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RESEARCH ARTICLE

Impact of Free-Roaming Domestic Carnivores on North American Agriculture: a Survey of Government Agencies

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Abstract

Over millennia dogs, cats, and ferrets became domesticated in part due to their respective roles in the management of agricultural resources. When allowed to roam free of human control ("unconfined"), these carnivores have the potential to harm or kill livestock, destroy crops and property, and become vectors for disease transmission. As part of a larger environmental survey, government agencies of the United States and Canada were queried regarding the number and frequency of sightings of unconfined dogs, cats, and ferrets in agricultural areas, evidence for harm, and resulting degree of concern for livestock, agricultural crops, and fisheries. Of the 119 jurisdictions queried, 107 (89.9%) had agriculture components. Twenty-five (23.4%) reported the existence of "incidents" (impact) from unconfined dogs and cats on agriculture, which 14 (13.0%) agencies rated as "definitely a concern" to livestock and crops. Cat sightings exceeded those for dogs in both frequency and absolute animal numbers, although differences did not reach statistical significance. Twenty-one (19.6%) respondents reported ferrets as "rarely" or "never seen" in agricultural settings, and no agency reported an impact from ferrets on livestock, fisheries, or crops. Balancing today's societal perceptions regarding the benefits of employing domestic carnivores in the agricultural setting against the potential risks, remains an important policy and management debate.

Keywords: Agriculture; Domestic carnivores; Free-roaming, North America; Survey

Introduction

Three carnivore species, the dog (*Canis lupus familiaris*), the cat (*Felis silvestris catus*), and the ferret (*Mustela putorius furo*), have been closely associated with humans, initially as working animals and more recently as companion animals [1, 2]. Encounters between humans and dogs began an estimated 10,000 to 40,000 years ago [3-5]. Cats interfaced with humans starting around 7,000 years ago, although more recent estimates go back 10,000 years [6]. Although less well-documented, the ferret's interactions with humans may extend back at least 2,500 years [7, 8]. There is general agreement, however, that animal and plant domestication underwent explosive expansion during the Neolithic Period, 10,000 to 12,000 years ago, with the introduction of agriculture [9].

Animal domestication has been described as an interactive process "based on a shared need for shelter, food and protection [10]." The transition of prehistoric humans from "hunters and gatherers" to agrarian societies resulted in changes in the carnivores that performed necessary functions in the agricultural setting. Cats cemented their beneficial role in protecting valuable crops from damaging pests both in the field and during storage. Cats today are being "employed" as working animals to control pests on farms, ranges, mills and warehouses [11, 12]. Dogs, while historically utilized for protection and for tracking and chasing prey alongside early humans during the hunt, became tasked with guarding and managing livestock. Domestication of dogs can be tracked through dietary changes, reflected in genomic alterations signaling increased intake of agricultural crops, in contrast to the strict carnivorous diet of wild canids [13]. The later breeding of dogs by humans allowed dogs to assume highly specific roles in hunting and agriculture, exemplified by hounds, terriers, and retrievers which search out and return prey, and by shepherds bred for herding and protecting livestock. Dogs today are being trained to identify crop contamination and disease [14], and to screen for harmful plant pests and for foreign animal diseases at the US borders [15].

The ferret also participated in the hunt. Due to their diminutive size (1 to 4 pounds) and streamlined body habitus, ferrets were used to flush out rabbits and other small prey and to control rodent populations [16]. The domestic ferret is thought to have arisen from a subspecies of the wild European polecat, *M. putorius*, a species distinct from that of the wild, highly endangered Black-footed Ferret (*M. nigripes*) of the North American western plains [17]. In the early part of the 20th century, the United States Department of Agriculture (USDA)

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actively promoted the use of ferrets for agricultural purposes. An official USDA brochure recommended that ferrets be raised or purchased by farmers to rid barns and warehouses of rodents [18]. Other books, such as "Ferret-Keeper" (1912), described the care, breeding, and training of domestic ferrets as work animals [19].

As humans migrated to new geographic regions, including the Americas, they brought with them domestic carnivores to protect the food supply. Introduction of these non-native species resulted in unwanted effects on local habitats and wildlife. Where supply of native or introduced prey was adequate, some domestic carnivores have become free-roaming, forming natural-breeding (feral) populations. Left unchecked, their subsequent impact on agricultural resources is best summed up by Baker, et al.: "At present, carnivores affect food production by: (i) killing human producers; killing and/or eating (ii) fish/shellfish; (iii) game/wildfowl; (iv) livestock; (v) damaging crops; (vi) transmitting diseases; and (vii) through trophic interactions with other species in agricultural landscapes [20]."

In an attempt to document the negative effects of free-roaming domestic carnivores, the state agricultural departments of the United States conducted a survey in 1974. The data, while considered "inconclusive" at the time, showed dogs to be the major cause of livestock damage [21]. In 1990, the state of Texas reported on the adverse effects of feral dog packs, known to kill deer, rabbits, domestic cattle, sheep, and goats, amounting to "$5 million in damage to livestock annually [22]." Bergman, et al., reviewed a decade (1997-2006) of reports submitted to the USDA Animal and Plant Health Inspection Service (APHIS) and US wildlife services, in which feral dogs were documented to exist in all 50 states, causing damage to livestock and other agricultural resources that exceeded $620 million annually. The majority of damage from free-roaming dogs was to sheep, goats, and cattle [23, 24].

The source of offending animals may be tracked to the increasing "pet" populations. As of 2017, estimated numbers in the US were: 89.7 million dogs; and 94.2 million cats [25]. As many as 7 million domestic ferrets have been reported in the US, of which approximately 500,000 ferrets exist in California by the state's own reporting [26, 27]. Although numbers of unconfined domestic carnivores are largely unknown, the resulting economic impact is not insignificant. Free-roaming carnivores are known to be opportunistic feeders, making them potential threats both to wildlife and to livestock [28-32]. In 2013, Loss, et al., reported unconfined cats killed from 1.3 to 4.0 billion birds and 6.3 to 22.3 billion mammals annually in the US, accounting for an estimated 14 billion dollars per year in damage. A US study of "free-ranging" cats in and around livestock conducted by the Northwest Georgia Unit (US), reported that "…rodents and lagomorphs were the preferred prey of cats; birds, invertebrates, and reptiles are also hunted, depending on mammal availability and geographic location." Aside from predation, unconfined dogs are reported to chase and harass both livestock and humans, disrupting the normal behavior of their targets, as well as causing damage to crops and to agricultural irrigation systems. Without proper healthcare domestic carnivores may cause spread of diseases, such as rabies, distemper, and Rocky Mountain spotted fever [33].

Ownership of dogs and cats is legal throughout the North American continent and the surrounding islands; however, ferrets are prohibited in the following jurisdictions: Hawaiian Islands, California (CA); and the city of New York [34-36]. In 1933, CA categorized the domestic ferret as a "wild" animal, thereby outlawing its sale and possession in the absence of a state-issued permit. Responding to legislation to re-legalize the ferret, CA state agencies claimed (among other reasons) that "[t]he European ferret's predacious nature and wanton destruction of poultry, rabbits and other small livestock is well documented…" and concluding that ferrets, if legalized, would be harmful to the state's vast agricultural resources [37].

To examine the impact of dogs, cats, and ferrets on the environment and on agricultural resources, SeaSearch Biological Surveys (SeaSearch) undertook a survey of the state and provincial agencies of the US and Canada (CAN), respectively. Both CA state and county agencies where included, in view of the state's significant agribusiness and its publicized concerns over the existence of ferrets and their potential impact on agriculture within the state. Results from the environmental portion of the survey have been previously published [38]. This current report focuses on the agricultural survey data. Specifically, study objectives included the documentation and the effects ("impact") from unconfined dogs, cats, and ferrets on agriculture resources.

Materials and Methods

A survey was conducted of government agencies, as previously described. Briefly, agency personnel were contacted by e-mail, telephone, and facsimile representing natural or environmental resources, fish, game and wildlife, agriculture, recreational areas (parks, beaches), human and veterinary health departments (e.g., "State Veterinarian"), where such a department or position had been designated. The CA county agencies included agriculture, animal control, health, and parks and beaches as pertinent for the particular county. The survey was in the form of a questionnaire, which was distributed electronically in .pdf format (Adobe Acrobat®), by facsimile, or mailed in "hard-copy." Upon receipt, completed surveys and correspondence were saved in or converted to electronic media, and the data set was maintained in an electronic database (Microsoft Access®).

Agency personnel were queried regarding the "frequency of sightings," of unconfined dogs, cats, and ferrets, the "existence of incidents" on livestock, fisheries, and crops, and the "degree of concern" regarding harm to agriculture this created within the respondents' jurisdictions. An "unconfined" animal was defined as outside the control of humans, i.e., "stray," released or abandoned, or one that has become "feral" or "naturalized."

Responses categories were: "completed survey" (S), "nonsurvey response" (NS), or "nonresponse" (NR). NS was

used when some identifying information was provided in the absence of response to the actual survey questions (e.g., "we are the wrong agency"). Failure or refusal to respond in the absence of any responsive information was recorded as a "nonresponse" (NR). Prior to designating a NR, multiple attempts were made to reach the agency or individual, which were documented. The results reported herein reflect all responding state or provincial agencies (S + NS). Separate analyses were performed for the CA county agencies.

Respondents were asked to report the observed "frequency of unconfined animal sightings" in various settings, one of which was designated "rural-agricultural." In the section "effects on agriculture" respondents were instructed to identify the impact of unconfined domestic carnivores based on the "existence of incidents" on livestock and crops in their respective jurisdictions and to rate the "degree of concern" caused by unconfined domestic carnivores. For "animals sighted," respondents were instructed to select from a list of descriptors regarding whether they were deemed as "pets," "stray or feral," or "naturalized animals." Each respondent was also asked how their agency would manage the animals, once sighted. Responses included numerical ratings and narratives, as described in the respective table or figure. The statistical methodologies used in this report have been previously described.

Results

Overview

A total of 119 jurisdictions were queried, of which 107 (89.9%) had an agricultural (Ag) component. The state and provincial level consisted of 61 jurisdictions, of which 58 had Ag agencies. However, 59 of the 61 (96.7%) jurisdictions responded to the agricultural section of the survey, representing 108 agencies (85 S; 23 NS). Responding agencies were: 9.3% Ag, 53.7% fish and wildlife, 24.7% State Veterinarian, 12.0% parks and recreation, and 11.1% health department. Of CA's 58 counties, 35 (60.3%) responded to the survey, of which 32 (91.4%) had an Ag component. The county responses were received from 26.7% Ag, 51.1% animal control, 13.0% parks and recreation, and 8.9% health departments. Two states, Arizona and Kansas, were rated NR, after no response was received from any of the queried state agencies. Reasons when given for NR by a jurisdiction, were: they did not wish to participate; lacked the funding or time to participate; or refused to participate unless they knew more about the surveyor.

Sightings of Unconfined Animals – reported by US and CAN agencies

(Figure 1) shows the results for the "frequency of sightings" of unconfined dogs, cats, and ferrets in agricultural settings within the participating jurisdictions. State/provincial agencies rated unconfined cats and dogs as "commonly seen (>1 time per year)," cats sightings reported more frequently than for dogs. CA counties reported similar results. Sightings of unconfined ferrets were generally rated as "never" (cats versus [vs] ferrets: $p<0.001$; dogs vs ferrets $p<0.001$).

The "number of animals" observed at each sighting was also recorded [data not shown]. Sightings of single dogs and cats were reported by the states and provinces, whereas the CA county agencies reported seeing dogs and cats more often in groups of 2 or more. Cats specifically were reported in very large numbers, versus dogs or ferrets. The majority of responders rated ferret sightings as nonexistent ("never"), with the few reports submitted qualified as a case of misidentification of local wild mustelids.

Impact: Existence of Incidents ("impact") on Agriculture reported by US and CAN agencies

The impact of unconfined domestic carnivores on livestock, fisheries, and crops, was based on the "existence of incidents," shown in (Figure 2) and (Table S1). Dogs ranked highest, followed by cats, and then ferrets (overall means: dogs: 2.2; cats: 1.6; ferrets: 0.5). Mean rankings by CA county agencies were lower than those from state/provincial agencies, although the order remained the same (overall means: dogs: 1.2; cats: 1.1; ferrets: 0.3).

For "Cattle," "Swine," and "Poultry," states/provinces ranked incidents from unconfined dogs and cats as "reported to exist"

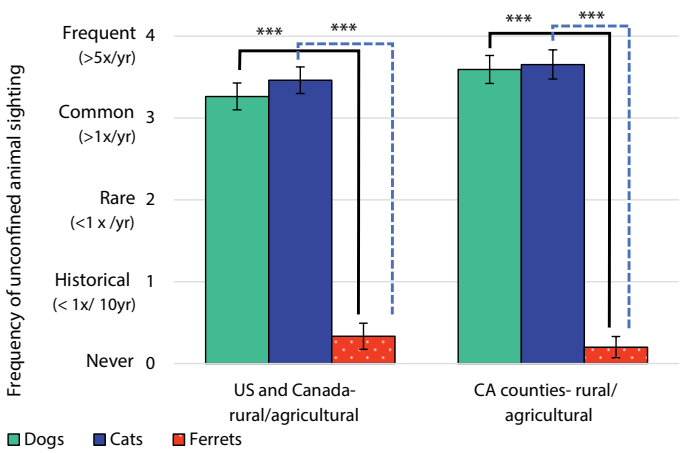


Figure 1: Categorical ratings for "frequency of sighting for unconfined" dogs, cats, and ferrets in rural/agricultural settings for all United States and Canada agencies, including for California (CA) counties. Rating mean ± standard error of the mean (sem). Asterisk represents significant difference; *** $p < 0.001$.

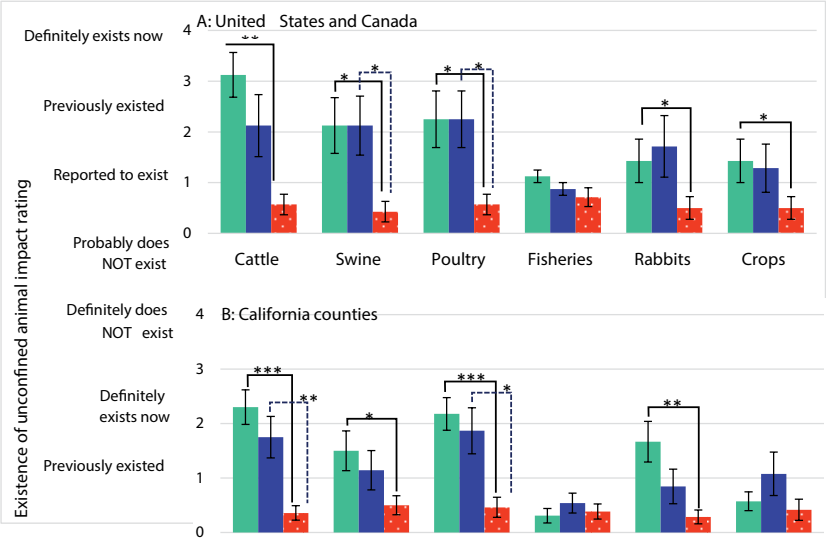


Figure 2: "Existence of incidents "(impact) on agriculture from unconfined dogs, cats, ferrets reported by all agencies (**A**) United States, Canada, and (**B**) California counties. Rating mean ± standard error of the mean (sem). Asterisk represents significant difference; * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

or "previously existed" (means >2). In contrast, incidents from ferrets were consistently rated as "probably did not exist" (<1). Rankings compared between dog incidents versus ferrets were statistically significant ($p<0.05$) for all components except "Fisheries." Rankings compared cat incidents versus ferrets were statistically significant ($p<0.05$) for "Swine" and "Poultry." No other comparisons reached statistical significance.

Similarly, CA county agencies ranked dogs the highest for "existence of incidents" on "Cattle" and "Poultry" (>2), whereas cats were ranked lower. Ferrets consistently ranked the lowest, reflecting that incidents from unconfined ferrets "probably do not exist." Rankings compared between dog incidents versus ferrets were statistically significant ($p<0.05$) for all components except "Fisheries" and "Crops," and the rankings compared between cat incidents versus ferrets were statistically significant ($p<0.05$) for "Cattle" and "Poultry."

"Degree of Concern" reported by US and CAN agencies

Respondents were asked to rank their "degree of concern" from sightings of unconfined dogs, cats, and ferrets, as shown in (Table 1). In the rural/agricultural setting, state/provincial agencies generally responded with the greatest "degree of concern" from the presence of unconfined dogs, and the least concern for ferrets (overall means: dogs: -1.0; cats: -0.6; ferrets: -0.1). Exceptions were cats ranking the greatest concern for "Rabbits" (cats: -1.0; dogs: -0.8; ferrets: 0.0); cats and ferrets were similar for "Fisheries" (cats: -0.3; dogs: -0.4, ferrets: -0.3). For "Cattle" the comparison of rankings between dogs, or cats, versus ferrets were both statistically significant ($p<0.05$).

The CA county agencies gave similar rankings, rating dogs of greatest concern, and ferrets of least concern (overall means: dogs: -0.8; cats: -0.6; ferrets: -0.2). Cats generated the greatest "degree of concern" for "Fisheries" (cats: -0.7; dogs: -0.3; ferrets: -0.2), and for "Crops" (-0.6; dogs: -0.3; ferrets: -0.2). Comparisons of rankings between dogs versus ferrets, and dogs versus cats for "Cattle" and "Crops" were statistically significant ($p<0.05$). Comparisons of rankings between dogs versus ferrets for "Swine," "Poultry," and "Rabbits" were statistically significant ($p<0.05$).

Impact: Existence of Incidents on Agriculture - reported by US and CAN agriculture (Ag) agencies

Results from Ag agencies were compared to those from "all agencies" (i.e., inclusive of agencies with other responsibilities), shown at (Figure 3) (see also (Table S2), and (Table 2), respectively. Overall state/provincial Ag agencies ranked the impact ("existence of incidents") of unconfined animals lower than did "all agencies." Dogs still ranked highest for impact, followed by cats, and then ferrets (overall means from Ag agencies: dogs: 2.1; cats: 1.3; ferrets: 0.5), and for "Cattle" and "Swine" the impact of dogs versus ferrets reached statistical significance ($p<0.05$).

Similarly, the CA county Ag agencies also rated dogs and cats as having a greater impact to agricultural resources, than ferrets (overall means: dogs: 1.0; cats: 1.0; ferrets: 0.5), although no interspecies comparisons were statistically significant. Ratings from CA county Ag agencies were overall somewhat lower than those from the state/provincial counterparts, with the exception of impact on "Poultry" and "Rabbits." Regarding unconfined ferrets, the "existence of incidents" reported by all state/provincial agencies on all agricultural components were ranked as "probably does not exist" (1) to "definitely does not exist" (0); within the CA counties, this was true for "Cattle," "Fisheries," "Rabbits," and "Crops."

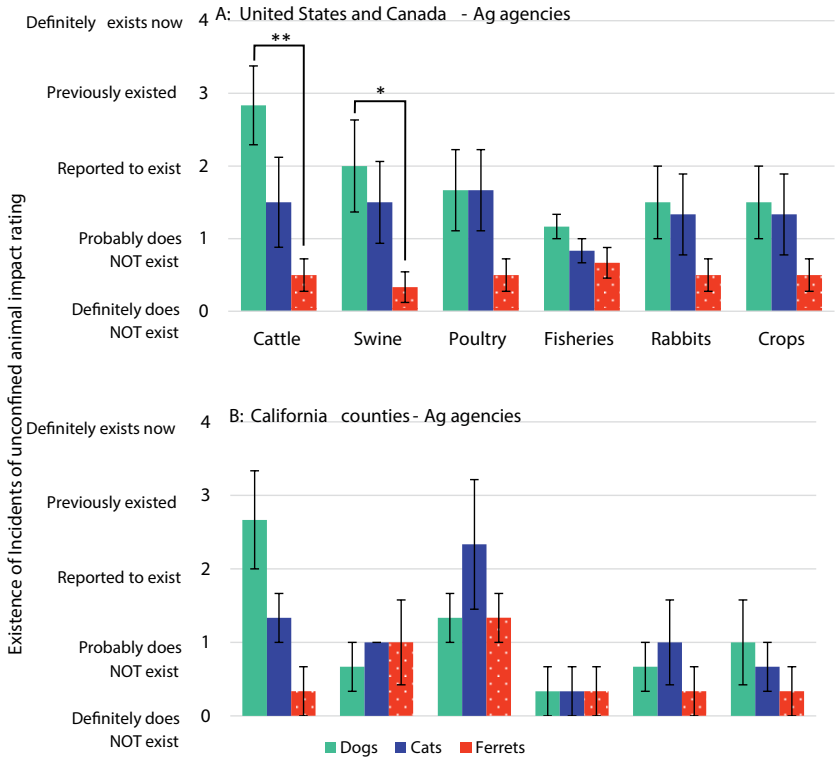
"Degree of concern" from unconfined domestic carnivores reported by US and CAN Ag agencies

Table 2 shows the results reported by US and CAN Ag agencies for "degree of concern" due to the "existence of

Table 1: "Degree of concern" regarding the impact of unconfined animals on agriculture reported by US and CAN agencies

Effects on Agriculture	Dogs		Cats		Ferrets		p- value
	Mean ± sem	[1]Rating Range	Mean ± sem	Rating Range	Mean ± sem	Rating Range	
United States, DC and Canada							
Cattle	-1.6 ±0.2	(-2)-(-1)	-0.5 ±0.3	(-2)-0	0.0 ±0.0	0	[a]p<0.05 [b]p<0.01 [c]ns
Swine	-1.0 ±0.4	(-2)-0	-0.4 ±0.2	(-1)-0	0.0 ±0.0	0	[abc]ns
Poultry	-1.5 ±0.3	(-2)-0	-0.8 ±0.2	(-1)-0	-0.3 ±0.3	(-1)-0	[abc]ns
Fisheries	-0.4 ±0.2	(-1)-0	-0.3 ±0.3	(-1)-0	-0.3 ±0.3	(-1)-0	[abc]ns
Rabbits	-0.8 ±0.2	(-1)-0	-1.0 ±0.0	-1	0.0 ±0.0	0	[abc]ns
Crops	-0.6 ±0.2	(-1)-0	-0.4 ±0.2	(-1)-0	0.0 ±0.0	0	[abc]ns
Other (Sheep)	-2.0	-2	-	-	-	-	-
Overall Mean:	-1.1		-0.6		-0.1		
California counties							
Cattle	-1.5 ±0.2	(-2)-0	-0.5 ±0.3	(-2)-0	-0.1 ±0.1	(-1)-0	[a]p<0.01 [b]p<0.001 [c]ns
Swine	-1.2 ±0.2	(-2)-0	-0.5 ±0.3	(-2)-0	-0.1 ±0.1	(-1)-0	[ac]ns [b]p<0.01
Poultry	-1.4 ±0.2	(-2)-0	-1.2 ±0.3	(-2)-0	-0.4 ±0.3	(-2)-0	[ac]ns [b]p<0.01
Fisheries	-0.3 ±0.3	(-2)-0	-0.7±0.4	(-2)-0	-0.2 ±0.2	(-1)-0	[abc]ns
Rabbits	-1.2 ±0.3	(-2)-0	-0.6 ±0.3	(-2)-0	-0.1 ±0.1	(-1)-0	[ac]ns [b]p<0.05
Crops	-0.4 ±0.3	(-2)-0	-0.6 ±0.3	(-2)-0	-0.2 ±0.2	(-1)-0	[ab]p<0.001 [c]ns
Other (Sheep)	0.0 ±0.0	0	0.0 ±0.0	0	0.0 ±0.0	0	-
Overall Mean:	-0.8		-0.6		-0.2		

[1] Ratings: "Definite Concern" (-2); "Some Concern" (-1); "No Concern" (0); "Some Benefit" (+1), or "Definite Benefit" (+2).
Statistical comparisons: [a] dogs vs. cats, [b] ferrets vs. dogs, [c] ferrets vs. cats
sem: standard error of the mean; ns: nonsignificant.



(Figure 3): "Existence of incidents" (impact) on agriculture from unconfined dogs, cats, ferrets (**a**) United States, Canada, and (**b**) California counties – Agriculture (Ag) agencies only. Rating mean ± standard error of the mean (sem). Asterisk represents significant difference; * $p < 0.05$, and ** $p < 0.01$.

Table 2: "Degree of concern" regarding the impact of unconfined animals on agriculture – Ag agencies only

Effects on Agriculture	Dogs		Cats		Ferrets		p-value
	Mean ± sem	[1]Rating Range	Mean ± sem	Rating Range	Mean ± sem	Rating Range	
United States, DC and Canada – Ag agencies							
Cattle	-1.6 ±0.2	(-2)-(-1)	-0.3 ±0.3	(-1)-0	0.0 ±0.0	0	[a]p<0.05 [bc]ns
Swine	-0.8 ±0.5	(-2)-0	-0.3 ±0.3	(-1)-0	0.0 ±0.0	0	[abc]ns
Poultry	-1.5 ±0.5	(-2)-0	-1.0 ±0.0	-1	-0.5 ±0.5	(-1)-0	[abc]ns
Fisheries	-0.7 ±0.3	(-1)-0	-0.5 ±0.5	(-1)-0	-0.5 ±0.5	(-1)-0	[abc]ns
Rabbits	-0.8 ±0.3	(-1)-0	-0.8 ±0.3	(-1)-0	0.0 ±0.0	0	[abc]ns
Crops	-0.5 ±0.3	(-1)-0	-0.5 ±0.3	(-1)-0	0.0 ±0.0	0	[abc]ns
Other (Sheep)	-2.0	-2	-	0	-	0	-
Overall Mean:	-1.1		-0.6		-0.2		
California counties – Ag agencies							
Cattle	-1.3 ±0.5	(-2)-0	0.0 ±0.0	0	0.0 ±0.0	0	[a]ns
Swine	-0.7 ±0.7	(-2)-0	0.0 ±0.0	0	0.0 ±0.0	0	[b]ns
Poultry	-0.3 ±0.3	(-1)-0	-0.7 ±0.3	(-1)-0	0.0 ±0.0	0	[abc]ns
Fisheries	0.0 ±0.0	0	0.0 ±0.0	0	0.0 ±0.0	0	-
Rabbits	0.0 ±0.0	0	-0.5 ±0.5	(-1)-0	0.0 ±0.0	0	[ac]ns
Crops	0.0 ±0.0	0	0.0 ±0.0	0	0.0 ±0.0	0	-
Other (Sheep)	0.0	0	0.0 ±0.0	0	0.0	0	-
Overall Mean:	-0.3		-0.2		0.0		

[1] Ratings: "Definite Concern" (-2); "Some Concern" (-1) ; "No Concern" (0); "Some Benefit" (+1), or "Definite Benefit" (+2).
Statistical comparisons: [a] dogs vs. cats, [b] ferrets vs. dogs, [c] ferrets vs. cats; NB: P-values were not computed for comparisons when both values of sem = 0.0.
Ag (Agriculture); sem: standard error of the mean; ns: nonsignificant.

incidents" of unconfined domestic carnivores. Similar to Table 1, the overall means show that unconfined dogs caused the greatest "degree of concern," followed by cats. Ferrets caused the least concern (overall means: dogs: -1.1; cats -0.6; ferrets -0.2). The overall means for the CA Ag agencies suggest "no concerns" for ferrets (0.0), and "little concern" for dogs (-0.3) and cats (-0.2); unconfined dogs caused the greatest "degree of concern" for "Cattle," "Poultry," "Swine," and "Sheep" and unconfined cats ranked highest for "Poultry" and "Rabbits."

Discussion

This is the first survey to our knowledge to evaluate the relative impact of unconfined dogs, cats, and ferrets on North American agriculture, exploring not only the impact on livestock but also on fisheries and crops. Prior studies, most of which were "grey literature" (government reports and position papers, and meeting presentations), were limited in scope, describing either the general impact of unconfined carnivores, or the impact of a specific carnivore species. Even so, our survey has both strengths and some weaknesses. A strength of the survey instrument includes the use of discrete ratings in addition to narratives, allowing participants to provide both categorical and subjective responses. Respondents represent a broad range of government agencies with similar roles and backgrounds within their respective agencies, producing a level of uniformity across jurisdictions. Also, the number of nonresponders is relatively small [39, 40]. Potential limitations are attributable to issues common to most surveys: inherent inaccuracies of retrospective reporting ("recall error"); intra-observer variation due to individual bias or experience; potential bias due to local laws, regulation and policies; and lack of documentation from respondents in support of their ratings [41, 42]. The potential for animal misidentification is also a possibility. Confusion in dog sightings could have arisen from sightings of wild canids, such as coyotes and wolves [43], or for cats, in sightings of bobcats, or in colder regions, lynx [44]. A reported "ferret sighting" near Fisheries, is refuted by an Oregon agency, writing: "… someone saw American River Otters or American Mink and mistook them for ferrets, which are not aquatic in nature." Other wild North American mustelids include weasels, martens, fishers, and the endangered wild native Black-footed Ferret; although, confusion with the latter species is highly improbable due its extreme rarity and limited range [45].

The survey results are generally consistent across reporting jurisdictions and agencies. No significant differences are noted between the ratings from Ag agencies and those of their non-agriculture counterparts from the same jurisdiction. Unconfined dogs and cats are observed in a variety of agricultural settings across the North American continent. Sightings of unconfined dog are cause for the greatest "degree of concern," with dogs having the greatest negative impact on livestock, which is consistent with prior reports. Under "Special Concerns," Wyoming and Texas call out "feral" dogs as causing depredation threats and harassment to livestock. An Ag respondent who rated dogs as having equal impact for both cattle and sheep, comments: "Under Wyoming Law, feral dogs and cats are allowed to be taken on sight by any legal means. If dogs are harassing or killing livestock they may be shot on sight." A Texas agency comments that unconfined dogs

are the second most common predators to cattle, goats, and sheep, following wild canids, such as coyotes, as the primary predators to livestock, reflecting previous reports from the state.

Under ("Special Concerns"), unconfined cats receive the majority of narrative comments. Many agencies cite difficulties in managing unconfined ("feral") cat populations in their respective jurisdictions, describing the negative impact of feral cats on other species. For example, Rhode Island writes, "Feral cats are becoming a large problem. Due to their semi-domestic nature, people have a lot of contact with them. We have had a couple of cases of rabies in these animals, and because people can handle some of them and often feed them, they are viewed as a high-risk population of animals for rabies from a public health viewpoint." Connecticut describes "over population by feral cats--rabies found in feral cats." Florida states: "We treat a number of people for rabies who have fed or handled feral cats."

Notably absent are sightings of unconfined ferrets. No state or provincial agency reports incidents from ferrets and, despite the state's official position that damage from unconfined ferrets is "well-documented," none of the California county agencies report ferret sightings, recording them as "historical" or "never." All agencies rank "existence of incidents" from ferrets as "probably does not exist" or "definitely does not exist." Furthermore, the CA county agencies rank the presence of ferrets in rural and agricultural areas at the lowest "degree of concern," with county Ag agencies rating ferrets of "no concern" to agriculture. In particular, the CA counties report "no concern" regarding the impact of ferrets on either "Poultry" and "Rabbits," two agricultural species that the state considers to be prey for "feral ferrets."

Though not a specific focus of the SeaSearch survey, several agencies chose the "Special Concerns" narrative to describe the potential for unvaccinated carnivores to transmit zoonotic diseases. New Hampshire reports: "Bites by all three species occur and pose a risk to rabies, injuries, and bite-related bacterial infections. This is a greater concern in stray and feral animals than in owned animals due to the difficulty in capturing [the animal] to monitor for signs of disease and decreased likelihood [that the] animal was vaccinated." Wisconsin states that unconfined animals pose a "…safety threat to general public and staff. Stray and feral animals can be harmful to wildlife populations, habitats, and other natural resource concerns such as disease."

Responding agencies mention a multitude of factors complicating their management of agricultural resources with regard to unconfined domestic carnivores. Not the least of which are the wide variability and the local nature of regulatory oversight, as well as changing public attitudes. In 1994, Green and Gipson reviewed the regulatory status, writing: "Many states, particularly those in the west, permit individuals to shoot dogs that are chasing or killing game animals or livestock. State agencies or agriculture departments usually are responsible for controlling feral dogs in rural areas. No states consider feral dogs to be game animals. Most cities have animal control agents to pick up abandoned and free-ranging domestic dogs [46]." At present, many jurisdictions, such as Virginia, have passed laws to curtail the aggressive behavior of unconfined dogs [47].

In our survey there were no agency reports that unconfined dogs, cats, or ferrets do- or would provide "some benefit" or "definitely a benefit" with respect to agriculture. Regardless, the merits of the "barn cat" and "farm dog" are being hotly debated across the continent. Proponents argue for the use of these animals in the agricultural setting and for them to remain free-roaming in order to perform their respective beneficial roles. Some jurisdictions are now implementing programs to promote the care and management of unconfined dogs and cats. Humane organizations are promulgating policies that promote the use of free-roaming cat populations both in urban, as well as agricultural settings [48, 49].

Healthcare programs are also being promoted by "barn cat" societies, addressing the need for immunizations, spay/neuter, flea and tick treatments, at no direct cost to individuals. In Europe, similar sentiments have led to the creation of the CALLISTO Project [**C**ompanion **A**nimals multisectoria**L** interprofessiona**L** **I**nterdisciplinary **S**trategic **T**hink tank **O**n zoonoses], with goals to promote a healthy balance of the benefits and risks to people and livestock when companion animals are maintained with livestock, and to develop recommendations to control the spread of zoonotic illnesses among companion animals, livestock, and humans [50]. Similar education of North American farmers is still needed. A 2018 survey of Ohio livestock owners revealed a lack of awareness and concern regarding the potential for zoonotic spread of disease between livestock and working dogs, or between working animals and their human counterparts [51].

Arguments for and against the use of free-roaming domestic carnivores in the agricultural setting are neither novel nor constrained to a particular geographical region. As the human population increases, the need for greater food production also grows, commensurate with the global expansion of agriculture. This increasing use of the planet by humans has resulted in the reduction of the natural habitats of wild carnivores, as well as the habitats of their prey. The negative impact of agriculture on carnivore species is succinctly summarized by Baker, et al.: "…the present status of many carnivores is intimately linked to historical and ongoing conflicts with humans concerning food production." These authors further argue that domestic cats and dogs, in particular, have ultimately benefited from human activities, many times at the expense of their wild counterparts.

In summary, this survey of government agencies of the US and Canada reports on the relative impact of unconfined domestic dogs, cats, and ferrets in agricultural settings. Results confirm frequent sightings of unconfined dogs and cats throughout North America, and the demonstrable negative impact of these two species on livestock and, in some cases, crops. In contrast, there are no reports of recent sightings of domestic ferrets

in agricultural settings, with most agencies considering such reports of historical interest, or a misidentification of local wild mustelids. No jurisdiction, including the county agencies of California, a state in which ferret ownership is currently banned, report on any ferret incidents or impact on agriculture. Although none of the government agencies surveyed report that agriculture "benefited" from unconfined domestic carnivores, ongoing efforts continue based on public sentiment to develop programs for managing unconfined dogs and, in particular, cats, in North American agricultural settings.

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Conflicts of Interest

The authors declare no conflict of interest.

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The following Supplemental Tables represent the data upon which Figures 2 and 3 are based.

Table S1: "Existence of incidents" (impact) on agriculture from unconfined dogs, cats, ferrets (all agencies)

Effects on Agriculture	Dogs		Cats		Ferrets		p-value
	Mean ± sem	Rating Range	Mean ± sem	Rating Range	Mean ± sem	Rating Range	
United States and Canada							
Cattle	3.1 ±0.4	1-4	2.1 ±0.6	0-4	0.6±0.2	0-1	[ac]ns
							[b]p<0.001
Swine	2.1 ±0.6	1-4	2.1 ±0.6	0-4	0.4 ±0.2	0-1	[a]ns
							[bc]p<0.05
Poultry	2.3 ±0.6	0-4	2.3 ±0.6	0-4	0.6 ±0.2	0-1	[a]ns
							[bc]p<0.05
Fisheries	1.1 ±0.1	1-2	0.9 ±0.13	0-1	0.7 ±0.2	0-1	[abc]ns
Rabbits	1.4 ±0.4	1-4	1.7 ±0.6	0-4	0.5 ±0.2	0-1	[ac]ns
							[b]p<0.05
Crops	1.4 ±0.4	1-4	1.3 ±0.5	0-4	0.5 ±0.2	0-1	[ac]ns
							[b]p<0.05
Other (Sheep)	4.0	4	1.0	1	0.5 ±0.5	0-1	-
Overall Mean:	**2.2**		**1.6**		**0.5**		
California Counties							
Cattle	2.3 ±0.3	0-4	1.8 ±0.4	0-4	0.4 ±0.1	0-1	[a]ns
							[b]p<0.001
							[c]p<0.01
Swine	1.5 ±0.4	0-4	1.1 ±0.4	0-4	0.5 ±0.2	0-2	[ac]ns
							[b]p<0.05
Poultry	2.2 ±0.3	0-4	1.9 ±0.4	0-4	0.5 ±0.2	0-2	[a]ns
							[b]p<0.001
							[c]p<0.05
Fisheries	0.3 ±0.1	0-1	0.5 ±0.2	0-2	0.4±0.1	0-1	[abc]ns
Rabbits	1.7 ±0.4	0-4	0.9 ±0.3	0-4	0.3±0.1	0-1	[ac]ns
							[b]p<0.01
Crops	0.6±0.2	0-2	1.1±0.4	0-4	0.4 ±0.2	0-2	[abc]ns
Other (Sheep)	0.0	0	0.5 ±0.5	0-1	0.0 ±0.0	0	-
Overall Mean:	**1.2**		**1.1**		**0.3**		

Rating scale: 0= Definitely does not exist, 1= Probably does not exist, 2= Reported to exist, 3= Previously existed, does not exist now, 4 Definitely exist now; Statistical comparisons: [a] dogs vs. cats, [b] ferrets vs. dogs, [c] ferrets vs. cats; sem: standard error of the mean; ns: nonsignificant.

Table S2: "Existence of incidents" (impact) on agriculture from unconfined dogs, cats, ferrets (Ag agencies)

Effects on Agriculture	Dogs		Cats		Ferrets		p-value
	Mean ± sem	Rating Range	Mean ± sem	Rating Range	Mean ± sem	Rating Range	
United States and Canada							
Cattle	2.8 ±0.5	1-4	1.5 ±0.6	0-4	0.5 ±0.2	0-1	[ac]ns
							[b]p<0.01
Swine	2.0 ±0.6	1-4	1.5 ±0.6	0-4	0.3 ±0.2	0-1	[ac]ns
							[b]p<0.05
Poultry	1.7 ±0.6	0-4	1.7 ±0.6	0-4	0.5 ±0.2	0-1	[abc]ns
Fisheries	1.2 ±0.2	1-2	0.8 ±0.2	0-1	0.7 ±0.2	0-1	[abc]ns
Rabbits	1.5 ±0.5	1-4	1.3 ±0.6	0-4	0.5 ±0.2	0-1	[abc]ns
Crops	1.5 ±0.5	1-4	1.3 ±0.6	0-4	0.5 ±0.2	0-1	[abc]ns
Other (Sheep)	4.0	4	1.0	1	0.5 ±0.5	0-1	-
Overall Mean	**2.1**		**1.3**		**0.5**		
California Counties							
Cattle	2.7 ±0.7	2-4	1.3 ±0.3	1-2	0.3 ±0.3	0-1	[abc]ns
Swine	0.7 ±0.3	0-1	1.0 ±0.0	1	1.0 ±0.6	0-2	[abc]ns
Poultry	1.3 ±0.3	1-2	2.3 ±0.9	1-4	1.3 ±0.3	1-2	[abc]ns
Fisheries	0.3 ±0.3	0-1	0.3 ±0.3	0-1	0.3 ±0.3	0-1	[abc]ns
Rabbits	0.7 ±0.3	0-1	1.0 ±0.6	0-2	0.3 ±0.3	0-1	[abc]ns
Crops	1.0 ±0.6	0-2	0.7 ±0.3	0-1	0.3 ±0.3	0-1	[abc]ns
Other (Sheep)	0.0	0	0.0	0	0.0	0	-
Overall Mean	**1.0**		**1.0**		**0.5**		

Rating scale: 0= Definitely does not exist, 1= Probably does not exist, 2= Reported to exist, 3= Previously existed, does not exist now, 4 Definitely exist now; Statistical comparisons: [a] dogs vs. cats, [b] ferrets vs. dogs, [c] ferrets vs. cats; sem: standard error of the mean; ns: nonsignificant