricting the moral community, we expand it. Some recent research on insects suggests that certain species may be sentient (see, e.g., Klein and Barron 2016 and Tye 2017), and even if they aren't, there is interesting evidence that some of them have a belief/desire psychology (see Carruthers 2007 for an overview), which may itself be morally relevant. It is, of course, very tricky to know what to say about the insect minds, if any there are, but the implications for our estimate are extraordinary. It's very difficult to estimate the number of insects present in agricultural contexts, but it's obviously an enormous

[11] This seems plausible even if it turns out that our actions don't make any difference to the total number of wild animals that die. After all, it seems unlikely that the predators who kill exposed field animals would go hungry otherwise; if that prey weren't available, they would probably just kill other animals in other locations. But on the assumption that intervening can create responsibility, and our interventions influence which animals end up dying, our hands don't seem to be clean.

quantity: a conservative estimate is well over 250 million insects per hectare, and some judge that it's over a billion per hectare (see Sabrosky 1952 and Pearse 1946, respectively).[12] Even if we stick with the lower number, make the supposition that only 1/100 of those insects are candidates for sentience, make the further supposition that the odds of the candidates actually being sentient are only 1/10, and finally assume that pesticides only manage to kill 1/10 of the candidates for sentience, we're now talking about an additional 20,000 deaths per hectare. When we recall that the 7.3 billion number was generated with a 100 deaths per hectare estimate, it becomes obvious that the moral significance of insect sentience is difficult to overstate.

It may be the case that this way of approaching moral considerability is too simplistic: perhaps sentience is a necessary but not sufficient condition for mattering morally, and that insects don't satisfy the other conditions. Or perhaps a relational account of the moral community is the correct one, and insects aren't part of it. Or perhaps the badness of insect suffering and death is negligible, so that we can discount those harms almost entirely. Or perhaps insects experience even greater harm in animal agriculture. We take no stance on these issues here, but it's plain that they need to be addressed before we can come up with a complete picture of the costs of plant agriculture.

The Relative Value of Lives

The line-drawing problem immediately suggests a third issue: are all lives of equal value? Many players in the animal ethics literature have argued for something akin to the principle of equal consideration of *interests*, according to which comparable interests deserve the same weight in our moral deliberations. However, there is no consensus to the effect that we ought to say that each *life* ought to be given the same weight in our moral deliberations. And when we reflect on the principle of equal consideration of interests, it is easy enough to see why this would be: it isn't obvious that each being has the same interest in continuing to exist, and so death may harm some beings more than it harms others. Insofar as most animal ethicists view death as a greater harm to persons than to merely sentient beings, they already accept this idea. However, what does this point imply about the badness of death for mice as opposed to the badness of death for sparrows? Is it the case that, in general, members of one of those species are harms more by death than are the members of the other?

If that were the case, then we would face two difficult tasks: one empirical, and one philosophical. The empirical challenge would be to offer more fine-grained estimates than we've tried to offer here, distinguishing death rates by species. The philosophical challenge would be to quantify the relative badness of death by species, so that we can provide a more nuanced account of the overall badness of field animal death in plant agriculture. The empirical task will be difficult to

[12] As Brian Tomasik pointed out to us, almost all the creatures in Pearse's study were mites and springtails, which aren't in the class *Insecta*. So, we are simply using "insects" here as shorthand for the wide range of small invertebrates that are affected by our agricultural practices.

complete for reasons that we've already articulated, and the philosophical one faces a number of hurdles,, including difficult questions about what, if anything, makes death bad for animals in the first place.[13]

The Counterfactual Problem

The authors of the Argentinian study on grass mice implicitly raise a fourth problem. They note that the arrival of agriculture in central Argentina had increased the local populations of some field animals. "Some rodent species benefitted from the changes because of increased food availability and decreased predator abundance" (Cavia et al. 2005: 95). In other words, some of the animals killed by contemporary agriculture may owe their existence to the same systems that kill them. If they weren't vulnerable to death via combine, owl, or poison, they wouldn't have existed in the first place.

This strange counterfactual makes it difficult to know we ought to think about the harm footprint of contemporary plant agriculture. Do the births of beings who wouldn't otherwise have existed somehow offset the deaths caused by plant agriculture? If so, then presumably we ought to weigh total deaths against total births. But we might think more broadly still. After all, land developed for plant agriculture would have supported even more wild animals had it not been developed, and so there would have been that many more deaths. Should we compare the number of deaths for which plant agriculture is actually responsible (perhaps offset by the births for which plant agriculture is responsible) to the number of deaths that humans would have caused had the land remained wild—by hunting, polluting, or what have you? Whatever we say here, we will be taking a position on the non-identity problem, which is notoriously thorny (Parfit 1984: 351–80). Granted, many people have thought that the differences between human and nonhuman animals justify some differences in their treatment, Robert Nozick famously wondered whether the right story involves utilitarianism for animals and Kantianism for people. If that's correct, then the non-identity problem gets a bit easier to navigate, but we would leave us with the difficult task of defending Nozick's proposition.

Wild Animal Suffering

Finally, there is the tricky problem of wild animal suffering. The basic idea goes as follows. On one end of the spectrum there are K-strategists: they don't produce many offspring, investing fairly heavily in them, with the result that many of them survive to be reproductively successful themselves. On the other end of the spectrum are r-strategists: they produce a lot of offspring, not investing in any of them, with the goal that a small fraction will survive to be reproductively successful themselves. (Humans are toward the K-strategy end of the spectrum; most field animals are toward the r-strategy end.) What happens to most of the offspring of r-strategists? In short, they die as a result of a lack of food, water, or shelter; they are

[13] For an overview of the current debate, see Visak and Garner (2015).

eaten by predators; they contract diseases; they suffer from debilitating genetic abnormalities. What's more, since they live such short lives, there may not be many pleasures available to them to compensate for their pain. So, it may well be the case that, since most animals are r-strategists, most animals live net negative lives: their lives are, on balance, bad for them; it would be better for them not to exist. This may feel like a radical claim, but that feeling may be best explained by a kind of rosy optimism on our part. As the authors of UCLA's Animal Care and Use Training Manual put it,

> It is often assumed that wild animals live in a kind of natural paradise and that it is only the appearance and intervention of human agencies that bring about suffering. This essentially Rousseauian view is at odds with the wealth of information derived from field studies of animal populations. Scarcity of food and water, predation, disease and intraspecific aggression are some of the factors which have been identified as normal parts of a wild environment which cause suffering in wild animals on a regular basis. (1994: 2)

Granted, such a radical claim needs more defense, though we don't have room to provide such arguments here. (For additional considerations in favor of this dark hypothesis, see Ng 1995; Horta 2010; Tomasik 2015.) For present purposes, let's simply take for granted that this is a possibility deserving further exploration. And if it turns out that most animals do indeed live net negative lives, then strange conclusions may well follow.

Consider an argument from Michael Cholbi (2017), who isn't focused on wild animals, but on when we ought to euthanize companion animals. He writes this:

> Not to euthanize an animal at the point of its optimum life span, based on the best evidence available to us, is therefore wrong because of its cruel effects on the animal—as it amounts to willfully deciding that an animal will live less than the best life available to it—but it also betokens a lack of respect for the animal as a being separate from oneself, with interests and a point of view of its own, worthy of consideration in its own right (272).

According to Cholbi, an animal's optimum lifespan extends from birth to the point at which, had its life gone on to some later time, the animal would have been worse off for having lived to that later time. But if most animals live net negative lives, and if much of that pain comes in the later portions of their lives, then most animals are already past their optimum lifespan: it would be better for them to die. And, although our obligation to euthanize companion animals in those circumstances maybe best explained by our relationships with those animals, it still seems possible that such an obligation suggests that it is at least permissible to kill wild animals in similar circumstances. Given all that, insofar as there is anything wrong with contemporary plant agriculture, it may be that it doesn't cause enough death—not that it causes too much.

Philosophical considerations don't affect our estimates of field animal deaths in the way that empirical studies do. They don't show that more or fewer shrews are being poisoned by eating insects covered in insecticides. Instead, philosophical considerations are relevant to our judgment about those deaths that are morally relevant. If it turns out that we are not responsible for deaths due to predation, then the harms associated with plant agriculture may be fairly easily addressed: after all, it's a relatively small number of deaths that we would need to eliminate. If, on the other hand, we are indeed responsible (even if only partially) for deaths due to predation, then the problem is significantly more challenging. Likewise, if it turns out that insects aren't morally important, the task is relatively small compared to the task if they deserve equal consideration. It also matters how we factor in the "benefit" of existence that plant agriculture may confer on various animals, and whether we conclude that wild animals live net negative lives. These philosophical issues promise—or threaten, depending on your perspective—to seriously alter the way we think about the scope and severity of field animal mortalities.

If, for instance, we aren't responsible for deaths due to predation, then we might generate an estimate by averaging the numbers that we get from Davis (excluding the deaths due to predation that he counts) and Archer (once we fix his calculation errors).[14] That would give us roughly one death per hectare, and so roughly 127.5 million field animal deaths per year. But this would be to ignore the worries about generalizing from one crop to another, as well as from one set of farming practices to another. It isn't at all clear how much we should hedge based on these concerns, but if we assume that our estimate is as likely to be low as high, and off by as much as 50%, then we can generate a lower bound of approximately 63.75 million field animal deaths per year. This is now squarely in between the number of cattle and pigs killed each year, which means that tractability and neglectedness considerations are going to become highly relevant, as neither is likely to be swamped by the scope of the problem. So, insofar as we're focused on cause prioritization, responsibility for predation is highly relevant. And, of course, the same is true when it comes to arguments against veganism. It's quite difficult to find diets that include meat with a smaller harm footprint, and so many anti-vegan arguments would fall apart on empirical grounds.

But on the other hand, if it turns out that we are responsible for deaths due to predation, and we can't discount the mortality estimate based on, for instance, any benefits that agriculture may provide to animal populations, then things get dicier. Our overall estimate should still be much lower than the one we mentioned at the outset, and given all the issues we've discussed, no one should be particularly confident in any number he generates. However, it's highly unlikely that a plausible estimate will vindicate either Davis's or Archer's argument. So, while some anti-vegan arguments may still have promise, at least on empirical grounds, they'll generally be ones that didn't require any particular estimate at all—e.g., Bruckner's (2015) case for eating roadkill.[15] Of course, there are plenty of other questions to ask about those arguments, and this isn't the place to assess them generally. The point is only that our assessment of any such argument has to include reflecting on

[14] We say that we "might" generate such an estimate because this number assumes a number of stances on the choice points discussed earlier, each of which requires defense.

[15] Arguments that do require a particular estimate have a better shot at working if they attempt to defend eating animals that haven't been fed grain and other crops, since they won't have to factor in all the field animals killed to provide feed for those farmed animals.

all the issues raised above. There is no simple route to an estimate of the impact of plant agriculture on animals.

Future Directions for Humane Agriculture

Though we haven't argued as much here, our inclination is to say that we should indeed take steps to reduce the number of animals harmed by plant agriculture. In this final section, we want to provide some cause for optimism that this can indeed be accomplished.

It's instructive to take note of recent changes that have occurred regarding how some pest species are managed. In Europe, for example, international treaties have promoted wildlife conservation by restricting the hunting of large grazing birds (Nilsson et al. 2016: 164). Where killing was once the default option to limit agricultural damage caused by geese, cranes and swans, contemporary methods now involve non-lethal practices such as scaring campaigns, diversionary fields and refuge sites (Nilsson et al. 2016; Jensen et al. 2008). Such methods were unheard of prior to the 1990s. Although these particular methods may not be directly transferrable to the management of rodents and other small mammals, they illustrate the cultural nature of agricultural pest management. Rather than a brute given, steps taken to manage crop damage evolve in response to changing technology and values. To date conservation has been an influential driver of change where animal rights have not. Nevertheless, there are existing agricultural trends that do promise greater well-being of field animals.

Consider, for instance, alternative tillage practices. No-till methods are popular in South America, where they're used on 50% of cropland in Brazil and over 80% of cropland in Argentina, Paraguay and Uruguay (Gianessi 2014). Currently, no-till methods are used on 34% of cropland in the U.S. (USDA 2014). In Europe, conservation tillage is employed on 25.8 percent of cropland (Kertész and Madarász 2014: 91). No-till and conservation tillage seek in varying degree to prevent soil erosion by minimizing soil disruption. As noted above, there is debate over the relative impact of conventional tillage on field animals compared to no-till. Still, insofar as no-tillage and conservation tillage reduce the number of times plows and row cultivators pass through crops, they may pose fewer threats to field animals. Although the spread of both practices has been due to environmental considerations rather than any concern with animal protection, they nevertheless represent a well-established trend away from conventional tillage. Informed debate over the deaths of field animals require further research on the possibly varying effects of different tillage practices.[16]

Another existing trend likely to favour field animals concerns indoor agriculture. Greenhouses for example are popular in the Netherlands, where the food grown in them constitutes 22% of the country's total agricultural value (Marcelis and

[16] This isn't to suggest that there are no other costs to no-till and conservation tillage: they do tend to use more herbicides, which may offset any gains for animal populations. But based on the data surveyed above, it seems fairly clear that deaths due to herbicides are going to be a relatively small portion of the total deaths associated with plant agriculture.

Hemming 2013). Recent years have also seen the birth of so-called vertical farms, which see plant crops grow in indoor structures ranging from skyscrapers to stacked shipping containers. Rationales for the practice are commonly environmental. "We conserve our resources, we recycle our water and nutrients, we don't use any tractors and aren't emitting any hydrocarbons or greenhouse gas as we plant and harvest," states the founder of one U.S. vertical farm (Strasser 2014). Similarly, the managers of the world's largest indoor farm, based in Japan, claim that their operation is 100 times more water efficient than outdoor fields (MacDonald 2015). Be that as it may, indoor farming promises to have an extremely low harm footprint, as there are no animals involved in those systems.

Another existing practice likely to reduce field animal deaths is the use of contraception as a form of pest control. In 2013 New York City began testing a new product to control the rat population in its subways. Bait eaten by female rats made them permanently infertile, to the point that rat populations near subways decreased 43% (Flegenheimer 2013; Molteni 2017). Prior the subway trial the rat contraceptive was researched in agricultural locations in Laos, India and the Philippines, and the company that created the contraceptive is now working on versions targeting mice and pigs. This raises the possibility that at some point in the future non-lethal agricultural pest control may be feasible on a large scale.

There are, in addition, entirely new agricultural practices that may ultimately take off. For instance, there is some evidence that the height of crops can influence the population trends of small mammals that live in fields (Jacob and Hempel 2003: 49). This finding might inform the management of cover or other crops so as to reduce anthropogenic field-animal mortality. Similarly, existing research suggests that the manipulation of adjacent non-crop habitats, such as ensuring vegetation does not grow above 10 centimetres, can naturally reduce the population of field rodents, an approach that might be extended to the management of inter-row plants and weeds in crop fields (White et al. 1998). Fencing practices and agricultural machinery design might also be modified so as to protect field animals. The embryonic field of floating farms, which currently are at the proposal stage and which involve very large vertical farms that float on pontoons, might be encouraged for the same reasons (Smart Floating Farms 2017).

Alternative tillage practices, indoor farming and rodent contraceptives are existing agricultural practices that have the potential to reduce field animal deaths, and there are others that we might eventually develop. However, none of these practices have received any attention in the conversation about field animal mortalities. George Schedler, for example, writes that "there is no reason to believe a method of commercially harvesting vegetables that causes no suffering to field animals will ever be found. There is no effort underway to discover such a method" (2005: 505). Schedler's remark does not describe current reality. Agriculture has taken a wide variety of forms throughout history, and current trends would seem to raise the serious possibility that plant agriculture might someday kill very few animals—perhaps even none.

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