CENTER for BIOLOGICAL DIVERSITY — Because life is good.

***Via Electronic Transmission***

February 25, 2019

Representative Brad Witt
House Committee on Natural Resources
900 Court St., NE, H-478
Salem, Oregon 97301

**RE: Opposition to House Bill 2746**

Chair Witt and Members of the Committee:

The Center for Biological Diversity submits these comments on behalf of our nearly 30,000 Oregon members and supporters. The Center is a national, nonprofit conservation organization with more than 1.4 million members and online activists nationwide dedicated to the protection of endangered species and wild places. We have been deeply involved in Oregon wolf recovery, conservation and management issues since wolves began to return to the state in the early 2000's.

We oppose House Bill 2746 and urge you to not let this bill pass out of committee. We oppose the bill for the following three reasons:

**The Bill Would Compromise Discussions Which Took Place Between Stakeholders and Which Could Resume.** Currently, Oregon's Wolf Conservation and Management Plan (Wolf Plan) is in the process of being updated. At this stage, all stakeholders are opposed to multiple revisions to the Wolf Plan which have been proposed by the Oregon Department of Fish and Wildlife (ODFW), with no shared agreement by stakeholders. In an effort to find significant areas of agreement which would allow for the Wolf Plan update to move forward, last fall and winter ODFW held facilitated meetings with stakeholders. Multiple wolf-related issues were part of the discussions and negotiations, and the wolf compensation program is one of them. Most unfortunately, ODFW badly mishandled the stakeholder meetings – preventing the facilitator from doing her job, refusing to adequately consider the perspectives of conservation stakeholders, and announcing its intent to ask the state fish and wildlife commission to adopt a threshold for when wolves could be killed for livestock conflicts which is so low it would disincentive livestock operators to use any nonlethal conflict deterrence measures. ODFW's malfeasance in these meetings resulted in the conservation groups leaving the stakeholder process. It is possible stakeholder meetings could resume but even if not, increasing funding for compensation while ODFW is proposing quickly killing wolves instead of encouraging responsible livestock husbandry practices that would reduce conflicts – and thus the need for

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Amaroq Weiss, West Coast Wolf Advocate • 911 Lakeville Street #333 • Petaluma, CA 94952
Phone: 707-779-9613 • Fax: 800-637-7457 • aweiss@biologicaldiversity.org

more compensation – is the wrong approach. Note that the compensation program was called for in the Wolf Plan, and that the law creating compensation came from negotiations between the Governor, ODFW, conservationists, and the livestock industry. It is thus much more appropriate for this topic to be part of any facilitated multi-stakeholder discussions on the Wolf Plan. There's no emergency; if stakeholders fail to reach agreement, the legislature can take this up again next year. We request that the legislature allow for the possible resumed discussions between stakeholders without any interference or impediments caused by legislation.

**The Bill Expands the Compensation Program Without Requiring Needed Reform.** Oregon's wolf compensation program has been the subject of investigative reporting demonstrating a program rife with abuse and in substantial need of reform. In 2017, an exposé by Oregon Public Broadcasting revealed, among other things, inordinately large payments to counties with few wolves, insufficient documentation to verify that livestock for which compensation was given were in fact lost due to wolves and a scattershot approach between the county committees administering the compensation fund payments in their respective counties. HB 2746 seeks to make the compensation fund a permanent entitlement and expand the funds available without taking a single step towards reforming the program's abuses. The compensation fund is financed by taxpayers, who deserve assurance their money is being spent responsibly.

**The Bill Codifies into Law a False Premise That is Unsupported by Science.** HB 2746 seeks to tie the amount of funds available for compensation to the rate of growth of the wolf population. However, existing science does not conclude that the more wolves there are, the more wolf-predations on livestock there will be. On the contrary, published, peer-reviewed science concludes that a key correlative factor in wolf-livestock conflicts (predations) is the spatial overlap between wolves and livestock on the land, wolf density and livestock density. One study in Wisconsin was able to predict where there would be future conflicts by creating a risk map using locations of wolf pack territories and locations of livestock as predictors. (Treves et al 2011.) Another recently published study examined wolf-livestock conflicts in the northern Rockies and found that key predictive factors for conflicts were whether there had been conflicts in prior years in the same locations, and wolf density and livestock density with spatial geographic overlap. (DeCesare et al. 2018.) Spatial overlap between wolves and livestock and their densities in those locations -- not the overall size of the wolf population in the state at any given time -- are predictors of wolf-livestock conflict and thus potential need for compensation.

Oregon's own experience demonstrates that livestock predation is not correlated to the wolf population. As can be seen from the charts on the next page, if anything, reduced livestock predation in Oregon is correlated to enforceable requirements for non-lethal and a higher bar for killing wolves. The chart, labeled Figure 7, is taken from ODFW's annual wolf report from 2016. In the chart on the right, those years in which there existed enforceable requirements for non-lethal and a higher bar for killing wolves, 2013-2015, are highlighted in black. During this period the wolf population doubled and tripled but wolf predation events declined. To the extent the Wolf Plan's compensation program had support from multiple stakeholders it was predicated on the idea that it was a transitional tool to help ranchers readjust to the reality of wolves returning to the landscape - especially when the bar was low for when wolves could be killed. If anything, the program should be scaled back as the novelty of wolves wears off and the bar continues to be lowered for when wolves can be killed.

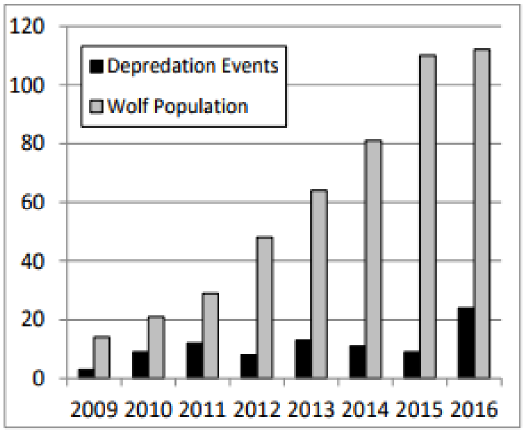


Figure 7. Number of depredation events and wolf population (2009-2016).

**Chart from 2016 ODFW annual wolf report, p. 11.**

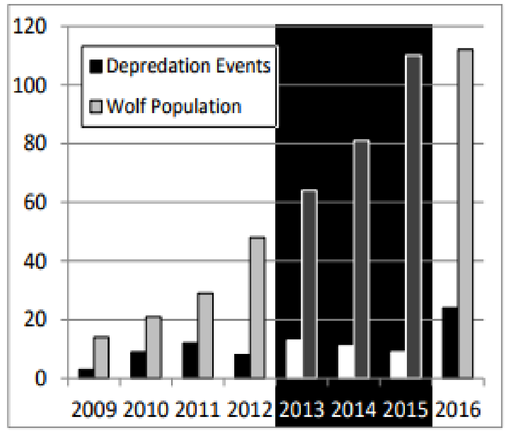


Figure 7. Number of depredation events and wolf population (2009-2016).

**Chart from 2016 ODFW annual wolf report, p. 11**
**(*black highlighting added for emphasis)***

## Conclusion

HB 2746 interferes with stakeholder discussions aimed at finding common ground, betrays the trust of Oregon taxpayers by avoiding needed reform, and codifies a false premise counter to current best available science. We oppose HB 2746 and urge you to do the same.

Sincerely,

Amaroq Weiss, M.S., J.D.
West Coast Wolf Advocate
Center for Biological Diversity
aweiss@biologicaldiversity.org

## Literature Cited (copies attached)

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CC: House Committee on Natural Resources
Governor Brown
House Speaker Tina Kotek

https://www.opb.org/news/article/questionable-payments-oregon-ranchers-wolves-cattle/

by **Tony Schick** Follow OPB/EarthFix July 17, 2017 noon | Updated: Sept. 29, 2017 8:22 a.m. | Halfway, Oregon

# Questionable Payments To Oregon Ranchers Who Blame Wolves For Missing Cattle

Many western states pay livestock operators for cattle and sheep lost to wolves depredation. But an EarthFix investigation found Oregon is making questionable payments to ranchers.
**Photo:** Tony Schick, OPB/EarthFix

Chad DelCurto parked his pickup beside the road winding the Snake River canyon, surveying the jagged green edge of Oregon where his cattle grazed. This is where he lost them.

There's ample feed and room to wander on these remote and rugged stretches of public land. But there's added risk to open range: harsh weather, disease, rustlers, predators.

"This is the reality — this is outside, all natural, grass-fattened beef," he said.

DelCurto dresses in denim from neck to ankle, with mud-splattered black on his boots and hat. He's been ranching all his life, and he's teaching his 9-year-old son to do the same.

Last year, DelCurto claimed he lost 41 calves and 11 cows out here in Baker County. Each calf could be worth over $700, the cows almost twice that.

He blames wolves. Alerts from state wildlife officials showed them in the area. He said the landscape showed some scat and tracks. And he could sense it in his cattle.

"You got up in there and tried to move them, could tell they'd been spooked," DelCurto said. "I can't prove it because there's no carcasses, but I know damn good and well the wolves had a big part in it."

So DelCurto filed for state-funded compensation for the losses, just as he did for nine missing cattle the year before.

A pack of wolves makes their way through the snow in Northeastern Oregon.
Courtesy of the Oregon Department of Fish and Wildlife

But here's the issue: There hasn't been a confirmed wolf kill of livestock in Baker County since 2012. And according to state biologists, there are only three known resident wolves in the county. Given that, a wolf-related loss of that size, with no carcass to show, would be unheard of.

Despite all that, the Baker County wolf compensation board approved DelCurto's claim. That left one state official with the dilemma of whether to deny the rancher compensation or approve a loosely documented claim so large it would have decimated the state program's budget.

Ever since wolves' return in the West, states have experimented with some form of compensation for ranchers, with mixed results.

Since 2012, Oregon has kicked in money for ranchers to hire range riders and purchase radios and fence lining, called fladry, to deter wolves. The state has also compensated livestock operators for both confirmed or unconfirmed losses of cattle, sheep or working dogs. It's a well-regarded program that provides some relief for ranchers feeling the added strain of a returned predator: even some of the wolf-advocate groups who clash with ranchers say it was necessary.

But an EarthFix examination found the state has made a questionable pattern of payments that contradicts established knowledge of the state's wolf population.

The investigation also found state and county officials do not take all the necessary steps to confirm claims of missing livestock and ensure a limited money pool flows toward legitimate claims of wolf kills. That can mean less money to prevent wolf conflicts, and less money for documented losses.

With no consistent system for verifying unfound livestock losses, the state has little way of knowing for sure whether it's denying some ranchers their due compensation or paying out claims it shouldn't.

**No biological explanation**

Chart the payments year over year, and a pattern emerges.

Since 2012, payments for missing cattle have increased when actual confirmed losses did not. Experts say those rates should track together.

"There is no possible biological or ecological explanation for this," said Luigi Boitani, an international expert on wolves who reviewed the data. In 2010, the University of Rome professor uncovered problems with wolf compensation in his home country of Italy.

"Small variations are understandable but the huge variation in the last few years has no justification," Boitani said. "The rate of confirmed deaths and missing livestock should track together."

Roblyn Brown, acting wolf coordinator for the Oregon Department of Fish and Wildlife, had a similar assessment: "I don't know of a biological explanation for why claims for missing livestock have gone up."

Others, like the Oregon Department of Agriculture, which administers the compensation program, say the change could be attributed to awareness: more and more ranchers discovering and utilizing these compensation programs.

Map the payments and another pattern emerges that confounds wolf biologists.

Since 2012 the state of Oregon has paid a total of over $150,000 to compensate ranchers for over 380 missing cattle and sheep. All of it has gone to three Northeast Oregon counties: Wallowa, Umatilla, and Baker.
Umatilla and Wallowa have large known wolf populations, and a history of confirmed depredations. Baker County has little of either, yet ranchers there have received more money than anywhere else in the state, at $65,000.

Brown had no explanation for this, either.

“We would expect wolf-caused missing livestock to be more likely in areas where we have seen confirmed depredations, and have high wolf density,” Brown said.

In total, payments for livestock losses in Eastern Oregon have far surpassed what state officials had projected based on data from other states.

The government might not believe DelCurto’s numbers, but he doesn’t believe the government’s either.

# An aerial view of land used for grazing in northeast Baker County, Oregon. Ranchers say the rough, forested terrain make it difficult to find missing or dead cattle.

**Photo:** Tony Schick, OPB/EarthFix

**Needle in a haystack**

He searched by horseback, trudging up ridges of snow. He searched by helicopter. Still, he couldn’t find his missing cattle.

“A foot of snow and you’re not cutting any tracks,” DelCurto said. “At that point, you start counting up and cutting your losses.”

He turned out about 350 head of cattle, including pregnant cows to give birth on the open range. DelCurto has done it many times. Usually, he said, more of them come back.

“That just doesn’t happen,” he said. “You don’t go to grass and have them die.”

Fellow ranchers near Halfway reported a combined 21 livestock missing that year they say were wolf-related.

There’s a reason ranchers expect to be compensated for losses, even without proof wolves are to blame: You try finding a cow carcass in 10,000 acres of wilderness.

“It’s just damn rugged and steep. Trying to find a corpse or something like that is like trying to find a needle in a haystack,” DelCurto said.

If you could take the flight DelCurto did, you would see what he means.

It is not the open pasture you might picture for cattle ranching. An hour soaring over Northeast Baker County reveals miles of dense timber and canyons.

But even discovering the remains of a cow thought to have been preyed upon by wolves doesn’t always mean much to cattlemen. Some no longer bother to report wolf kills to ODFW, they say, because they are unsatisfied with the response. Ranchers in Eastern Oregon have complained to the state that dead livestock investigations are too slow and allow the deterioration of evidence that could implicate wolves.

“We’re losing it. You’ve lost a lot of it,” Todd Nash of the Oregon Cattlemen’s Association told ODFW commissioners at a meeting in May. “Most of these aren’t called in in Wallowa County anymore. You have to backtrack into talking ranchers into participating again.”

There are at least 112 wolves statewide, mostly scattered across Wallowa, Umatilla and Union counties further north. There’s also a population further southwest, in the Klamath area.

The state’s best data show three wolves known to be residing in Baker County.

Dean Tucker, cow boss at the Pine Valley Ranch, left, and rancher Chad DelCurto talk wolves at Tucker's place in Richland, Oregon.
Tony Schick, OPB/EarthFix

DelCurto disagrees. So does his neighbor, Dean Tucker, the cow boss at Pine Valley Ranch in Halfway.

"When the Department of (Fish and) Wildlife tells the public there's only X number of wolves running around, they're full of s***," Tucker said.

Last year, Pine Valley Ranch reported five cattle missing because of wolves. The year before, it was seven.

"There's a hell of a lot more wolves than what they tell us," Tucker said.

Brian Ratliff, the local ODFW biologist, said the state's wolf population likely is higher than the official minimum estimates, but not by much. And there are wolves, like the Snake River Pack, for which the agency can only make educated guesses of their whereabouts.

He said his agency is almost surely under-counting the number of cattle and sheep killed by wolves, too, though he can't say by how many.

"You could not find 100 percent of livestock depredations. You could not do it," Ratliff said, referring to the forested landscapes where DelCurto and Tucker turn out cattle. "It's too broken, it's too rough."

In 2003, a research team from the U.S. Fish and Wildlife Service tackled the question of how many are missed. That often-cited study estimated for every livestock carcass you find killed by a wolf in rough country like this, there are seven more out there you don't find.

Baker County's payments fly in the face of that. For one proven depredation there, ranchers have been compensated for 85 missing cattle.

Other counties have much lower rates. In Umatilla County, the rate is just over one in seven. In Wallowa County, more cattle were confirmed dead from wolves than were claimed missing.

# Cattle poke their heads through the fence at Kelly Birkmaier's property east of Enterprise, Oregon.

**Photo:** Tony Schick, OPB/EarthFix

**The case for compensation**

Most Western states have some form of wolf compensation, an attempt to help ranchers with the added costs and stress from a predator they didn't want and felt was forced on them by people who don't bear the burden.

But payments for dead livestock don’t cut it, many say.

Kelly Birkmaier, who ranches in Oregon’s Wallowa County, said wolves have killed her cattle, injured them, spooked them and caused them to run through fences. The cost of all that adds up.

Harassment from wolves stresses cattle in ways that can reduce their weight gain or pregnancy rates, according to ranchers and others in the livestock industry. Beyond that, wolves can render cattle dogs useless, because cattle begin to associate them with wolves.

“Is this something we can keep doing? At this point in time, yes, it seems to still be working. But the added hardship and the added labor from the wolves make it challenging,” Birkmaier said.

Ranchers take pride in their cattle, she said, and when something out of their control threatens that, “it is very hard, mentally, on you.”

Kelly Birkmaier, Wallowa County rancher, at her property outside Enterprise, Oregon.
Tony Schick, OPB/EarthFix

For many years, the pro-wolf group Defenders of Wildlife compensated ranchers for losses as an attempt to increase tolerance for the predators, said Suzanne Stone, the organization’s Northwest representative. As wolves became more established, they stopped and states began creating their own, she said.

Idaho no longer compensates for missing livestock anymore, only for government-confirmed losses. When Idaho did compensate for missing livestock several years ago, its program was plagued by complaints about fraudulent claims.

“They would give compensation to their friends, sometimes they would compensate themselves,” said Stone, who is based in Boise, Idaho. “It was very loosely run. It would run out of money super quick, and people were only compensated for pennies on the dollar.”

Wyoming pays for missing cattle, but only if there’s also a confirmed kill. Using the ratio in the Fish and Wildlife study, Wyoming compensates for up to 7 missing cattle for each confirmed loss.

Washington recently began paying for indirect wolf losses, including missing animals, weight loss and reduced pregnancy rates. So far only two ranchers have used it since 2015. Its process is long and involved — each file for a livestock producer’s claim is over 50 pages of documentation. In Oregon, sometime’s it’s only two or three pages.

In Oregon, ranchers submit their claims through county boards, made up of county commissioners, ranchers, business members and wolf advocates.

When Oregon established its local-focused program, Stone said it had the potential to become the best in the country. The plan was to try it for a year or two, she said, and then re-evaluate to see if the right people are being compensated.

“I don’t think that the program’s been evaluated, at all,” she said. “And that really is an important step, so that you can make sure that it’s transparent, honest and sustainable.”

# Cattle graze in a pasture in Baker County, Oregon.

**Photo:** Tony Schick, OPB/EarthFix

**Questions over large claim**

Last year, the claim from Baker County was so large it raised questions at the Department of Agriculture.

Mike Durgan sat on Baker County’s compensation board at the time, when it approved a request of payment for 73 missing animals — 52 of which were DelCurto’s. Durgan quit, fed up with the county’s lack of due diligence.

“Baker County’s was not believable,” he said. “It was baffling to me how we let that slide by.”

He said unverified claims discredit a good program for honest ranchers.

“Some of the most anger I got was from other ranchers,” he said. “They realize something like this impacts them in a negative way.”

After the state started raising questions, Durgan said the board simply asked for less money, rather than trying to find the right number. Ultimately, Baker County received a total $16,125, still more than any other county. That included paying DelCurto for 12 missing cattle.

“I will say that the committee here, we started off with some missteps,” said Mark Bennett, a Baker County commissioner and rancher who sits on the compensation board.

Bennett said the county didn’t want to set a bar so high no rancher could clear it.

“We didn’t have a clear picture for our producers, what all was required,” Bennett said. “Some of them could come up with some really decent documentation, and some it was weak.”

**Lapses in oversight**

Across Oregon these requests are supposed to document ranchers used techniques to prevent wolf damage. They’re supposed to document that all other potential factors for the loss besides wolves have been ruled out.

State and county records show some do not, and the amount of evidence varies widely from claim to claim. Counties and ranchers are under no obligation to consult with ODFW, the state’s authority on wolf populations, about missing livestock.

Missing livestock compensation requests also rely extensively on documents detailing cattle counts at the start and end of grazing season, as well as estimates of historical losses. But the state has no standard for what evidence suffices, meaning not all ranchers are held to the same standard.

Claims that sailed through the process left one worker at the Department of Agriculture, Jason Barber, doing the job meant for several county compensation boards. In the past two years, Barber has raised questions about claims in Umatilla, Wallowa and Baker counties that were submitted without supporting documentation.

The result is a system with spotty evidence and large gray areas, meaning legitimate claims could be denied and questionable ones could be paid.

In one case, the state paid nearly $1,500 for a confirmed wolf kill, only to realize it wasn’t one more than a year later. The county was allowed to simply move the funds to the “missing livestock” category.

Last year, the state approved Wallowa County's grant application despite the fact that its compensation board never met to approve the request. Under deadline, a county commissioner sent the application to ODA without going through the process required by statute.

Barber, director of Internal Services and Consumer Protection at the Department of Agriculture, said the agency is working to improve the program and plans to create a checklist that counties can use "to make sure everything is kosher as far as what's in statute, what's in rule."

The state also has been unable to prove that ranchers are using the wolf-deterrent materials it's paid for ranchers to use, including fladry fence lining and radio boxes. The Agriculture Department didn't collect some counties' annual reports until EarthFix filed a public records request for them.

State-purchased fladry often sits in storage, as locals officials and ranchers say it is ineffective in the most problematic areas for wolf conflict.

To deter wolves, Baker County used the money to hire a range rider whom ranchers said they never saw. That left officials considering new ways to verify his time spent on the range.

Verifying the proper use of these funds has gained importance as wolves spread and more counties draw from the same pool of money — just over $210,000 this year. Already, the state has too little money to fund the requests it gets.

**Based on trust**

# Wallowa County rancher Dennis Sheehy at the Diamond Prairie Ranch near Enterprise, Oregon. Sheehy and a fellow rancher devised the first draft of Oregon's compensation plan back in 2010.

**Photo:** Tony Schick, OPB/EarthFix

Dennis Sheehy saw this coming. The longtime rancher is the father of Oregon's compensation plan.

As the sun set over Wallowa County, the cows mooed and cold air crept in over the Diamond Prairie Ranch. Sheehy was just finishing a long day of branding, and was facing another one in the morning.

"All of this was thought about when we put it together," said Sheehy, who devised the first draft of the compensation plan with a fellow rancher in 2010. It was adopted by the Legislature a year later.

"What it's based on is trust within the livestock industry here," he said. "There may be some people that do or do not have the same set of integrity and honor, you might say, about that."

As for a claim of 41 calves, like DelCurto's? It all depends.

"That might be a little extreme, but then another guy that I really do trust, they lost 16 or 17," he said.

Wolves are not the biggest threat, Sheehy said. At least to his ranch, they're just another problem that takes incremental bites into his operation's bottom line, along with drought, weather and cattle prices.

A few years ago, prices spiked and Oregon's cattle industry surpassed $900 million in total value, making it the state's top agricultural industry. Prices have fallen since.

“You’re going to see people going out of business,” he said, if prices stay low, and predators are just one more thing to tip the scale.

“Low prices, you get the wolves eating on you, lose two or three calves, it could be a little more serious,” he said. Sheehy said compensation has done its job: Lessen the blow to ranchers. But wolf territory is expanding in Oregon, and Sheehy doubts state leaders would fund a statewide compensation program.

He now wonders what will become of what he started.

# Forecasting Environmental Hazards and the Application of Risk Maps to Predator Attacks on Livestock

ADRIAN TREVES, KERRY A. MARTIN, ADRIAN P. WYDEVEN, AND JANE E. WIEDENHOEFT

*Environmental hazards are distributed in nonrandom patterns; therefore, many biologists work to predict future hazard locations from the locations of past incidents. Predictive spatial models, or* risk maps, *promise early warning and targeted prevention of nonnative species invasion, disease spread, or wildlife damage. The prevention of hazards safeguards both humans and native biodiversity, especially in the case of conflicts with top predators. Top predators play essential ecological roles and maintain biodiversity, but they can also threaten human life and livelihood, which leads people to eradicate predator populations. In the present article, we present a risk map for gray wolf (*Canis lupus*) attacks on livestock in Wisconsin between 1999 and 2006 that correctly identified risk in 88% of subsequent attack sites from 2007 to 2009. More-open habitats farther from any forest and closer to wolf pack ranges were the riskiest for livestock. Prediction promotes prevention. We recommend that the next generation of risk mappers employ several criteria for model selection, validate model predictions against data not used in model construction before publication, and integrate predictors from organismal biology alongside human and environmental predictors.*

*Keywords: animal damage management, carnivore conservation, human–wildlife conflict, probability surface, spatial model*

**Environmental hazards, such as emerging diseases and** wildlife damage, are distributed in nonrandom patterns. Therefore, many biologists work to predict hazards' future locations from their past patterns. Risk maps (also known as probability surfaces or predictive spatial models) can help predict where hazards will occur, whether they concern invasive species, emerging diseases, or predator–prey ecology (Jones et al. 2008, Kaartinen et al. 2009, Venette et al. 2010). Thus risk maps promise early warning and a way to target preventive action, which can safeguard both humans and ecosystems. Such prevention is particularly important when humans react to hazards by destroying the environment or retaliating against species, as is seen in conflicts between people and predators (Treves and Naughton-Treves 2005, Woodroffe and Frank 2005, Treves 2009). Predators play essential roles in ecosystems by exerting direct and indirect control of the numbers of herbivores and smaller predators, which in turn influence vast food webs (Estes et al. 1998, Terborgh et al. 2001, Smith et al. 2003, Ripple and Beschta 2004, Berger J 2007, Wallach et al. 2010). Yet predators sometimes pose threats to human life and livelihoods, which makes it difficult for most people to coexist with them (Gompper 2002, Treves and Naughton-Treves 2005, Shivik 2006, Treves 2009). Over the past two centuries, people have eradicated numerous populations of predators, including two species driven to extinction (Woodroffe and Ginsberg 1998, Woodroffe and Frank 2005, Woodroffe et al. 2005, Dickman et al. 2007, Sillero-Zubiri et al. 2007). Preventing conflicts between people and predators at the outset would support worldwide efforts to conserve biodiversity and to restore ecosystems (Terborgh and Estes 2010, Walston et al. 2010). Prevention of conflicts with predators would also protect human life and livelihood.

## Risk-mapping procedures

In this article, we present a risk map for conflicts between people and predators that includes several advances beyond past efforts. We describe novel methods usable in addressing other environmental hazards, from nonnative species invasions to emerging infectious diseases (Jones et al. 2008, Venette et al. 2010). Foremost, we verified the model's predictions on "future" data that were not used in model construction: We constructed a model for gray wolf attacks on livestock that took place from 1999 to 2006 in Wisconsin, and its predictions were verified by the data from subsequent affected sites from 2007 to 2009. Because the latter sites played no part in the model's construction, we concluded that the risk map is valid and predictive. We also integrated the organism's biology (wolf demographic and ecological variables) into the model, alongside human land-use and vegetation-cover predictors. Finally, we used exacting criteria for the retention of predictors so as to avoid overfitting our model with spurious predictors.

Locations of environmental hazards and the landscape features of these locations are the essential starting points for risk mapping. Wisconsin's wolf range contains temperate

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forests interspersed with open areas, wetlands, and many bodies of water (Mladenoff et al. 1997). Livestock farms ($n$ = 42) averaged 136 ha and 86 cattle kept on fenced private pastures, some partly forested (Treves et al. 2004). The Wisconsin Department of Natural Resources (WDNR) mapped and verified wolf attacks on domestic animals (depredations) statewide, using methods described previously (Treves et al. 2002, Ruid et al. 2009). The livestock ($n$ = 283) involved in these attacks were bovids (89%, mostly calves), ovids (14%), equids (4%), or two of the preceding types (7%). Livestock losses in this period resembled those from 1976 to 2000 (Treves et al. 2002). We examined 211 incidents recorded between 28 August 1999 and 22 May 2009. Before 2002, the WDNR recorded depredation locations ($n$ = 29) in standard legal coordinates (direction, township, range, and section) at a resolution of 2.56 square kilometers ($km^2$). From 2002 to 2009, the verifiers from the WDNR used ground-based global positioning system (GPS) coordinates to record locations more precisely ($n$ = 104). Therefore, we had 133 affected sites from 1999 to 2006 (figure 1) and 60 affected sites from 2007 to 2009. We discarded 18 additional depredation records from 1999 to 2009, because another had occurred on the same property within 48 hours, the location data were missing, or the GPS and legal coordinates were irreconcilable. The WDNR estimated the ranges of wolf packs every year, using direct and indirect methods (Wydeven et al. 2009). They located radio-collared wolves weekly in the winter with aerial telemetry (GPS location error was estimated at 142 m, in the range of error reported by Devault et al. 2003) and directly observed associated pack members in 40 to 60 packs annually. The WDNR used minimum convex polygons to estimate the ranges of wolves that had more than 20 radio locations. Two or fewer outliers more than 5 km from other locations were excluded from the range estimates, so the range polygons are underestimates (Wydeven et al. 2009). The WDNR estimated the ranges of packs without radio-collared individuals by repeated track surveys during snow-cover periods. These wolf pack ranges should therefore be considered estimates with error margins that vary among packs and among years. We assume that this uncertainty affects both our affected and our comparison unaffected sites because of their proximity (see below).

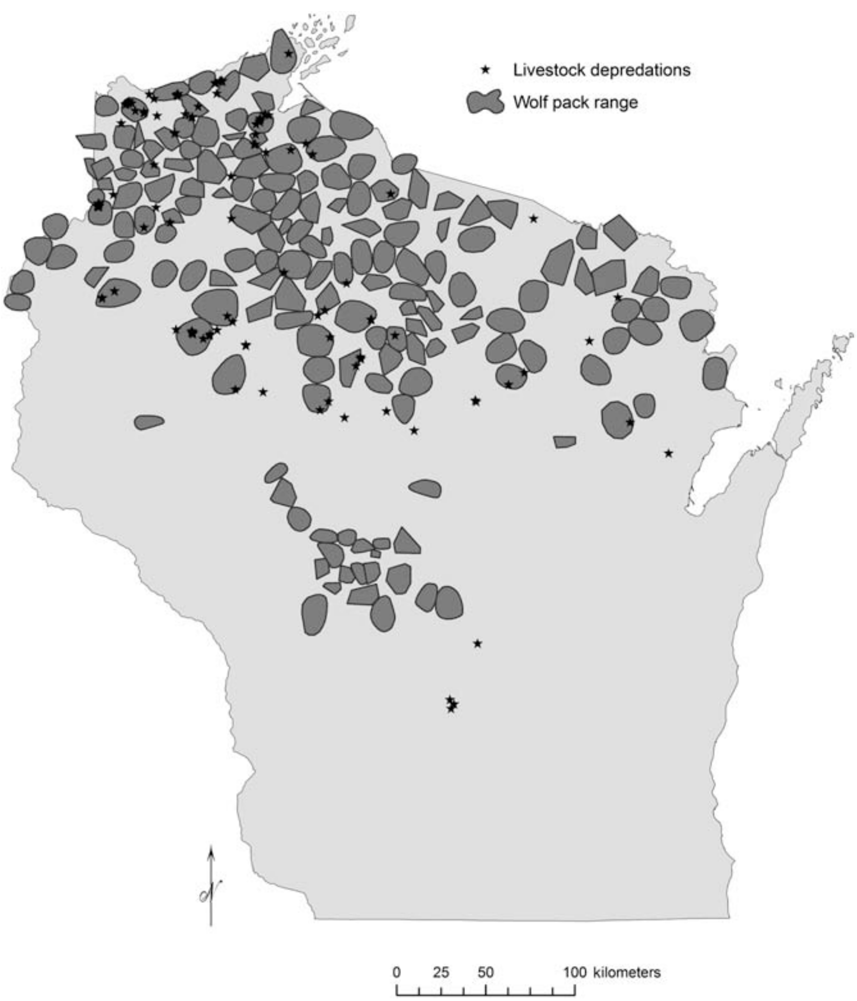


*Figure 1. Sites of wolf attacks on livestock (stars) in Wisconsin, between 1999 and 2006. The small gray polygons are the estimated wolf pack ranges. Cumulatively, 47 wolf packs were implicated in such attacks during this period; expressed as a percentage of the total number of packs, between 4% and 17% of the packs attacked livestock annually.*

To discriminate high-risk from low-risk sites for risk mapping, one needs a comparison set that minimizes framing bias—that is, a comparison set in which *absence* or *unaffected* sites are representative of the available landscape (Keating and Cherry 2004, Alexander et al. 2006, Venette et al. 2010). When one is finding the appropriate comparison set of unaffected sites, the biology of the study organism should be taken into account. We knew that wolves have crossed virtually all habitat types, except perhaps dense urban areas or deep water that never freezes (Wydeven et al. 1998, Kohn et al. 2009), so we did not set a habitat criterion other than to exclude Lake Superior and neighboring states (for which landscape data collection differed). However, framing bias can still arise. At one extreme, comparison sites might be inaccessible to the organism, thereby leading to trivial conclusions (e.g., wolves do not cause problems where wolves rarely occur, such as areas remote from wolf packs, which are only entered by the rare, dispersing wolf; Martin 2007, Treves et al. 2009a). At the other extreme of framing bias, one's comparison set should not resemble the affected sites too closely, lest one nullify significant predictors of risk. To balance these extremes of framing bias, we stipulated that unaffected sites not overlap affected sites but that they must be nearby. Distance is a known predictor of risk in other species (Naughton-Treves 1998, Hoare 1999), so we randomly chose unaffected sites from a ring-shaped area around each affected site, no farther than 10.2 km away, irrespective of the location of the nearest wolf pack (see the supplementary figure at *http://dx.doi.org/10.1525/bio.2011.61.6.7*). We also assigned unaffected sites to a year, in the same distribution observed for the affected sites, so that we could calculate wolf pack attributes for each unaffected point. Because packs change, appear, or disappear over time, the pattern of wolf demographics in the unaffected set was not identical to that in the affected sites. After model construction, we verified that our unaffected sites were representative of the unaffected area as a whole (see the supplementary figure at *http://dx.doi.org/10.1525/bio.2011.61.6.7*).

We identified the best predictors of the differences between the affected and unaffected sites from an array of variables collected over a 23.3-$km^2$ buffer area around the affected and unaffected sites (table 1). The wolf pack attributes were the averaged prior and subsequent winter counts (Wydeven et al. 2009) for the following four measures: (1) the distance to the nearest wolf pack range in kilometers (*DW*), (2) the number of pack members, (3) the area of the pack range, and (4) the number of wolves per square kilometer. We also collected the percentage of the area in each of nine land-cover classes (30-meter [m] resolution; Homer et al. 2007) and derived two new measures using ArcGIS Version 9.1 (ESRI, Redlands, California): (1) the length of the edge of all forest types in kilometers and (2) the distance to the closest forest of any type in kilometers (*DF*). A recent finding of systematic error in the forest-cover estimates (Nowak and Greenfield 2010) should influence the affected and unaffected sites equivalently. Finally, we estimated the density of people, houses, farms, roads, deer, cattle, and livestock premises in various geopolitical units (Mladenoff et al. 1997, US Census 2000, Treves et al. 2004). The buffers often spanned more than one geopolitical unit (census block, county, or township), so we calculated the average areal densities from each overlapped unit.

Previous efforts at risk mapping have involved single-model inference or multimodel inference with one or two criteria for selection of the best models (for a review, see Garamszegi 2011). We used two criteria before including a predictor in a multivariate model: The univariate logistic regression had to be significant, and the predictor could not be collinear with a stronger predictor. For multivariate modeling, we employed four additional criteria before adding a "surviving" predictor to the model. That predictor had to have a beta coefficient (± the standard error) that did not include zero (i.e., a "stable direction of relationship," after Mazerolle 2006), which was also significant at $p < .025$ (correction for the second use of the predictor in a logistic regression); it had to improve Akaike's information criterion (AIC) by two; and it had to improve the receiver operating characteristic (ROC), which is an estimate of discriminating power, by ≥1%. We used JMP Version 8 (SAS Institute, Cary, North Carolina) for statistical tests.

If the newest predictor met the preceding conditions, we retained it in the model and tested its interactions with prior predictors. These stringent criteria helped us to avoid overfitting the model and to hold each model to a performance criterion rather than to an arbitrary AIC criterion (Arnold 2010). Following Alexander and colleagues (2006) and Arnold (2010), we compared our final model with two

***Table 1. Predictors that discriminate sites of wolf attack on livestock from unaffected sites in Wisconsin between 1999 and 2006.***

| | Affected | | Unaffected | | | |
|---|---|---|---|---|---|---|
| **Predictor** | **Mean** | **Standard deviation** | **Mean** | **Standard deviation** | **Goodness of fit[a]** | **ROC** |
| Grass/pasture/hayfield (percentage of area) | 15 | 11 | 5 | 7 | 65*** | .81 |
| Distance to forest (in kilometers) | 0.08 | 0.09 | 0.03 | 0.09 | 18*** | .74 |
| Distance to nearest wolf pack (in kilometers) | 4 | 9 | 11 | 16 | 22*** | .70 |
| Open water (percentage of area) | 1 | 3 | 3 | 4 | 9** | .70 |
| Wooded wetlands (percentage of area) | 5 | 7 | 12 | 12 | 28*** | .68 |
| Length of the forest edge (in kilometers) | 5 | 1 | 4 | 2 | 16*** | .66 |
| The number of wolves per 10 square kilometers | 0.8 | 0.6 | 0.6 | 0.7 | 8** | .62 |
| Coniferous forest (percentage of area) | 10 | 9 | 7 | 10 | 7** | .61 |
| Emergent wetlands (percentage of area) | 5 | 6 | 3 | 4 | 4* | .60 |
| Deciduous forest (percentage of area) | 51 | 15 | 56 | 22 | 4* | .58 |

[a]Univariate logistic regression ($\chi^2$), $n = 266$, degrees of freedom = 1.
ROC, receiver operating characteristic (predictive discrimination power analogous to sensitivity and specificity).
$*p < .05$, $**p < .01$, $***p < .001$

previously published models, one from Michigan (Edge et al. 2011) and one from Wisconsin and Minnesota (Treves et al. 2004). Finally and most importantly, we verified the best model against sites of predator attacks between 2007 and 2009 ($n = 60$) and mapped risk across Wisconsin's wolf range.

Out of 21 initial predictors, 10 were significant in univariate logistic regression (table 1). Although prior work suggested that livestock density would be important, our measures of cattle per county and livestock premises per township were both collinear with the percentage of cropland cover (Pearson's $r > .7$), so we retained the latter variable because it had finer resolution. No other predictors used in multivariate tests were collinear in pairwise comparisons ($|r| > .7$). We began with the strongest predictor—the percentage of the area that was grass, pasture, or hayfield (table 1), which had also been the strongest in 2004 (Treves et al. 2004)—then added the next-strongest predictor, in order of ROC.

We found only one model with high likelihood (equation 1; table 2; $n = 266$, $\chi^2(4) = 105$, $r^2 = .284$, $p < .0001$; no lack-of-fit $\chi^2 = 264$, $p = .29$),

$$P\,(\text{affected}) = \frac{1}{\left(1+e^{.7948 - 9.7366G - 12.0753DF + .0681DW + .6065(DW - 7.1806)(DF - .0544)}\right)}, \quad (1)$$

where $P$(affected) is the probability that a given area of 23.3 km$^2$ will be affected by wolf attack on livestock; $G$ is the percentage of the area under grass, pasture, or hayfield; $DF$ is the distance to the nearest forest; and $DW$ is the distance to the nearest wolf pack range.

The probability of wolf attack on livestock was higher at open habitat sites (which may correlate with livestock availability on pastures), closer to a known wolf pack range, and farther from any type of forest, with an interaction between the last two predictors such that sites far from forest and far from wolf packs were less risky. The mechanism underlying this interaction remains obscure.

Comparing new models with models derived from theory or with those in prior publications will help advance understanding and management. We did so, and the results are in table 2: The previously published models were not likely by AIC, nor did they improve the ROC, and equation 1 significantly outperformed each one. This result suggests either that temporal or regional variation exists in the sites of wolf attack on livestock or that our current model's inclusion of $DW$ and $DF$ improved the predictive performance of equation 1. We feel that $DW$ in particular reflected the probability of wolf attack more closely than had variables in previous models.

We set the threshold between the affected and unaffected sites at $P$(affected) = .365 in order to maximize the model's sensitivity and the specificity for past sites. At that threshold, equation 1 discriminated past sites of wolf attack on livestock with 87% sensitivity for the affected sites (115 of the 133 affected sites were identified correctly) and 77% specificity for the unaffected sites (103 of the 133 unaffected sites were identified correctly), which is significantly greater than would be expected from chance (assuming $P$(affected) = 63.5% , binomial exact $p < .0001$).

Model verification against future data is essential if we wish to disseminate risk maps with confidence. Therefore, we tested the predictive ability of our model using 60 sites of verified depredation between 2007 and 2009, which played no part in our model construction. Of these sites, equation 1 identified 53 (88%) correctly as affected ($p < .0001$). Therefore, the model appears robust to interannual variation and has real predictive power.

We made post hoc comparisons of classification errors ($n = 25$) and the correct predictions ($n = 168$) for all affected sites between 1999 and 2009. There was a higher

*Table 2. Alternative models of wolf attack on livestock in Wisconsin 1999–2006.*

| Predictors added | Log likelihood[a] | K | AIC | ΔAIC | ROC |
|---|---|---|---|---|---|
| **The present study** | | | | | |
| None | 184 | 1 | 371 | 97 | .500 |
| Grass/pasture/hayfield (percentage of area) | 152 | 2 | 308 | 33 | .813 |
| Distance to forest (in kilometers) | 149 | 3 | 303 | 29 | .825 |
| Distance to nearest wolf pack (in kilometers) | 138 | 4 | 283 | 9 | .841 |
| Distance to wolf pack × distance to forest | 132 | 5 | 274 | 0 | .867 |
| Saturated (predictors from table 1 added) | 129 | 11 | 280 | 6 | .874 |
| **Alternative models from the literature** | | | | | |
| Treves et al. 2004 (for Minnesota and Wisconsin townships) | 149 | 7 | 313 | 39 | .802 |
| Treves et al. 2004 (for Minnesota and Wisconsin farms) | 149 | 8 | 314 | 40 | .805 |
| Edge et al. 2011 (for Michigan) | 151 | 4 | 309 | 35 | .810 |

[a]From ordinal logistic regression ($n = 266$), all $p$-values < .0001.
$K$, one more than the number of predictors; AIC, Akaike's information criterion (lower values of AIC are more probable); ΔAIC, the difference in AIC relative to best model; ROC, receiver operating characteristic.

proportion of errors associated with large-livestock than small-livestock losses (28% versus 10%; $\chi^2(1) = 6$, $p = .012$; *small* refers to ovids, calves or foals, whereas *large* refers to adult cattle or adult equids). A similar analysis for type (ovid, equid, or bovid) was weaker ($\chi^2(2) = 5$, $p = .077$). A higher proportion of classification errors occurred when the verifiers had not implicated a specific wolf pack (29%, 11%, and 10% for *none implicated*, *uncertain*, and *confident* ratings, respectively, on the verification form: $\chi^2(2) = 7$, $p = .028$). Although such patterns deserve further attention in the field, they are probably not useful in predicting wolf attacks on livestock, because they are measured after an attack has occurred.

To disseminate the verified and validated model, we mapped risk within 100 km of every wolf pack from 2009 across 125,125 $km^2$ of Wisconsin. We calculated risk for each 30-m pixel as an average of landscape predictors in a 23.3-$km^2$-radius moving window. We mapped risk in six color categories within 100 km of the wolf pack ranges (figure 2). By visual inspection, high-risk clusters (areas larger than a few square kilometers with a >75% probability of being affected by equation 1) in red or orange occur near the coast of Lake Superior and the edge of the wolf range to the south, as was previously noted (figure 1; Treves et al. 2004). In addition, new high-risk clusters appear from the western to the south-central portions of the wolf range that were more recently recolonized (Wydeven et al. 2009). Two hot spots just south of Lake Superior had verified attacks between 2007 and 2009, but a third high-risk cluster somewhat inland did not. The two highest-risk categories with *P*(affected) > 75% covered 10.5% of the map pixels, the next three covered 22.1%, and the lowest-risk unaffected pixels covered 67.4% of the map (figure 2).

Interpreting risk maps requires care. These maps are correlational, not causal; therefore, any landscape predictor is best interpreted as a complex association of environmental variables. In our case, we cannot disentangle a wolf pack's history and individual membership from its landscape correlates, because the wolf pack ranges did not change much from year to year. Nevertheless, the predictive power of the associations that we demonstrated leads us to recommend that wildlife managers and livestock owners act to mitigate the risk posed by high concentrations of grassland, pasture, or hayfield far from forest and near wolf packs.

Interpreting the predictive power of land cover, we found ostensibly high-risk areas of northwest Wisconsin containing extensive open areas (barrens, savannas, and recent clearcuts) that are likely mostly devoid of livestock (figure 2). Our map suggests that bringing livestock into these areas would generate a high risk of wolf attack. Lower-risk areas are where forest is largely unbroken by open land covers (north) or far from wolf packs (northeast and south). The higher risk associated with open areas may reflect the presence of livestock, although our other estimators of livestock presence were not independently predictive (tables 1 and 2). In any case, this greater risk for livestock in open areas should not necessarily be interpreted as predators being attracted to livestock (Treves et al. 2004). Predators follow

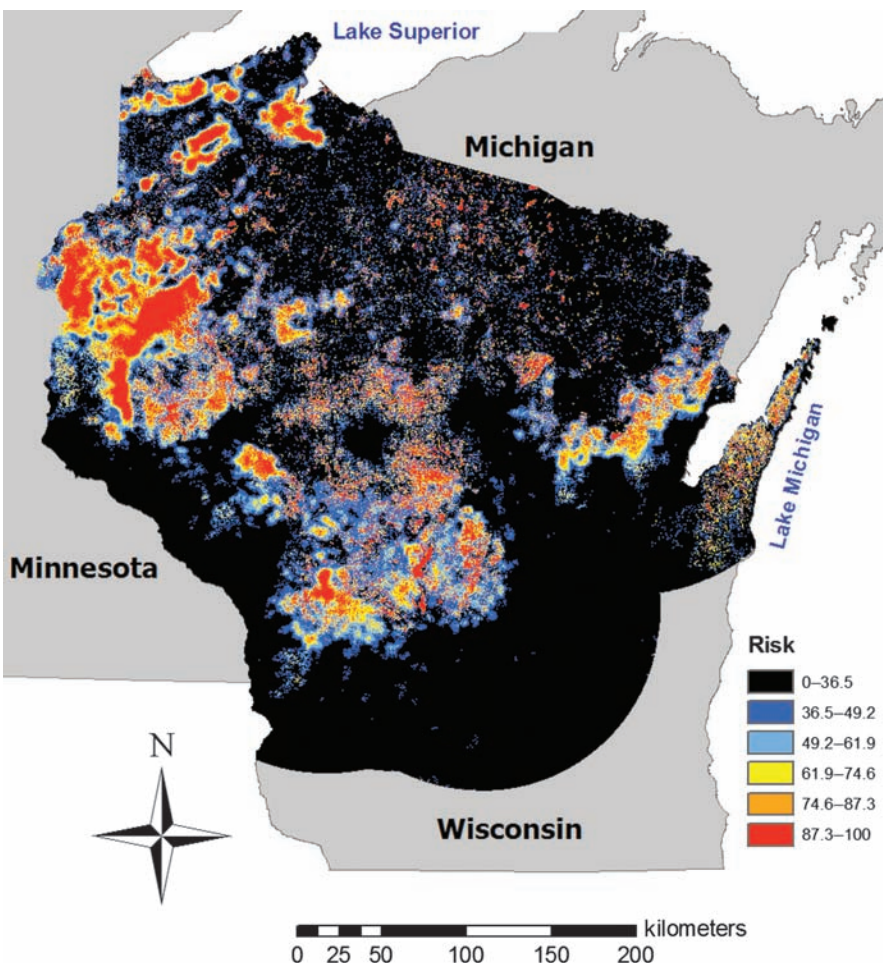


***Figure 2. Predicted percentage of future risk of wolf attack on livestock in Wisconsin from equation 1. The colors categorize risk by pixel (30-meter resolution) such that unaffected pixels are black (67.4% of the map); other colors represent P(affected) > .365 in evenly sized bins. The raster layer used to map risk introduced shifts of up to 30 meters in distance from forest (DF; equation 1), producing a 3% average mapping error.***

their wild prey and may thereby incidentally encounter humans or their property (Bradley and Pletscher 2005, Packer et al. 2005). For example, Norwegian *Lynx lynx* did not select sites with sheep, but rather those with many roe deer (*Capreolus capreolus*; Odden et al. 2008). The same may be true in Wisconsin after wolf movements are related to distributions of both deer and livestock with the greater spatial resolution afforded by GPS collars.

The proximity of wildlife habitat to crops and livestock is a known farm-level risk factor in species as diverse as elephants (*Loxodonta africana*), chimpanzees (*Pan troglodytes*), and brown bears (*Ursus arctos*) (Naughton-Treves 1998, Hoare 1999, Wilson et al. 2006). Our results emphasize the risk associated with raising livestock near a wolf pack. Indeed, we found classification errors by our model when the verifying agent did not implicate a specific wolf pack, which may reflect the distance from the known, established wolf packs. For example, four of the errors in the 2007–2009 verification were 47 to 58 km from the nearest wolf packs, which might be explained by the presence of new, unidentified wolf packs; nonpack wolves (loners or dispersers); or some other canid misidentified as a wolf (e.g., feral dog, wolf–dog hybrid, coyote [*Canis latrans*]). Although some loners or dispersers have attacked livestock (Treves et al. 2002, Wydeven et al. 2010), our map and model suggest that a few wolf packs are more likely livestock predators than others. Incorporating the distance from an animal's range and the histories of known individuals or groups seems a reasonable next step for other wildlife hazard models. Likewise, we recommend that those aiming to construct risk maps for other organismal hazards pay attention to any organism's sensory capacities and movements within its environment.

Most of the world's carnivores are recovering in less-glamorous landscapes such as Wisconsin's mixed-use agroecosystem, rather than in wildernesses. So the relevance of our work extends beyond the Great Lakes, or even the United States, to Scandinavia, Western Europe, and India (for wolves) and to many other regions for other large carnivores: Andean bears (*Tremarctos ornatus*), leopards (*Panthera pardus*) and tigers (*P. tigris*), to name just a few. Furthermore, we mapped risk across 125,125 km$^2$, which showed that approximately 10% of the state's wolf range is at high risk. Preventive intervention can be more focused and cost effective when high-risk clusters are targeted than when risk is assumed to be ubiquitous. Finally, gray wolves are the subjects of intense research interest and public policy debate in Europe and the United States as these governments deliberate over how to manage predators so as to reduce conflicts with recovering populations of various species. Our work offers a scientific path to minimizing conflicts and restoring top predators in areas beyond wilderness and vast protected areas.

Around the world, it is common for people to kill wildlife indiscriminately when they perceive them as threats (Karanth and Madhusudan 2002, Treves and Naughton-Treves 2005, Woodroffe and Frank 2005, Woodroffe et al. 2005). Predator attack prevention would be a preferable approach and would safeguard rare animals, such as top predators or keystone species with disproportionate or essential roles in ecosystem function. Selective responses to problem individuals are needed, whether these individuals are livestock producers or predators. To date, people have been largely unable or unwilling to discriminate between individual culprits and nonculprits when addressing problems with wild animals (Treves and Naughton-Treves 2005, Treves 2009). As a result, indiscriminate killing has been perceived as cost effective. Research on coyotes near sheep suggests that decades of government-financed, lethal coyote control with a variety of methods have not succeeded in reducing sheep losses (Knowlton et al. 1999, Bartel and Brunson 2003, Berger KM 2006). Indeed, routine elimination of large numbers of nonculprits can exacerbate sheep losses (Knowlton et al. 1999). Risk maps point the way to more selective interventions in conflicts between wild animals and people (Wilson et al. 2006, Kaartinen et al. 2009). First, private citizens may be able to modify activities, animal husbandry, or habitats to reduce their vulnerability with a diverse array of antipredator deterrents (Treves et al. 2009b). Second, managers can work proactively with residents on cost-effective preventions in areas where conflicts are most likely. Third, policymakers may use risk maps to promote selective treatment of both problem predators and problem properties. Prevention of most human–wildlife conflict promises to preserve the ecological function and aesthetic or recreational benefits of wildlife in mixed-use landscapes. However, a key prerequisite is for policymakers, managers, and the public to relinquish the outdated view that all predators are problems.

For others constructing risk maps, we recommend four steps that have not always been included in prior efforts: (1) Stringently filter predictors by multiple criteria that reflect their contributions to predictive power. (2) Incorporate human land uses, organismal biology, and land cover simultaneously. (3) Move beyond simple land cover to derived measures that can approximate the organism's movements through the environment (e.g., the distance to forest cover rather than the percentage of forest cover). Finally, (4) verify any model with subsequent data, because internal validation may not suffice. The idea that risk is ubiquitous and ever present must give way to a more nuanced understanding of the factors that make environmental hazards predictable and preventable.

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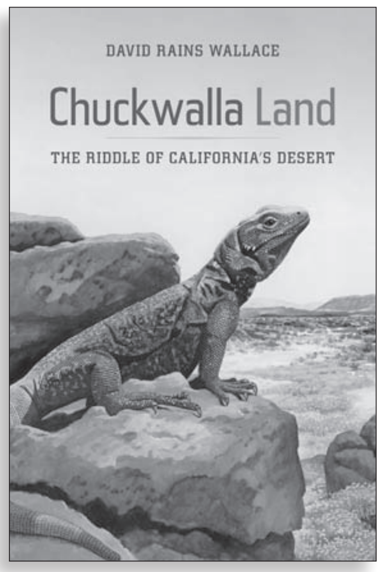
*Adrian Treves (atreves@wisc.edu) is an associate professor of environmental studies at the University of Wisconsin–Madison. Kerry A. Martin is assistant faculty associate in the Department of Zoology at the University of Wisconsin–Madison. Adrian P. Wydeven is a mammalian ecologist, and Jane E. Wiedenhoeft is rare mammal database and global information system specialist and carnivore tracker, at the Park Falls Service Center of the Wisconsin Department of Natural Resources.*



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*Research Article*

# Wolf-Livestock Conflict and the Effects of Wolf Management

**NICHOLAS. J. DeCESARE,**[1] *Montana Fish, Wildlife & Parks, Missoula, MT 59804, USA*
**SETH M. WILSON,** *Northern Rockies Conservation Cooperative, Missoula, MT 59801, USA*
**ELIZABETH H. BRADLEY,** *Montana Fish, Wildlife & Parks, Missoula, MT 59804, USA*
**JUSTIN A. GUDE,** *Montana Fish, Wildlife & Parks, Helena, MT 59620, USA*
**ROBERT M. INMAN,** *Montana Fish, Wildlife & Parks, Helena, MT 59620, USA*
**NATHAN J. LANCE,** *Montana Fish, Wildlife & Parks, Butte, MT 59701, USA*
**KENT LAUDON,**[2] *Montana Fish, Wildlife & Parks, Kalispell, MT 59901, USA*
**ABIGAIL A. NELSON,** *Montana Fish, Wildlife & Parks, Livingston, MT 59047, USA*
**MICHAEL S. ROSS,** *Montana Fish, Wildlife & Parks, Bozeman, MT 59718, USA*
**TY D. SMUCKER,** *Montana Fish, Wildlife & Parks, Great Falls, MT 59405, USA*

**ABSTRACT** Wolf (*Canis lupus*) depredations of livestock are a ubiquitous source of conflict in every country where wolves and livestock overlap. We studied the spatial and temporal variation of wolf depredations of livestock in Montana during 2005–2015, including evaluations of targeted control efforts and public harvest as potential means to reduce depredations. During this time we collected spatial data for all confirmed wolf-livestock depredations, tallied the annual number of depredation events within hunting districts, and collected data for variables potentially predictive of depredation events. We decomposed variation in depredation data into 2 distinct components: the binary presence or absence of depredation events in each district-year, and the count of depredation events in district-years with $\geq$1 event. We found that presence-absence of depredations increased with wolf presence and wolf density, increased with livestock density, were highest at intermediate proportionate areas of agricultural land, and were a recurrent phenomenon such that districts with depredations the previous year were more likely to continue having them. Targeted removal, but not public harvest, significantly reduced the recurrent presence of depredations. The number of conflicts in district-years with $\geq$1 depredation event was positively correlated with wolf density, cattle density, intermediate proportionate areas of forested land, and the number of events during the previous year. Public harvest reduced the counts of depredation events in areas where conflict reoccurred, though with a modest predicted effect size of 0.22 fewer depredations/district-year, or 5.7 fewer depredation events statewide/year (8% of the annual average). Minimizing livestock losses is a top priority for wolf management. These results shed light on the broad-scale patterns behind chronic problems and the effectiveness of wolf management practices in addressing them. © 2018 The Wildlife Society.

**KEY WORDS** *Canis lupus*, cattle, harvest, human-wildlife conflict, hunting, lethal control, livestock depredation, wolves.

Wolf (*Canis lupus*) depredations of livestock are a ubiquitous source of conflict in every country where wolves and livestock overlap (Fritts et al. 2003). Eliminating depredation was a primary reason behind historical efforts to exterminate wolves, and their subsequent recovery in portions of North America and Europe has brought familiar challenges of understanding, reducing, and mitigating conflicts with livestock (Bangs et al. 2009, Boitani and Ciucci 2009).

Wolf-livestock conflicts, in particular, can be difficult to explain or predict with statistical approaches relative to other forms of human-wildlife interactions (Mabille et al. 2015), yet some consistent patterns have emerged. The risk of livestock depredation has increased in areas with greater numbers of both wolves and livestock and with higher spatial overlap among them (Bradley and Pletscher 2005, Gula 2008, Kaartinen et al. 2009, Treves et al. 2011). Depredations have been positively associated with particular land cover types, including forested or agricultural vegetation or a mix of both (Bradley and Pletscher 2005, Kaartinen et al. 2009). Densities

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[1]*E-mail: ndecesare@mt.gov*
[2]*Present Address: California Department of Fish and Wildlife, Redding, CA 96001, USA.*

of wild ungulate prey have been linked to wolf-livestock conflicts in some regions, though results have included positive (Bradley and Pletscher 2005, Imbert et al. 2016, Nelson et al. 2016) and negative (Gula 2008, Kaartinen et al. 2009) correlations. Studies of temporal patterns of wolf-livestock conflict have shown strong seasonality, with monthly depredation totals peaking during late summer in North American and European study areas (Ciucci and Boitani 1998, Harper et al. 2008, Bradley et al. 2015). Also apparent from previous studies is a predictable pattern of recurrence of depredations in areas with prior conflicts (Karlsson and Johansson 2010, Bradley et al. 2015).

Efforts to reduce the occurrence of carnivore depredations of livestock have included 2 suites of widely applied tools: non-lethal deterrents such as visual or auditory deterrents, barriers, enclosures, or guardian animals, and lethal removal of carnivores, including targeted removal following depredation events and non-targeted reduction of populations through public harvest (Miller et al. 2016). Studies of targeted lethal control have been controversial regarding its effectiveness for reducing depredations by wolves (Harper et al. 2008, Wielgus and Peebles 2014, Poudyal et al. 2016, Treves et al. 2016, Kompaniyets and Evans 2017). Detailed assessments accounting for the autocorrelated nature of depredations have typically shown a significant effect of targeted removals in reducing future depredations by wolves (Harper et al. 2008, Bradley et al. 2015, Poudyal et al. 2016).

Little is known about the effects of public harvest on wolf-livestock conflicts, though studies in other carnivore-livestock systems suggest a range of possible outcomes (Treves 2009, Treves et al. 2016). Harvest can reduce sheep depredations by Eurasian lynx (*Lynx lynx*) primarily by reducing the overall abundance of lynx at broad spatial scales (Herfindal et al. 2005). To the contrary, hunter harvest of black bears (*Ursus americanus*) does not affect numbers of nuisance bear complaints (Treves et al. 2010) or bear-related depredation costs (Huygens et al. 2004). Regulated public hunter harvest of wolves began in portions of the western United States in 2009. Although harvest in this region significantly affects population dynamics of wolves (Gude et al. 2012, Ausband et al. 2015), it is unclear whether these effects or other behavior-mediated effects of harvest (Imbert et al. 2016) translate to changes in the rates at which the wolf population depredates livestock.

Efforts to reduce wolf-livestock conflicts in Montana have included a host of non-lethal practices implemented cooperatively by individual livestock producers, non-governmental organizations, and public agency staff (e.g., Wilson et al. 2017). Management to reduce conflicts also has included lethal removal of wolves by public agencies, permitted landowner take, and most recently public harvest, beginning in 2009 (Bradley et al. 2015). Despite these practices, depredations negatively affect some livestock producers, and the economic effects of these are partially mitigated through compensation programs. In Montana, financial reimbursements of >\$300,000 were paid during 1987–2008 for confirmed wolf-caused livestock depredations by a private fund administered by a non-government organization (i.e., Defenders of Wildlife; K. Paul, Defenders of Wildlife, unpublished data). Since 2008, compensation payments and funding for prevention efforts have been administered by the Montana Livestock Loss Board (MLLB), a state legislature-created panel of governor-appointed members. Payments for confirmed livestock losses to wolves from the MLLB have averaged \$96,245/year to producers within Montana during 2009–2015 (G. Edwards, MLLB, unpublished data).

Minimizing and mitigating livestock depredations are key priorities for wolf management and conservation in Montana and other jurisdictions, and future management will benefit from continued reassessment of and subsequent improvements to actions geared to minimize conflicts. Our objective was to summarize the spatial and temporal patterns of wolf-livestock conflict over the past decade within Montana and evaluate the influence of hypothesized predictors of conflict in local areas. We hypothesized that spatio-temporal factors influencing conflict in Montana during this period would be like those reported in previous studies, and we included a novel assessment of public harvest as a potential management strategy for reducing conflict.

## STUDY AREA

Our study was in Montana, USA during 2005–2015. Montana is 380,832 km$^2$ in area and ranges in elevation from 555–3,904 m. The western portion of the state consists predominately of a portion of the Rocky Mountains, whereas the eastern portion includes large expanses of prairie-badlands and prairie-agricultural lands mixed with timbered river drainages and island mountain ranges. January temperatures average $-12°$ to $-6°$C and July temperatures average 18° to 23°C. Precipitation varies widely depending on location and elevation, with average annual precipitation ranging from 17–88 cm/year. Most wolves and wolf-livestock conflicts occur in western Montana, where land cover includes a mix of coniferous forest-dominated mountains separated by large valleys containing grassland, rangeland, or agricultural vegetation types. Major wild prey species for wolves in Montana include elk (*Cervus canadensis*), deer (*Odocoileus* spp.), moose (*Alces alces*), and other species.

## METHODS

### Confirmed Wolf-Livestock Depredations

We briefly reviewed the time series of depredation events during 1985–2015 but restricted our spatio-temporal summaries and analyses to 2005–2015 to focus on contemporary patterns. We recorded depredations of livestock by wolves as events, such that the injuring or killing of ≥1 livestock at a given place and time was 1 event. The United States Department of Agriculture Wildlife Services staff confirmed depredation events following standardized protocols (Roy and Dorrance 1976). The number of depredation events and the number of livestock injured or killed per event represented minimum numbers of actual livestock loss given the occurrence of additional, unconfirmed depredations (Oakleaf et al. 2003). We restricted our analyses solely to confirmed events, and removed events from the data that included only animals deemed to be probable or possible cases of wolf-caused injury or mortality (3.6% of events).

Overall, 786 confirmed depredation events occurred during 2005–2015. To study spatial and temporal patterns of depredations at broad scales, we treated administrative hunting districts (districts) as polygonal sample units and assigned each depredation to 1 of 162 districts across the state. Sufficient spatial information (e.g., recording of spatial coordinates or district) were available to assign 760 (97%) of the 786 depredations to a specific district. We then counted the number of depredation events occurring within each district for each calendar year. District boundaries followed topographic and anthropogenic features, which led to variable sizes with a median area of 1,280 km$^2$ ($\bar{x} = 2{,}198 \pm 2{,}779$ [SD]; range = 44–18,688). To control for the influence of differences in area among districts when counting depredation events, we calculated standardized counts by adjusting counts according to the relative area of districts. We adjusted the raw counts ($x_{\text{raw}}$) to standardized counts ($x_{\text{adj}}$) for each hunting district ($i$) relative to the median district area by multiplying them by an adjustment factor ($a_i$) where,

$$a_i = \frac{\text{area}_i}{\text{area}_{\text{median}}}, \text{ and}$$

$$x_{\text{adj},i} = x_{\text{raw},i} \times a_i. \quad (1)$$

We used the median district area instead of the mean because the distribution of district areas is right-skewed by relatively few large-area districts in the eastern portion of the state.

**Potential Explanatory Variables**

*Wolf abundance, removals, and harvest.*—We tallied the numbers of wolves and packs within each district at the end of each calendar year, and used values at the end of a given year to predict the subsequent year's depredation responses. Thus, for the 2005–2015 study of depredations, we counted wolves at the end of each year during 2004–2014. We monitored the number of wolves and wolf packs (defined as groups of $\geq 2$ wolves with established territories) statewide using a combination of capture and radio-telemetry, direct observational counts, howling and snow-track surveys, remote cameras, and public wolf reports (Coltrane et al. 2016). Each year we sought to document pack size, determine pack territories, and verify wolf activity in new areas, indicating new packs. Counts of wolves were minimum counts and not population estimates (Coltrane et al. 2016). These efforts resulted in the documentation of 1,071 pack-years and 5,170 wolf-years across the state during the study period. We captured and handled wolves in accordance with Montana Fish, Wildlife and Parks' (MFWP) biomedical protocol for free-ranging wolves, which has been approved by the MFWP animal care and use committee (MFWP 2005).

We estimated spatial locations of packs using minimum convex polygon home range estimates from very high frequency (VHF) and global positioning system (GPS)-based radio-telemetry (39% of pack-years) and using survey and observational data to estimate the centroids of pack home ranges (61% of pack-years), which we then buffered to be circular home ranges equal in area to the statewide average home range size of 599.8 km$^2$ (Rich et al. 2012, Coltrane et al. 2016). We then estimated the annual numbers of wolves and packs within each district by summing pack home ranges and pack sizes contained within districts. When home ranges spanned multiple districts, we assigned counts of packs and wolves proportionately to each overlapping district according to the proportion of the home range area contained by each. To account for the differences in area among districts when monitoring wolves, we converted total counts of packs and wolves to densities of each per 1,000 km$^2$ by dividing the total counts by the district area (in thousands of km$^2$).

The numbers of wolves killed through targeted lethal removals and public harvest were also reported annually during the study period and tallied annually for each district. The United States Department of Agriculture—Wildlife Services (USDA-WS) conducted targeted removal efforts and methods included trapping and shooting from the ground or aircraft. We used pack identification information from each targeted removal to assign removals to hunting districts according to the district(s) overlapped by the packs' home range. Targeted removals were conducted by USDA-WS under statutory authority according to the Animal Damage Control Act of 1931 and in cooperation with the Montana Department of Livestock under statutory authority according to MCA 81-7-102. During the 2009 and 2011–2015 public wolf hunting and trapping seasons (there was no such season in 2010), MFWP monitored wolf harvest using a mandatory reporting requirement for all wolves harvested by hunters and trappers. Only hunting was allowed during the 2009 and 2011 seasons, and hunting and trapping were allowed during 2012–2015. Public harvest of wolves was regulated under the auspices of legal hunting and trapping seasons defined by the Montana Fish & Wildlife Commission, under the authority granted to them in statute MCA 87-1-301. Reporting requirements included a legal description (i.e., township, range, section) of the harvest location, which allowed us to spatially assign each harvested wolf to a district. Harvest totals were 72 wolves during the 2009–2010 season, 166 during the 2011–2012 season, 225 during the 2012–2013 season, 230 during the 2013–2014 season, and 207 during the 2014–2015 season, and location descriptions were available for 97% of wolves harvested. To account for the differences in area among districts when monitoring wolf mortality, we converted total counts of removals and harvest per district to densities of each per 1,000 km$^2$ by dividing the counts by the district area (in thousands of km$^2$). Like our treatment of pack and wolf densities, we tested the densities of removals and harvest for a given calendar year on the subsequent years' variation in depredation events.

*Agricultural land cover and livestock density.*—We estimated the proportionate area of rural agricultural land (including irrigated and non-irrigated grazing lands) within each district using property type attributes of each private land parcel provided by the Montana Cadastral Mapping Project of the Montana State Library (Montana State Library 2015). We then estimated the proportionate area of forested land within each district using Montana Land Cover Framework data from the Montana Natural Heritage Program (Montana Natural Heritage Program 2013).

We obtained annual head counts per county during 2004–2015 for livestock (cattle and domestic sheep) in Montana from the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS 2015). We estimated the proportion of agricultural land within each county that was contained within each hunting district and used these values to divide the total numbers of livestock per county among overlapping hunting districts. Lastly, we estimated the density of cattle, sheep, and livestock (cattle and sheep) per hunting district in 2 ways: density per area as head count divided by district area, and density per agricultural area as the head count divided by area of agricultural land per district. We conducted all spatial analyses using ArcGIS 10.1 (ESRI, Redlands, CA, USA).

## Statistical Modeling of Spatial and Temporal Patterns in Wolf-Livestock Depredations

We used descriptive statistics and maps to summarize patterns of livestock depredations across the state and over time. These included characterizations of the annual numbers of depredation events over time, number of individual livestock killed per event, and spatial patterns of depredation events per unit area. We assessed spatial variation among districts first in terms of the proportion of years during which $\geq$1 depredation occurred within each district. This characterized the degree to which depredations were a chronic problem within a district. We also evaluated the average annual count of depredations within each district to characterize the within-year frequency at which depredations occurred. We then used statistical modeling to ask 3 questions about variation in depredation events over space and time.

*Presence-absence versus number of depredations.*—Our first question was if annual variation in the statewide number of depredation events was influenced by changes in the presence–absence of depredations among varying numbers of districts or by changes in the number of depredations per district in areas where they occur. In other words, was a year with high overall depredations characterized by numerous places with conflict, or instead by higher numbers of conflicts in the same typical places? During subsequent analyses (questions 2 and 3), we sought to understand the factors influencing each of these 2 processes. Initially asking about the relative contribution of each process to the statewide totals established a basis for us to interpret how much emphasis should be placed on the factors influencing each process.

To address our first question, our response variable was the annual count of depredation events statewide, during 2005–2015 ($n = 11$ annual counts). We used multiple linear regression to regress the extent to which 1) the annual number of districts with $\geq$1 depredation event and 2) the average number of depredation events per district with $\geq$1 explained variation in the overall statewide total. We then used estimates of the average semi-partial correlations of each component to assess how much of the total variance was explained by each (Kim 2015).

*Factors affecting presence-absence and number of depredations.*—To study the spatial and temporal factors influencing depredations across Montana during 2005–2015, we followed a form of hurdle modeling wherein we distinctly modeled covariates of the presence-absence of depredations in a given district-year (question 2) and the count of depredations in a district-year given $\geq$1 event (question 3; Bolker et al. 2012). The approach is called hurdle modeling because the user first models what variables describe the likelihood of clearing a hurdle, in this case having $\geq$1 depredation. Then, among those districts with $\geq$1 depredation, a second model is fit to describe the relative frequency, in terms of the count of depredation events per year. In a framework of generalized linear mixed-effects models (GLMMs), we used logistic regression to develop binary models of the initial presence of depredations (zero vs. non-zero) and a truncated negative binomial regression to develop count models for the subsequent number of depredations when present. Preliminary comparisons among Poisson, negative binomial (NB), and truncated negative binomial distributions (with NB1 and NB2 variance parameterizations; Bolker et al. 2012) concluded the latter with an NB1 variance parameterization best fit the data for counts of depredations. We screened sets of predictor variables included in multivariable models to avoid having correlated ($r > 0.6$) variables together within models, and we checked models for error inflation or coefficient changes due to multicollinearity. We conducted all statistical analyses using Program R, version 3.1.1 (R Core Team 2014), and the packages ppcor version 1.1 (Kim 2015) and glmmADMB version 0.8.3.2 (Bolker et al. 2012).

We developed models assessing patterns of variation in presence and count of depredations over space (among districts within a given year) and over time (among years within a given district). We treated each district-year as a sample unit and included a random intercept for year to treat each year as a new trial comparing variation among districts. This approach parameterized a spatial comparison of variation in depredations among districts within each year and with respect to spatially varying covariates concerning wolf and livestock densities and land cover types measured per district. In addition to measuring the effect of wolf density, we also included a binary covariate for the presence or absence of wolves, as determined at the end of the previous year. We recognize that the presence of wolves is an innate component of a depredation event in real-time, yet our minimum count data instead represented an imperfect depiction (including false negatives) of wolf presence during the prior year. We used this covariate to control for spatial variance in the annual statewide presence of wolves while testing for the effects of other covariates on spatial variance in livestock depredations.

To additionally study the temporal rate of change in depredations within a given district over the 11 years of study, we also included a covariate characterizing the presence or count of depredations in the previous year. This approach tested whether depredations were a temporally autocorrelated phenomenon, such that the presence or number of depredations in any one year could be predicted by that of the previous year. We then included additional variables that interacted with the previous year's presence or count, which allowed us to test whether other variables such as targeted removals or public harvest had any effect on the recurrence of depredations over time.

We used Akaike's Information Criterion (AIC) to evaluate the relative support for both binary and count models, and conducted comparisons among models in batches using a mix of *a priori* groupings of candidate models and manual forward stepping comparisons (Arnold 2010). We first evaluated different covariates characterizing wolf populations in each district, including wolf presence, pack density, and wolf density. Upon selecting a best model with the lowest AIC from this suite of variables, we then evaluated new models including suites of candidate variables characterizing livestock densities. We next evaluated models including land cover variables, using quadratic terms to accommodate non-linear relationships. Next, we tested for temporal autocorrelation by adding to the model a variable characterizing the previous years' presence-absence or count of depredations within each district. This evaluated whether patterns of the previous year were predictive of the current year, which would imply temporal autocorrelation. We then tested interactions of public harvest and targeted removals with this autocorrelation parameter to assess whether harvest or removals had any effect on the trend in depredations from year to year within a given district. We tested the binary presence-absence of any level of harvest or removals and the number and proportion of wolves harvested or removed within each district. When evaluating the effects of public harvest, we restricted analyses to a subset of depredation data during years that followed harvest (2010, 2012–2015). In using AIC to evaluate model support, we followed recommendations of Arnold (2010), which included using additional information (e.g., values of β/SE) to identify and remove models with non-informative parameters when comparing nested models.

## RESULTS

### Descriptive Statistics and Maps of Wolf-Livestock Depredations

With natural recolonization of wolves into northwest Montana came an initially small number of livestock depredation events, ranging from 0 to 5 annually during 1987–1995 (Fig. 1a). Following the 1995 reintroductions of wolves into Yellowstone National Park and central Idaho, USA annual numbers of wolves and depredations in

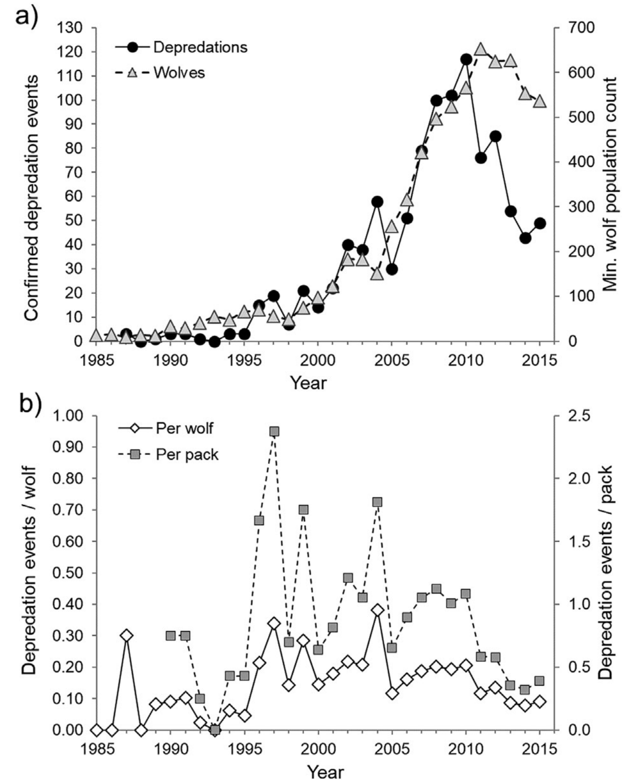


**Figure 1.** Annual numbers of a) confirmed livestock depredations by wolves and minimum wolf counts and b) depredations per known wolf and pack statewide, Montana, USA, 1985–2015.

Montana rose gradually, from 15 confirmed depredations in 1996 to a peak of 117 in 2010. However, as the minimum population counts for wolves leveled off during 2011–2015, numbers of depredation events showed a disproportionate decline. For comparison, annual *per capita* depredation events during 1995–2010 appeared relatively stable, averaging $0.20 \pm 0.08$ events/wolf, but decreased during the subsequent 5 years, averaging $0.10 \pm 0.02$ events/wolf (Fig. 1b).

During our 2005–2015 study period, there were 786 confirmed depredation events of livestock, 80% of which were attacks on cattle, 15% on sheep, and 5% on other domestic animals including (in order of abundance) horses, llamas, and goats. We excluded 26 additional events during which dogs were killed or injured without harm to livestock from these analyses. Among confirmed cattle depredation events, 13% involved injury to livestock but no deaths, 74% were lethal to a single animal, and 12% were lethal to more than one animal; the mean deaths per event involving cattle was 1.03 animals (median = 1, SD = 0.66, range = 0–6). Among sheep depredation events, 1% involved injury to livestock but no deaths, 33% were lethal to a single animal, and 66% were lethal to more than one animal; the mean deaths per event involving sheep was 5.03 animals (median = 2, SD = 8.49, range = 0–82). Depredation events occurred primarily on private land (83%) but also on public (14%) and tribal lands (3%).

Comparison of the cumulative proportion of statewide depredations with cumulative area covered by districts showed a notable concentration of events in relatively few districts. For example, 95% of depredation events occurred in 22% of the state. Spatial display of the proportionate presence of livestock depredation events across the 11-year period revealed several regions of Montana where depredations were chronic (Fig. 2a). After adjusting counts of depredation events for each district to be relative to the median district area (eq. 1), 16% of district-years included ≥1 depredation event. For those districts with ≥1 event during the 11-year study period, there was on average an event in 35% of years, and the maximum was 100% of years (11 of 11 years), which occurred in 2 districts. Among districts with ≥1 depredation event, the raw number of events for a given district-year varied from 1–19, though adjusting these data to a standardized median area resulted in an adjusted range of 1–21 depredation events/district-year. Average annual numbers of depredation events followed a similar spatial pattern to their proportionate presence (Fig. 2b).

**Statewide Annual Depredation Totals**

The annual totals of wolf-livestock conflicts mathematically reflect changes in both the number of districts with depredations and the number of depredations per district in affected districts. Multiple linear regression analysis of the average semi-partial correlations for each component indicated that approximately 48% of the variation was influenced by changes in the number (or proportion) of districts with depredations, whereas 51% of the variation was influenced by variation in the average number of depredations per district when and where they occurred (Fig. 3). This result establishes the equal importance of understanding the factors influencing the presence-absence of depredations and the number of depredations where and when present.

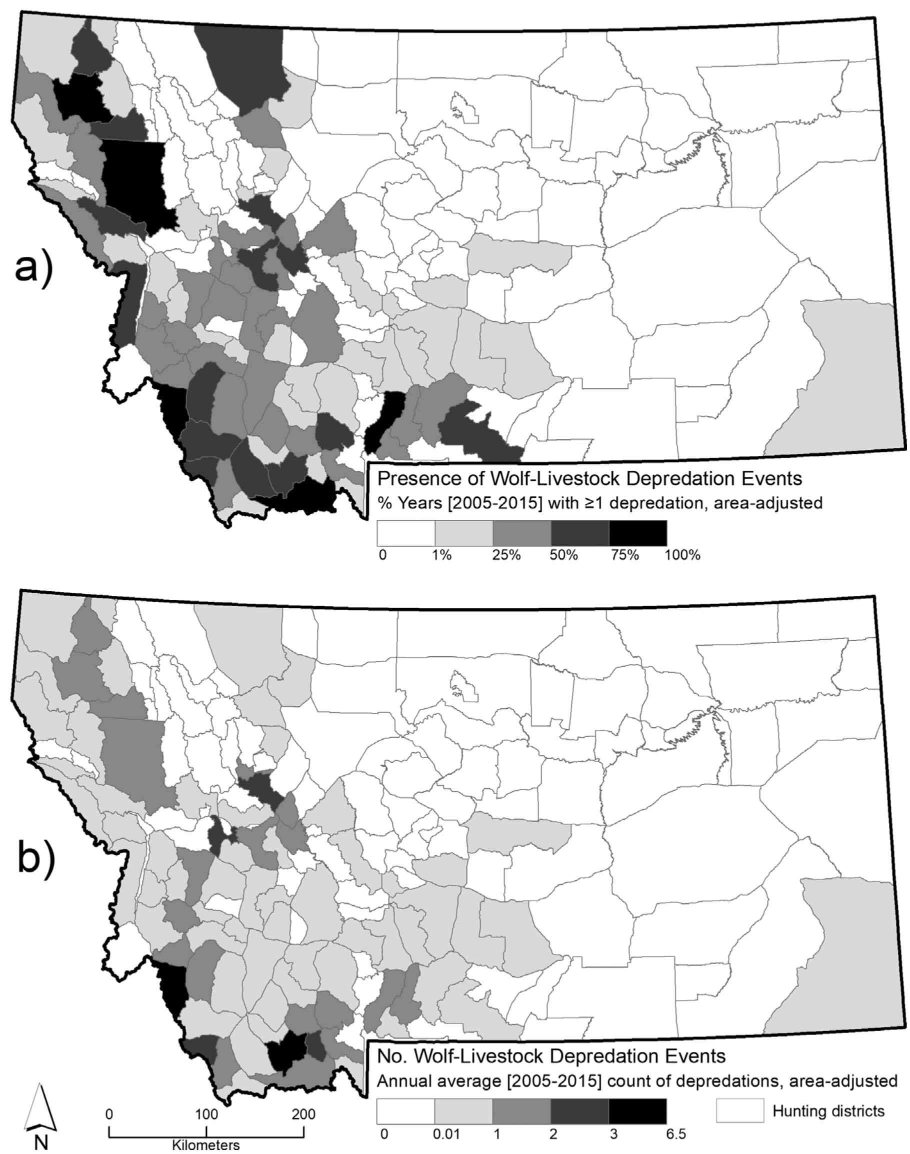


**Figure 2.** Spatial variation in wolf-livestock conflicts as measured by a) percent of years with ≥1 confirmed depredation event and b) average annual count of depredation events, each standardized by the area of each district relative to the median area of 1,280 km$^2$, Montana, USA, 2005–2015.

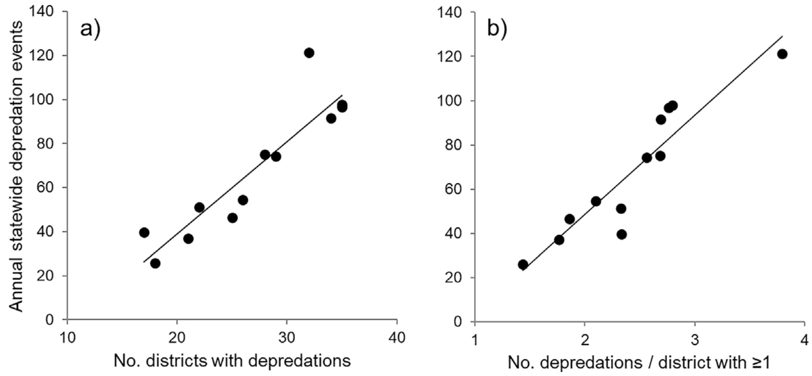


**Figure 3.** Linear regression showing positive relationships between the statewide annual total of wolf-livestock depredation events (*y*-axis) and annual variations in a) the number of districts with depredations and b) the average number of depredation events occurring in districts with ≥1 event, Montana, USA, 2005–2015.

### Factors Affecting Presence–Absence of Depredations

We used GLMMs to study the presence-absence of wolf depredation events for a data set of 1,782 district-years over 162 districts and 11 years. Model selection of candidate logistic regression models yielded several statistically significant predictors of the presence or absence of wolf depredations of livestock (Tables 1 and 2). Depredations were more likely to occur in districts where wolves were documented as present during the previous year, and with greater densities of wolves (Table 2 and Fig. 4). The density of wolves (the product of pack density and the number of wolves per pack) was more predictive than that of packs, though both were statistically significant in univariate models. The density of livestock (cattle and sheep), measured per unit of agricultural land within each district, was also positively related to the probability of depredations (Table 2 and Fig. 4). The proportionate area of agricultural land showed a significant quadratic relationship with the presence of depredations, such that the peak probability of a depredation occurring with respect to this variable occurred at 48% agricultural land within a district.

**Table 1.** Sequential model selection results for 5 steps comparing batches of multiple logistic regression models of the probability of ≥1 wolf-livestock depredation event occurring in each hunting district and year, including model log-likelihoods (ll), degrees of freedom (df), and Akaike's Information Criterion (AIC), Montana, USA, 2005–2015. We carried the best model ($\Delta$AIC = 0) from each step to the next modeling step.

| Step | Variables | ll | df | AIC | $\Delta$AIC |
|---|---|---|---|---|---|
| 1 | Wolf presence + wolf density | −654.7 | 4 | 1317.3 | 0.0 |
| | Wolf presence + pack density | −657.4 | 4 | 1322.7 | 5.4 |
| | Wolf presence | −658.7 | 3 | 1323.4 | 6.1 |
| | Wolf density | −741.6 | 3 | 1489.1 | 171.8 |
| | Pack density | −748.9 | 3 | 1503.9 | 186.6 |
| | Intercept only | −787.6 | 2 | 1579.1 | 261.8 |
| 2 | Step 1 + livestock density (per agricultural area) | −629.7 | 5 | 1269.4 | 0.0 |
| | Step 1 + cattle density (per agricultural area) | −630.1 | 5 | 1270.2 | 0.8 |
| | Step 1 + cattle density (per agricultural area) + sheep density (per agricultural area) | −629.5 | 6 | 1271.1 | 1.7 |
| | Step 1 + sheep density (per agricultural area) | −634.0 | 5 | 1278.1 | 8.7 |
| | Step 1 + livestock density (per total area) | −635.3 | 5 | 1280.5 | 11.1 |
| | Step 1 + cattle density (per total area) | −637.4 | 5 | 1284.7 | 15.3 |
| | Step 1 + cattle density (per total area) + sheep density (per total area) | −636.7 | 6 | 1285.5 | 16.1 |
| | Step 1 + sheep density (per total area) | −644.4 | 5 | 1298.8 | 29.4 |
| | Step 1 | −654.7 | 4 | 1317.3 | 47.9 |
| 3 | Step 2 + proportionate agricultural land + proportionate agricultural land$^2$ | −606.7 | 7 | 1227.5 | 0.0 |
| | Step 2 + proportionate forested land + proportionate forested land$^2$ | −615.2 | 7 | 1244.3 | 16.8 |
| | Step 2 + proportionate agricultural land | −625.2 | 6 | 1262.4 | 34.9 |
| | Step 2 | −629.7 | 5 | 1269.4 | 41.9 |
| | Step 2 + proportionate forested land | −629.7 | 6 | 1271.4 | 43.9 |
| 4 | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal density) | −559.5 | 9 | 1136.9 | 0.0 |
| | Step 3 + depredations$_{t-1}$ | −562.3 | 8 | 1140.7 | 3.8 |
| | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal proportion) | −561.9 | 9 | 1141.9 | 5.0 |
| | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal presence) | −562.3 | 9 | 1142.7 | 5.8 |
| | Step 3 | −606.7 | 7 | 1227.5 | 90.6 |
| 5[a] | Step 4 | −269.4 | 9 | 556.8 | 0.0 |
| | Step 4 + (depredations$_{t-1}$ × public harvest density) | −269.2 | 10 | 558.4 | 1.6 |
| | Step 4 + (depredations$_{t-1}$ × public harvest presence) | −269.4 | 10 | 558.8 | 2.0 |
| | Step 4 + (depredations$_{t-1}$ × public harvest proportionate) | −269.4 | 10 | 558.8 | 2.0 |

[a] We used a subset of data for this final step to include only those years following an administrated wolf harvest; thus, AIC values are not comparable with models from previous steps.

**Table 2.** Coefficients (β), standard errors, Wald test statistics (*Z*), and significance values (*P*) of the best multiple logistic regression model characterizing predictors of the probability of ≥1 wolf-livestock depredation event occurring in each hunting district and year in Montana, USA, 2005–2015.

| Variable | *β* | SE | *Z* | *P* |
|---|---|---|---|---|
| (Intercept) | −5.61 | 0.417 | −13.5 | <0.001 |
| Wolf presence | 2.22 | 0.300 | 7.40 | <0.001 |
| Wolf pack density (wolves/km$^2$) | 0.048 | 0.017 | 2.84 | 0.005 |
| Livestock density (head/km$^2$ of agricultural land) | 0.036 | 0.008 | 4.56 | <0.001 |
| Proportionate agricultural land | 5.96 | 1.31 | 4.55 | <0.001 |
| Proportionate agricultural land$^2$ (quadratic term) | −6.17 | 1.49 | −4.14 | <0.001 |
| Prior depredations, *t*−1 | 1.72 | 0.181 | 9.50 | <0.001 |
| Wolf removals (count) × prior depredations, *t*−1 | −0.116 | 0.050 | −2.32 | 0.021 |

Depredation events were autocorrelated over time, such that districts with depredations the previous year were more likely to keep having them (Table 2 and Fig. 5). However, this effect was dampened by a significant negative effect of targeted removals on the probability of repeated depredations (Table 2 and Fig. 5). Removing a greater number of wolves through targeted removal in 1 year significantly decreased the probability of having any depredations during the subsequent year. Contrary to targeted removals, hunter harvest did not significantly reduce the probability of repeated depredations. When restricting analyses to a subset of years following public harvest of wolves by hunting or trapping, there was no evidence that spatial variation in either the presence of public harvest ($P = 0.874$) nor the number of wolves harvested ($P = 0.515$) had significant effects on the probability of repeated depredations within districts.

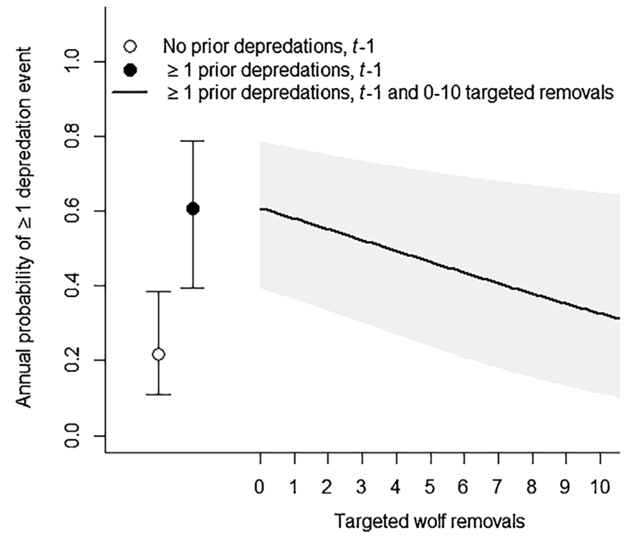


**Figure 5.** Predicted probabilities and 95% confidence intervals (error bars and shaded area) of ≥1 wolf-livestock depredation event occurring in each hunting district and year as a function of the prior occurrence of a depredation event in the same district during the previous year and as mediated by targeted lethal removal of wolves in districts with prior depredations, based on logistic regression modeling of depredations in Montana, USA, 2005–2015.

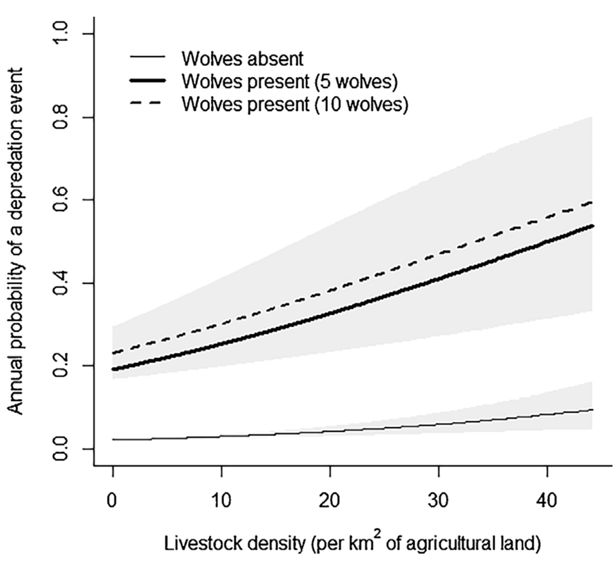


**Figure 4.** Predicted probabilities and 95% confidence intervals (shaded area) of ≥1 wolf-livestock depredation event occurring in a given hunting district and year as a function of livestock density, the presence or absence of wolves and the number of wolves present based on logistic regression modeling of depredations in Montana, USA, 2005–2015.

**Factors Affecting Counts of Depredations When Present**

We used GLMMs to study the count of wolf depredation events where and when they occurred for a restricted data set of 288 district-years. Model selection results from truncated negative binomial GLMMs showed a suite of variables that were predictive of the count of depredation events when and where at least 1 occurred (Tables 3 and 4). Higher counts of depredations occurred in district-years with higher density of wolves, and the total density of wolves was more predictive than the density of packs, though both were statistically significant in univariate models (Table 4). The density of cattle, measured per unit of agricultural land within each district, was also positively related to the number of depredations (Table 4). The proportionate area of forested land showed a significant quadratic relationship with the count of depredations, such that the peak predicted count of depredations with respect to this variable occurred at 44% forested land.

There was autocorrelation in the depredation count data like that in the presence-absence data, such that the count of depredations for a given year was positively correlated with the count of depredations during the previous year. In other words, areas with high numbers of depredations were more likely to continue having high numbers of depredations. Unlike models for presence-absence of depredations, the recurrence of depredations occurring in districts that had ≥1 was not significantly affected by targeted removal of wolves during 2005–2015. However, there was a significant reduction in the recurring number of depredations in districts where a large proportion of the known wolf population was harvested (Table 4 and Fig. 6). A plot of the predicted values of this relationship shows that the magnitude of this effect was small at the level of the district, with the average predicted number of depredation events per district decreasing by 0.8 depredations (from 2.1 to 1.3) as

**Table 3.** Sequential model selection results for 6 steps comparing batches of truncated negative binomial (NB) models of the number of wolf-livestock depredation events given at least 1 in each hunting district and year, including model log-likelihoods (ll), degrees of freedom (df), and Akaike's Information Criterion (AIC), Montana, USA, 2005–2015. We carried the best model ($\Delta$AIC = 0) from each step to the next modeling step, and used models in step 0 to select an appropriate distribution.

| Step | Variables | ll | df | AIC | $\Delta$AIC |
|---|---|---|---|---|---|
| 0 | Intercept only, truncated negative binomial distribution, NB1 formulation[a] | −485.0 | 3 | 975.9 | 0.0 |
| | Intercept only, truncated negative binomial distribution, NB2 formulation[b] | −497.7 | 3 | 1001.5 | 25.6 |
| | Intercept only, negative binomial distribution, NB2 formulation[b] | −567.1 | 3 | 1140.2 | 164.3 |
| | Intercept only, negative binomial distribution, NB1 formulation[a] | −569.4 | 3 | 1144.7 | 168.8 |
| | Intercept only, Poisson distribution | −595.5 | 2 | 1194.9 | 219.0 |
| 1 | Step 0 + wolf density | −482.0 | 4 | 972.0 | 0.0 |
| | Step 0 + wolf presence + wolf density | −481.4 | 5 | 972.8 | 0.8 |
| | Step 0 + pack density | −483.3 | 4 | 974.5 | 2.5 |
| | Step 0 + wolf presence + pack density | −482.6 | 5 | 975.2 | 3.2 |
| | Step 0 + wolf presence | −483.7 | 4 | 975.3 | 3.3 |
| | Step 0 | −485.0 | 3 | 975.9 | 3.9 |
| 2 | Step 1 + cattle density (per agricultural area) | −470.1 | 5 | 950.3 | 0.0 |
| | Step 1 + livestock density (per agricultural area) | −471.0 | 5 | 952.0 | 1.7 |
| | Step 1 + cattle density (per total area) | −474.0 | 5 | 957.9 | 7.6 |
| | Step 1 + cattle density (per total area) + sheep density (per total area) | −473.8 | 6 | 959.6 | 9.3 |
| | Step 1 + livestock density (per total area) | −470.1 | 5 | 963.8 | 13.5 |
| | Step 1 + sheep density (per agricultural area) | −477.3 | 5 | 964.6 | 14.3 |
| | Step 1 + sheep density (per total area) | −477.6 | 5 | 965.2 | 14.9 |
| | Step 1 | −482.0 | 4 | 972.0 | 21.7 |
| | Step 1 + cattle density (per agricultural area) + sheep density (per agricultural area) | NA[c] | 6 | NA[c] | NA[c] |
| 3 | Step 2 + proportionate forested land + proportionate forested land $^2$ | −461.4 | 7 | 936.9 | 0.0 |
| | Step 2 | −470.1 | 5 | 950.3 | 13.4 |
| | Step 2 + proportionate agricultural land | −469.8 | 6 | 951.6 | 14.7 |
| | Step 2 + proportionate forested land | −470.0 | 6 | 952.0 | 15.1 |
| | Step 2 + proportionate agricultural land + proportionate agricultural land$^2$ | −469.7 | 7 | 953.4 | 16.5 |
| 4 | Step 3 + depredations$_{t-1}$ | −450.4 | 8 | 916.8 | 0.0 |
| | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal density) | −449.8 | 9 | 917.5 | 0.7 |
| | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal presence) | −450.1 | 9 | 918.1 | 1.3 |
| | Step 3 + depredations$_{t-1}$ + (depredations$_{t-1}$ × targeted removal proportion) | −450.3 | 9 | 918.6 | 1.8 |
| | Step 3 | −461.4 | 7 | 936.9 | 20.1 |
| 5[d] | Step 4 + (depredations$_{t-1}$ × public harvest proportionate) | −208.5 | 10 | 435.0 | 0.0 |
| | Step 4 + (depredations$_{t-1}$ × public harvest presence) | −209.2 | 10 | 436.3 | 1.3 |
| | Step 4 + (depredations$_{t-1}$ × public harvest density) | −210.5 | 10 | 439.1 | 4.1 |
| | Step 4 | −212.0 | 8 | 440.0 | 5.0 |

[a] NB1 formulation: variance = $\phi\mu$.
[b] NB2 formulation: variance = $\mu(1 + [\mu/k])$.
[c] Model excluded because of coefficient sign-switching effect of multicollinearity.
[d] We used a subset of data for this final step to include only those years following an administrated wolf harvest; thus, AIC values are not comparable with models from previous steps.

the percent of known wolves were harvested increased from 0% to 100% (which does not necessarily mean that all wolves in the local area were harvested because not all wolves present are always known or detected). This negative effect of harvest was specific to districts where $\geq$1 event still occurred, whereas the modeling procedures for factors affecting presence-absence of depredations showed that public harvest would not be expected to prevent depredations altogether within a given area. To scale the predicted effect of public harvest up to an estimate of the net change in depredations statewide, we first calculated that an average of 22.8% of the known wolves were harvested each year during 2011–2015 from the 26 districts with $\geq$1 depredation. An average public harvest of 22.8% of known wolves would achieve an average predicted decrease of 0.22 depredations/district, or a combined decrease of 5.7 depredation events statewide/year.

# DISCUSSION

## Factors Influencing Wolf-Livestock Conflict

The strongest predictor of wolf depredations of livestock was the occurrence of depredations in the previous year. This result mirrors that of a study by Karlsson and Johansson (2010), who reported that the risk of depredation by wolves, lynx, and bears (*Ursus arctos*) in Sweden was 55 times higher in areas with depredations within the preceding 12 months. These findings suggest that there are additional mechanisms outweighing the spatial factors measured in our analysis in terms of predicting areas and times with particularly high risk of conflicts. Such mechanisms may include the conceptualization of livestock depredation as learned behavior by particular individual carnivores that become repeat offenders, differences in animal husbandry practices by livestock producers that create unmeasured differences in susceptibility to depredations (Miller et al. 2016), or additional unmeasured spatial mechanisms that put carnivores and livestock in close proximity.

There is some evidence to suggest that livestock depredations are a learned behavior by particular wolves, who become more likely to target livestock after an initial event (Harper et al. 2008, Bradley et al. 2015). Linnell et al. (1999) reviewed the concept of problem individuals and formulated 2 categories: type 1 individuals are any given carnivore that is likely to depredate livestock if found in the wrong place and time, and type 2 individuals are those that are more prone to depredate than others under similar conditions. Our finding that both presence and count of depredations in districts equally predicted statewide

**Table 4.** Coeffecients (β), standard errors, Wald test statistics ($Z$), and significance values ($P$) for the best truncated negative binomial regression model characterizing predictors of the number of wolf-livestock depredation events occurring, given the occurrence of at least 1 event, in a given hunting district and year in Montana, USA, 2005–2015.

| Variable | $\beta$ | SE | $Z$ | $P$ |
|---|---|---|---|---|
| (Intercept) | −0.461 | 0.284 | −1.63 | 0.104 |
| Wolf density (area-adjusted/mean-sized district) | 0.021 | 0.009 | 2.30 | 0.021 |
| Cattle density (head/km$^2$) | 0.015 | 0.005 | 2.96 | 0.003 |
| Proportionate forested land | 3.77 | 1.20 | 3.14 | 0.002 |
| Proportionate forested land$^2$ (quadratic term) | −4.31 | 1.29 | −3.35 | 0.001 |
| Number of prior depredations, $t-1$ | 0.069 | 0.013 | 5.14 | <0.001 |
| Proportionate wolf harvest[a] × prior depredations, $t-1$ | −0.375 | 0.143 | −2.62 | 0.009 |

[a] We estimated the coefficient and test statistics for the wolf harvest parameter separately by applying this model to a different subset of data consisting of only those years of data following harvest (2010, 2012–2015).

depredation numbers (Fig. 3) may be indicative of a roughly equal split between type 1 and type 2 depredations in Montana. Extrinsic conditions (e.g., animal husbandry practices, other preventative management practices, spatial proximity between wolves, and livestock) could dictate type 1 depredations by the general wolf population, but the intrinsic learning of this behavior by particular individuals may result in type 2 problem wolves that are more likely to depredate again.

As found elsewhere, wolf density and livestock density were significant predictors of the presence of depredations and their relative frequency (Gula 2008, Kaartinen et al. 2009, Treves et al. 2011). Mixed cover types, or intermediate proportions of agricultural (typically private) or forested (typically public) land, have been related to increased conflict likelihood in other areas (Bradley and Pletscher 2005, Kaartinen et al. 2009).

## Effects of Public Harvest

We found no evidence that removing wolves through public harvest affected the year-to-year presence or absence of livestock depredations by wolves. In other words, public harvest did not effectively turn off depredations in areas with reoccurring conflict. However, we did find evidence that public harvest of a greater proportion of the known wolves in a district reduced the number of depredations, within the subset of districts with conflicts. Although statistically significant, our estimate of the effect size of this relationship (5.7 fewer depredation events statewide/year) would amount to only an 8% reduction from the average annual total of statewide depredations during the 2005–2015 study period.

Prior research reported that partial pack targeted removals in the Northern Rocky Mountains ($\bar{x} = 2.2$ wolves killed/pack) were relatively ineffective as a response to wolf-livestock depredations compared to removal of the entire pack (Bradley et al. 2015). Public harvest in Montana has achieved a similar numerical effect to partial pack removals, averaging 1.6–2.2 harvested wolves/pack experiencing harvest during 2009–2014. Thus, in areas with recurrent conflicts, removing a relatively low number of wolves, whether through targeted control or public harvest, may do little to prevent future depredations.

Our results showed that 83% of depredations occurred on private land, yet a cursory look at harvest locations during the study period suggested that only 41% of public wolf harvest occurred on private lands (MFWP, unpublished data). Wolf home ranges in Montana are large enough (median area = 600 km$^2$; Rich et al. 2012) to span multiple ownership types, but further research may be warranted concerning the accessibility to problem wolves by a public constrained to predominately public lands.

We tested for direct effects of harvest in terms of a reduction in the prevalence or magnitude of depredations with increasing harvest. We might also expect a variety of indirect effects of harvesting wolves on levels of conflict with livestock. Wolf density is a consistent predictor of wolf-livestock conflict, and public harvest can negatively affect wolf population dynamics (Gude et al. 2012, Ausband et al. 2015). We conducted a *post hoc* analysis testing for an indirect effect of harvest as mediated by harvest effects on the wolf density covariate. We re-analyzed our best models with 2 treatments of wolf density including harvested wolves within the estimated wolf density versus excluding harvested wolves from the estimated wolf density. Excluding harvested wolves from the measure of wolf density marginally reduced model fit for predicting presence-absence of depredations (ΔAIC = 0.4) but significantly improved model fit for predicting the number of depredations in affected districts (ΔAIC = −4.6).

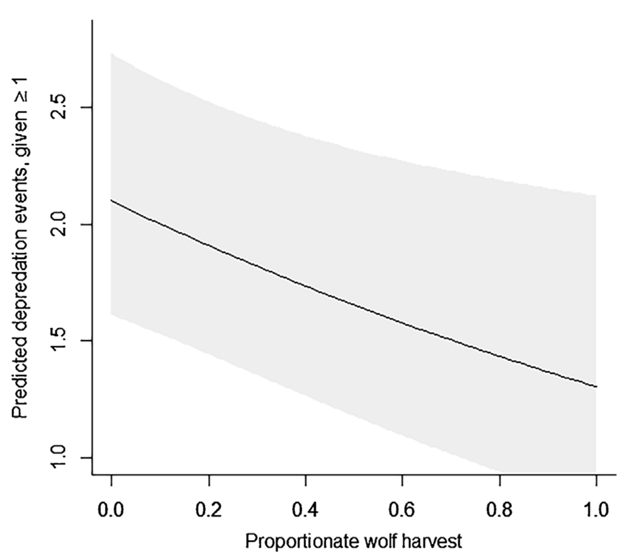


**Figure 6.** Predicted number and 95% confidence interval (shaded area) of wolf-livestock depredations in a hunting district, given at least 1 event, as a function of the proportion of the known wolf population that was harvested by the general public during the previous year, Montana, USA, 2010, 2012–2015.

In the latter but not the former case, there may be some evidence that harvest-mediated reductions in wolf density may further reduce conflicts. In addition to numerical effects, there may be other behavior-mediated indirect effects for which we could not account. Effects of harvest on wolf behavior would have been captured by our analysis only to the extent that the magnitude of those effects is correlated to the magnitude of harvest. Lastly, there is potential that the advent of public harvest has affected public perception or practices enough to change reporting rates of depredations and thus confound our measurement of depredations. Reporting rates can be variable or low in some cases (Lee et al. 2017), and it is unclear whether adding public harvest to carnivore management would necessarily affect public attitudes or responses (Treves 2009).

### Effects of Targeted Removals

Increasing levels of targeted lethal removal of wolves following depredations reduced the probability of their recurrence (Fig. 5), which mirrored results of another recent study at the scale of individual wolf packs (Bradley et al. 2015). Although targeted removals did not appear to significantly affect the frequency of depredations in places where they did reoccur, it seemed the primary effect was in reducing the probability that any depredation event occurred, effectively reducing the subsequent frequency of depredations to 0 as more wolves were removed.

Wielgus and Peebles (2014) recently reported a positive correlation between lethal removal of wolves and subsequent depredations using annual statewide totals in the western United States. However, 2 independent studies later reanalyzed their data with increased attention to autocorrelation and the growing wolf population during that time series and found, instead, negative effects of lethal removal on subsequent depredations (Poudyal et al. 2016, Kompaniyets and Evans 2017). In our study, we accounted for autocorrelation by testing targeted controls as an interaction variable with the previous year's depredation patterns, yielding additional support to the conclusions of the latter 2 studies (Fig. 5).

The results of our analyses do not account for potential differences in the application of targeted control according to how, where, and when it was employed. It can be practically difficult to target offending individuals, particularly for group-living carnivores (Gipson 1975, Linnell et al. 1999). In cases where the risk of recurring depredations hinges on 1 or few individuals with a learned behavior, the success of targeted removals may be tied to the removal of those specific individuals rather than the removal of a higher quantity of individuals overall. We were not able to distinguish between these 2 scenarios, and thus our results may reflect either an additive effect of removing each wolf or a higher probability of removing the problem individuals with each animal removed. Lastly, we wish to highlight the correlative nature of our results and acknowledge that unmeasured spatio-temporal factors were likely at play. We agree with recent calls for rigorous study of carnivore-livestock conflicts (Miller et al. 2016, Treves et al. 2016), yet also hold our own study up as a valuable example of evaluating the effects of ongoing management practices. In jurisdictions where management practices are used to address human-wildlife interactions, we encourage an adaptive management approach (Nichols et al. 2007).

## MANAGEMENT IMPLICATIONS

In accordance with our result that depredation totals were equally influenced by depredations in new areas and the severity of recurring depredations (Fig. 3), we recommend an equal split between preventative efforts to reduce the propensity for conflicts in places where they are less common and reactive efforts to reduce the severity or number of conflicts in places where they are more common. Our results also uphold the use of targeted lethal removals to reduce recurrent depredations (Fig. 5). Our findings are mixed with regards to the management utility of prescribing public harvest to reduce wolf-livestock conflict. Although we did find a significant effect of harvest in certain situations, the predicted magnitude of this effect was modest (5.7 events/year). Statewide depredation totals have decreased substantially in Montana since the advent of public harvest (from 119 in 2010 to 44 in 2014), yet we were unable to support a hypothesis that public harvest has been a primary factor influencing these decreases.

Depredation of livestock by wolves is a relatively rare phenomenon, making it likely that many additional and fine-scale factors are at play when prescribing preventative and reactive management approaches. We therefore advocate a case-by-case approach to deciding how each situation is managed with regards to the use of non-lethal or lethal tools. Managers are required to consider trade-offs between wolf population recovery goals and efforts to minimize conflict with livestock when managing North American wolves in the current era. Lastly, we acknowledge that there are other ethical and value-based aspects to management of wolves that are not reviewed here but require thorough consideration as components of effective and sound wolf management and conservation (Haber 1996, Nie 2002).

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# Oregon Wolf Conservation and Management

2016 Annual Report

***This report to the Oregon Fish and Wildlife Commission presents information on the status, distribution, and management of wolves in the State of Oregon from January 1, 2016 to December 31, 2016.***

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## EXECUTIVE SUMMARY

The Oregon wolf population is healthy and wolves continue to expand their range. Wolf program activities are guided by the Oregon Wolf Conservation and Management Plan (Wolf Plan) and the associated administrative rules based on how many successfully reproducing wolves are found in each management area. The end of 2016 marks the third consecutive year that at least seven breeding pairs of wolves were counted in the East Wolf Management Zone (WMZ) east of Oregon Highways 97/20/395. Reaching this population objective advances wolf management activities into Phase III for the East WMZ. The conservation objective of four breeding pairs for three years has not yet been reached in the West WMZ and wolves there are still managed under Phase I. In addition, wolves occurring west of Oregon Highways 395/78/95 continued to be federally protected as endangered under the federal Endangered Species Act (ESA).

The Oregon Department of Fish and Wildlife (Department) monitors the wolf population. The 2016 Oregon minimum known wolf population is 112 wolves. Eleven packs were documented and eight of those packs met the criteria as breeding pairs. In addition to the packs, five more groups of two to three wolves were identified. Known wolf groups occurred in parts of Baker, Grant, Jackson, Klamath, Lake, Morrow, Umatilla, Union, and Wallowa Counties. Eleven wolves were captured and GPS radio-collared and 21 total radio-collared wolves were monitored during the year. At year-end, nine radio-collared wolves (8% of the minimum known population) were monitored in Oregon. Nine dispersing radio-collared wolves were monitored during the year, and three of these dispersed out-of-state by the end of the year. Seven wolf mortalities were documented during the year.

The Department physically investigated reported livestock depredation by wolves. Confirmed depredation events of livestock increased significantly over 2015; 24 incidents of wolf depredation were confirmed in 10 areas of Oregon in 2016, compared to nine incidents in 2015. Per the Wolf Plan, the Department and area producers implemented non-lethal measures to minimize depredation per Oregon Administrative Rule (OAR) 635-110-0010 and -0020. In one instance, the non-lethal methods proved ineffective and four wolves of the Imnaha Pack were lethally removed by the Department to stop chronic livestock depredation. In another instance, a sheep herder shot a wolf caught in the act of killing a sheep.

The Oregon Department of Agriculture’s compensation program awarded grants of $129,664 to 13 counties in 2016. Funds were used for non-lethal preventative measures and for direct payment of confirmed depredations and missing livestock to livestock producers.

The Oregon State University/ODFW wolf-cougar research project in northeastern Oregon continued in 2016. This project is primarily focused on understanding competitive interactions and prey selection between wolves and cougars in the Mt Emily Wildlife Management Unit (Unit). Since 2014, researchers collected information by monitoring radio-collar data of 11 cougars and 11 wolves in four packs within the Mt Emily Unit. The project is expected to be completed in 2018.

The Department prepared this annual report for the Fish and Wildlife Commission. The report includes specific information about Oregon wolves, wolf program activities, livestock depredations and ongoing wolf research.

## OREGON WOLF PROGRAM OVERVIEW

### Regulatory Status

Federal Status: Wolves occurring west of Oregon Highways 395/78/95 continue to be federally protected as endangered under the ESA (Figure 1). In the federally listed portion of Oregon, the Department implements the Wolf Plan under the guidance of the Federal/State Coordination Strategy (March 2011). The United States Fish and Wildlife Service (USFWS) makes management decisions regarding harassment and take of wolves and assists in monitoring and depredation prevention.

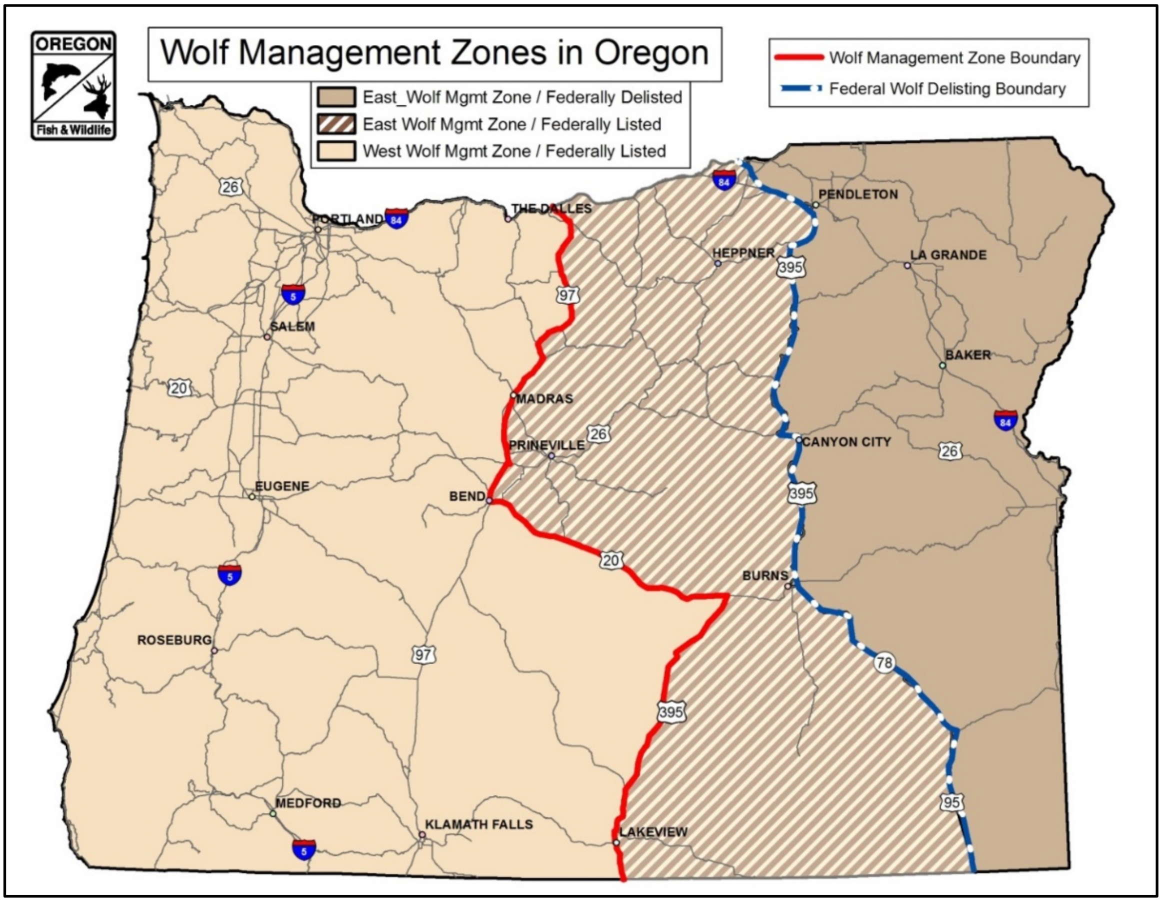


Figure 1. Wolf Management Zones and Federal ESA Status in Oregon

State Status**:** The Fish and Wildlife Commission (Commission) decision on November 9, 2015 removed wolves from the Oregon List of Endangered Species. During the 2016 Regular Session, the Oregon Legislature ratified the Commission's decision by passing House Bill 4040. A lawsuit challenging the Commission's 2015 delisting decision was filed by three environmental groups and the case is pending. Also during the 2016 Legislative Session, passage of House Bill 4046 raised the amount the Department may request for restitution for unlawful take of a wolf from $1,000 to $7,500 effective January 1, 2017.

Wolves are still protected by the Wolf Plan guidelines and its associated rules based on where they are located. During 2016, wolves in the East WMZ were managed under Phase II rules. Moving into

2017, wolves in the East WMZ are managed under Phase III rules. Wolves in the West WMZ are managed under the ESA-like Phase I rules until their population also reaches a minimum of four breeding pairs for three consecutive years.

Phase III continues to emphasize the use of non-lethal deterrents while addressing instances of wolf-human conflict. This management phase adds two opportunities not available under Phase II, including the use of controlled take in certain situations, and expands livestock producer options for investigating potential wolf depredations of livestock. The Wolf Plan states that controlled take of wolves can be allowed in two specific circumstances: 1) if wolves are determined to be causing declines in ungulate populations such as deer and elk or 2) in specific cases of chronic livestock depredation. Any take under these circumstances will be considered a management response only, there are no plans for controlled take at this time.

In Phase III, the current Wolf Plan allows either the Department or USDA Wildlife Services to confirm wolf depredations in Eastern Oregon. However, USDA Wildlife Services has stated that they will not assist in the lethal removal of wolves or expand their role in depredation investigations (including confirming wolf depredations) until it has evaluated its obligations under the National Environmental Policy Act.

Department staff worked with stakeholder groups on the Wolf Plan-mandated review during 2016. The status of the review process was presented at three Commission meetings (March, August, and October). In March, the Commission received testimony from two panels of invited guests on review of the Wolf Plan, and in October, public testimony was heard by the Commission. In addition, stakeholder groups and organizations, agencies, Tribes, and members of the public provided valuable review and input into the process.

**Population, Distribution, and Reproduction**

<u>Minimum Population and Distribution</u>: The Department provides a minimum known population of wolves in Oregon at the end of the year; this is a direct count of wolves, not an estimate. The minimum known wolf population in 2016 was 112, a 2% increase from 2015. The Department also documents pack numbers annually. A pack is defined as four or more wolves traveling together in winter. Eleven packs were documented in 2016 with pack size ranging between four and twelve wolves.

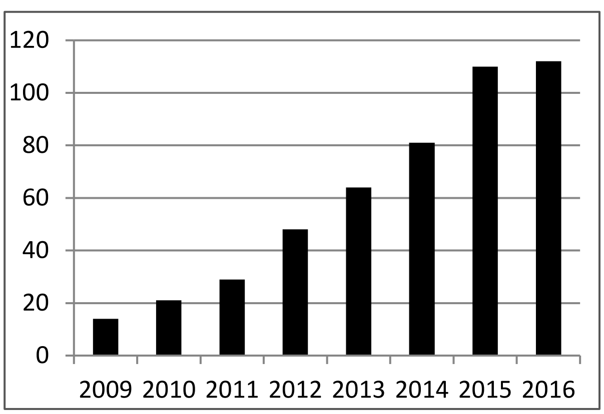


Figure 2. Minimum wolf population in Oregon (2009-2016).

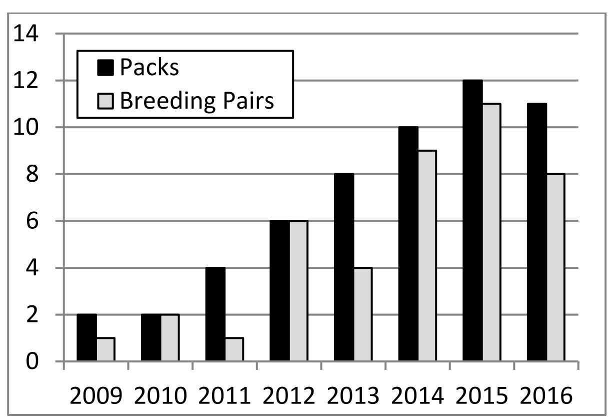


Figure 3. Number of packs and breeding pairs in Oregon (2009-2016).

The eleven packs were distributed in two geographic areas of Oregon; ten packs in northeastern Oregon and one in southwestern Oregon (Table 1). Eight percent of Oregon wolves were in the West WMZ. Known wolf groups occurred in parts of Baker, Grant, Jackson, Klamath, Lake, Morrow, Umatilla, Union, and Wallowa Counties (Figure 4). In 2016, 49% of documented locations for resident wolves were on public lands, 50% on private lands and less than 1% on tribal lands. For packs that had substantial GPS radio-collar data (n=6), the pack territory sizes ranged from 178 to 828 $mi^2$ (461-2,145 $km^2$) with a mean of 385 $mi^2$ (997 $km^2$).

Table 1**.** Minimum wolf population (Total = 112) in Oregon on Dec. 31, 2016 by pack and Wolf Management Zone. Underlined packs were counted as breeding pairs.

| **Pack/Group** | **WMZ** | **Total** |
|---|---|---|
| <u>Catherine Pack</u> | East | 5 |
| <u>Chesnimnus Pack</u> | East | 9 |
| <u>Harl Butte Pack</u> | East | 10 |
| <u>Meacham Pack</u> | East | 7 |
| <u>Minam Pack</u> | East | 11 |
| Mt. Emily Pack | East | 8 |
| North Emily Wolves | East | 3 |
| Rogue Pack | West | 6 |
| Shamrock Pack | East | 4 |
| <u>Snake River Pack</u> | East | 9 |
| Unnamed Wolves (Heppner Unit) | East | 3 |
| <u>Walla Walla Pack</u> | East | 11 |
| <u>Wenaha Pack</u> | East | 12 |
| OR29/OR36 Pair | East | 2 |
| OR30 Pair | East | 2 |
| Individual/Misc. Wolves | East | 7 |
| Individual Wolves | West | 3 |

The wolf population continued to expand in distribution during 2016. New areas of wolf activity were documented in northeastern and southwestern Oregon. In northeastern Oregon, OR30 is with a different wolf than he was found with in January 2016; the new pair is now resident in the northern Starkey and Ukiah Units south of I-84. OR37 was a resident and alone in the Lookout Mt Unit during 2016. OR29 and OR36 have been traveling together since February 2016 and are using the majority of the Pine Creek Unit. The Chesnimnus Pack occupies an area previously used occasionally by multiple packs in the in the Chesnimnus Unit. In southwestern Oregon, OR3 (an eight-year-old male originally from the Imnaha pack) paired with OR28, a three-year-old GPS radio-collared female originally from the Mt Emily pack. The two are believed to have produced at least one pup in 2016. They primarily used the Silver Lake Unit in western Lake County, a new area of wolf activity, and were called the Silver Lake wolves. OR28 was found dead in October. One large wolf has been documented in the area this winter, but the status of the pup is unknown.

Two previously occupied areas had new wolves. The North Emily wolves were documented in the territory previously held by the Umatilla River Pack. The Unnamed wolves in the Imnaha and Snake River Units have been named the Harl Butte Pack. This pack is using part of the area previously held by the Imnaha Pack.

The South Snake Pack, with no radio-collars, was not located during the spring, summer or fall. Three wolves were located in the southern portion of the use area during January 2017, but at this time it is unknown if they are resident new wolves or part of the South Snake Pack. The Unnamed Wolves in the Heppner Unit was a pack discovered in January 2016 in southwestern Umatilla County. The intent was to name the pack after further investigation determined its use area, but the pack was not located during the spring, summer or fall. This winter three wolves were once again discovered and counted in the Heppner Unit. The Desolation Unit was monitored throughout 2016, after March only one wolf was observed in the area.

Two collared lone wolves were monitored in southwestern Oregon. OR25 traveled alone through Klamath and Lake Counties, as well as California during 2016, but primarily used the Sprague and Fort Rock Units. OR33 dispersed though central Oregon, then spent February through August traveling alone throughout Klamath and Jackson Counties. OR33's collar failed in August, and his current status is unknown. Although three different wolves were documented in the Keno use area during the year, only one wolf was detected at the end of the year.

The past three years have seen the population increase by 27% to 36%. The weak 2016 population growth rate could be due to a number of factors such as; wolves present but not counted, decreased breeder success, known/unknown human-caused mortality, diseases affecting pup survival, and dispersal out-of-state. The Department will continue to monitor the population closely.

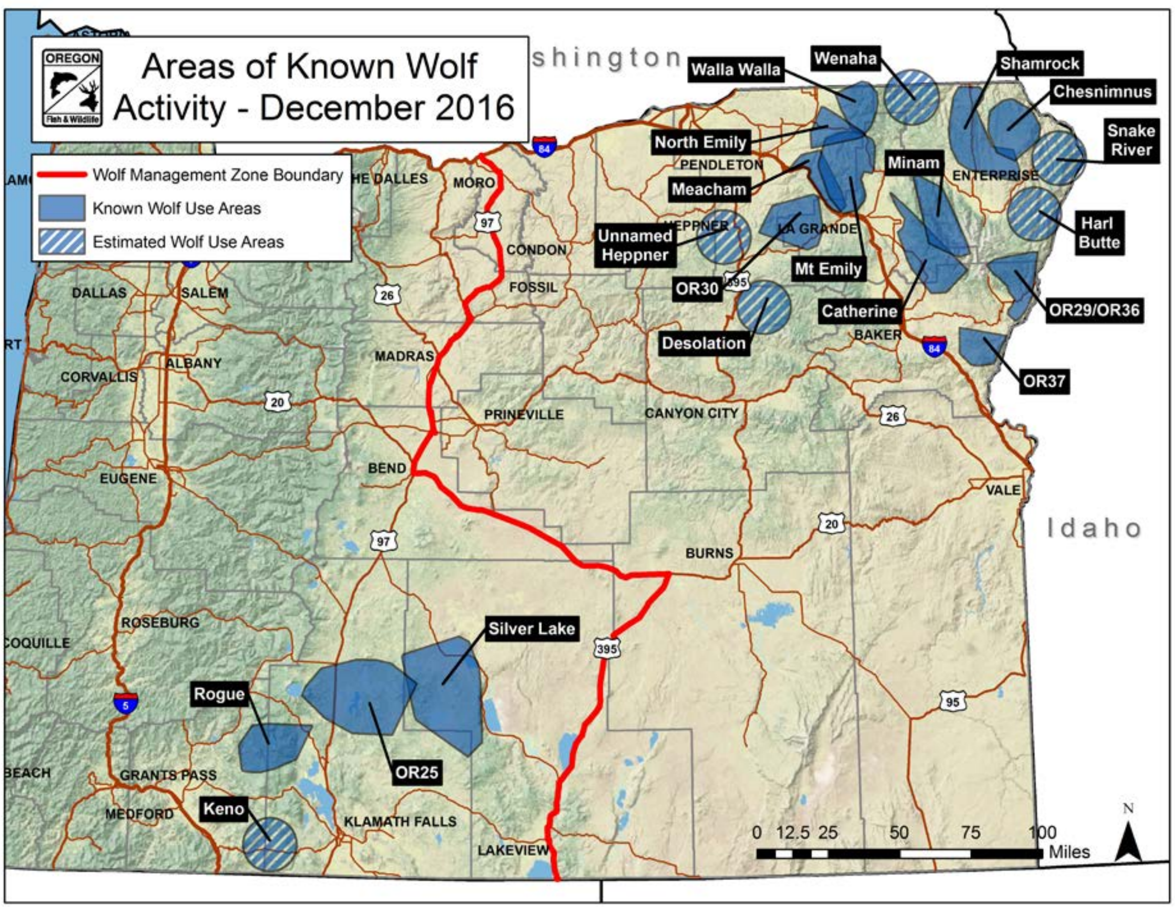


Figure 4. Distribution of Oregon wolves in December, 2016.

Reproduction: A breeding pair is defined as an adult male and adult female with at least two pups that survived to December 31 of the year of their birth. Eight successful breeding pairs were documented for 2016 (Table 1). All eight packs that qualified as breeding pairs were in Umatilla, Union and Wallowa counties of northeastern Oregon. Reproduction was confirmed in the North Emily wolves, Rogue Pack, Silver Lake pair (OR3/OR28), and suspected in the Shamrock Pack. By December 31, only one pup each was confirmed in the North Emily wolves and Rogue Pack.

**Monitoring**

The 2016 survey season proved challenging due to a lack of radio-collared packs and weather conditions that hindered some aerial and ground surveys until February, 2017. In Oregon, wolves disperse from their natal pack most often in November, January and February. Dispersing wolves are harder to locate and count than wolves in packs, so these wolves may be have been missed in the count. The 2016 pack and population count could increase if evidence is collected during 2017 of additional packs present during 2016.

Capture: Twelve wolves from five different groups were captured during 2016. Eleven were radio-collared with Global Positioning System (GPS) collars (Table 2). The DNA analysis done at the University of Idaho Laboratory for Ecological, Evolutionary and Conservation Genetics showed that three of the wolves were dispersing from their natal packs in Oregon when captured.

In June, a wolf pup was captured in a foothold trap in the Chesnimnus Unit, confirming that there was a pair of wolves breeding in the area. The two-month-old pup was too small to carry a radio-collar and was released unharmed. Later that month the breeding female was caught incidentally by USDA Wildlife Services, then successfully radio-collared by Department staff and released.

Table 2. Wolves captured in Oregon in 2016

| **Date** | **Wolf ID** | **Age/Color/Sex** | **Pack** | **Method** |
|---|---|---|---|---|
| 1/8/2016 | OR37 | Adult, gray, male | Dispersing wolf | Helicopter |
| 3/2/2016 | OR38 | Subadult, gray, male | Dispersing wolf | Helicopter |
| 3/9/2016 | OR4 | Adult, black, male | Imnaha | Helicopter |
| 3/9/2016 | OR39 | Adult, gray, female | Imnaha | Helicopter |
| 5/12/2016 | OR40 | Adult, gray, female | Walla Walla | Trap |
| 5/13/2016 | OR41 | Adult, gray, male | Shamrock | Trap |
| 6/6/2016 | Pup | Pup, gray, male | Chesnimnus | Trap |
| 6/29/2016 | OR42 | Adult, gray, female | Chesnimnus | Trap |
| 10/14/2016 | OR43 | Adult, black, male | Dispersing wolf | Trap |
| 12/12/2016 | OR29 | Adult, black, male | OR29/OR36 Pair | Helicopter |
| 12/12/2016 | OR36 | Adult, gray, female | OR29/OR36 Pair | Helicopter |
| 12/31/2016 | OR44 | Subadult, gray, male | Chesnimnus | Helicopter |

Monitoring: Radio-collars provide specific information on wolf movements. Twenty-one radio-collared wolves were monitored in Oregon in ten groups during 2016. At year-end approximately 8% (n=9) of the population were radio-collared in four packs (Catherine, Chesnimnus, Shamrock, and Walla Walla), two pairs (OR29/OR36 and OR30 pair) and one individual (OR25). Contact with 13 radio-collars was lost during the year because three wolves died, three wolves dispersed out of state, and seven radio-collars failed.

Four of the 11 radio-collars placed in 2016 failed within six months, causing the Department to consider other radio-collar options.  GPS collars collect large quantities of valuable location data, but have a high failure rate due to their technological complexity and the batteries are only expected to last three years.  The average life span of GPS collars placed by the Department since 2011 has been 18 months before mechanical failure.  VHF radio-collars must be monitored from the field, but the collars are less likely to fail and the batteries are expected to last 6.5 years.

In addition to monitoring information downloaded from radio-collars, Department biologists also visually monitored radio-collared and accompanying wolves from the air and ground, implemented track and howling surveys and remote camera surveillance.  During the year the Department collected a total of 14,896 wolf location data points in Oregon; most using GPS collars.

Wolf reports from the public increased over 2015, with 393 wolf reports received by Department biologists or the Department's online wolf reporting system (www.odfw.com/wolves) during the year. Subsequent follow-up of some of these reports yielded valuable information about packs without radio-collars and new wolf activity.

Disease testing:  Blood serum samples collected from 18 captured wolves were analyzed for exposure to common canine diseases such as: canine parvovirus, canine distemper virus, leptospirosis and canine adenovirus.  The samples were collected between 2014 and 2016 within the Chesnimnus, Imnaha, Meacham, Minam, Mount Emily, Shamrock, Snake River, South Snake, and Walla Walla packs.  A positive titer result shows that an animal has been exposed to the pathogen and does not necessarily indicate current active clinical disease.

Positive parvovirus titers were found in all but one wolf (a two-month-old pup) and in all nine of the packs tested.  Although parvovirus had been found in 89% of samples analyzed in 2013, only 5% of those samples had positive IgM titers.  Samples analyzed during 2016 had 68% positive IgM titers indicating a much higher prevalence of active or recent infections.  Though parvovirus can cause increased pup mortality affecting short-term population growth rates, it is not expected to significantly affect long-term wolf recovery.

Canine distemper virus was not detected in the Oregon wolf population when samples from 2010 to 2013 were analyzed, even though it is present throughout the state in both domestic and wild canids and raccoons.  In 2016 testing, positive distemper titers were discovered in three wolves from two packs (Minam and Chesnimnus).  Distemper outbreaks have been documented in other states and the disease appears to cause short-term population declines by limiting pup survival.  No positive leptospirosis titers were found in 2016, down from two samples in 2013.  Canine adenovirus titers (>1:8) were detected in 61% of the samples and in eight packs, similar to 2013.

Mortalities:  Seven mortalities were documented during 2016 (Table 3), including three radio-collared wolves.  Two wolves were killed and both investigations are ongoing.  Oregon State Police (OSP) and USFWS Law Enforcement are actively seeking more information about the cases.

Five wolves were killed lawfully per OAR 635-110-0020 (Phase II rule) in eastern Oregon.  Four wolves of the Imnaha Pack were lethally removed in response to a chronic depredation situation.  One wolf was killed legally under the Caught-in-the-Act (CIA) regulations.  Please see the Livestock Depredation Management section (below) for more information.

In October 2015, a radio-collared dispersing gray-colored wolf was shot by an individual who reported that he misidentified the animal as a coyote. The individual pled guilty to taking an endangered species in February, 2016. He was ordered to pay a $1000 fine, pay $1000 restitution to the Department and forfeited his gun to the state.

Table 3. Wolf mortalities in Oregon in 2016

| Date | Wolf | Pack | Cause of Death |
|---|---|---|---|
| 3/2/2016 | Subadult | Walla Walla Pack | Shot |
| 3/31/2016 | OR4 | Imnaha Pack | Lethal Removal |
| 3/31/2016 | OR39 | Imnaha Pack | Lethal Removal |
| 3/31/2016 | Subadult | Imnaha Pack | Lethal Removal |
| 3/31/2016 | Subadult | Imnaha Pack | Lethal Removal |
| 5/21/2016 | Adult | Walla Walla Pack | CIA Lethal Removal |
| 10/5/2016 | OR28 | Silver Lake wolves | Under Investigation |

Dispersers: Nine radio-collared dispersing or single wolves were monitored in 2016. Several wolves traveled to other states, and three were still out of state (OR38 and OR43 in ID, OR35 in WA) at the end of year. Mapping the starting and ending locations of 34 wolves that have dispersed from Oregon packs shows that some wolves have dispersed short distances within northeast Oregon and to southeast Washington, while others have made longer-distance dispersals to southwestern Oregon, California, Idaho and Montana (Figure 5).

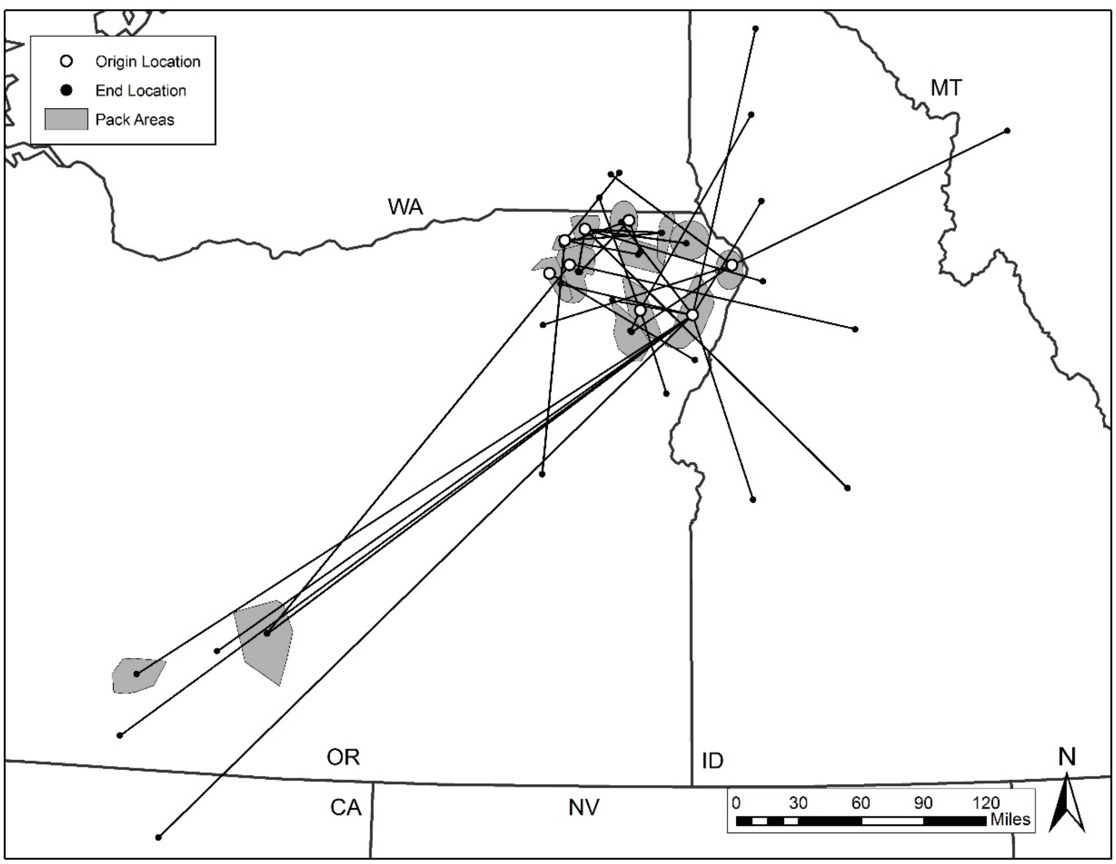


Figure 5. Approximate starting and ending points for wolves dispersing from Oregon packs (2010-2016).

# LIVESTOCK DEPREDATION MANAGEMENT

## Wolf Depredation Summary

Confirmed incidents of depredation increased significantly in 2016 from the previous year (24 vs. 9), and the number of losses also increased (Figure 6). Confirmed losses in 2016 were 11 calves, seven sheep, one goat, and one llama (Table 4), compared to three calves, 10 sheep and one working dog in 2015. Eight of Oregon's wolf packs (Chesnimnus, Harl Butte, Imnaha, Meacham, Mt. Emily, Rogue Shamrock, and Walla Walla), the Silver Lake wolves, and one individual radio-collared wolf (OR33) depredated livestock. During 2016, 57% of packs that were active during the year (n=14) depredated livestock.

Table 4. Summary of 2016 confirmed wolf depredation incidents in Oregon.

| Date | Animals Affected | County | Pack Area |
|---|---|---|---|
| 2/22/2016 | Cow (Injured: 1 calf) | Klamath | OR33 |
| 3/9/2016 | Cow (Dead: 1 calf) | Wallowa | Imnaha |
| 3/25/2016 | Sheep (Dead: 1 ram) | Wallowa | Imnaha |
| 3/28/2016 A | Cow (Dead: 1 calf; Injured: 1 calf) | Wallowa | Imnaha |
| 3/28/2016 B | Cow (Dead: 1 calf) | Wallowa | Imnaha |
| 3/30/2016 | Sheep (Injured: 1 ram) | Wallowa | Imnaha |
| 5/9/2016 | Llama (Dead: 1 dam) | Wallowa | Shamrock |
| 5/21/2016 | Sheep (Dead: 1 lamb) | Umatilla | Walla Walla |
| 6/10/2016 | Goat (Dead: 1 nanny. Injured: 1 nanny) | Jackson | OR33 |
| 6/13/2016 | Sheep (Dead: 1 adult) | Jackson | OR33 |
| 6/28/2016 | Cow (Dead: 1 calf) | Wallowa | Shamrock |
| 7/15/2016 | Cow (Injured: 1 calf) | Wallowa | Harl Butte |
| 8/20/2016 | Cow (Dead: 1 calf) | Umatilla | Meacham |
| 9/1/2016 | Sheep (Dead: 4 ewes) | Umatilla | Mt. Emily |
| 9/6/2016 | Cow (Dead: 1 calf) | Wallowa | Chesnimnus |
| 9/28/2016 | Cow (Dead: 1 calf) | Wallowa | Harl Butte |
| 9/29/2016 | Cow (Injured: 1 calf) | Lake | Silver Lake |
| 10/5/2016 | Cow (Dead: 1 calf) | Klamath | Rogue |
| 10/5/2016 | Cow (Dead: 1 calf) | Klamath | Rogue |
| 10/6/2016 | Cow (Injured: 1 calf) | Klamath | Rogue |
| 10/6/2016 | Cow (Injured: 1 calf) | Wallowa | Harl Butte |
| 10/13/2016 | Cow (Injured: 1 calf) | Wallowa | Harl Butte |
| 10/19/2016 | Cow (Dead: 1 calf) | Klamath | Rogue |
| 11/21/2016 | Cow (Dead: 1 calf) | Wallowa | Shamrock |

Oregon's confirmed depredation of cattle and sheep data across all years (n=89) shows that 70% of depredation events happen during five months (May, June, August, September and October). Domestic calf depredations peaked in May, September, and October. Sheep depredation was highest in May, June, and August. Since 2009, 71% of depredation events have occurred on private land. In 2016, the Department conducted 67 wolf depredation investigations in ten Oregon counties, which resulted in 24 (36%) *confirmed* incidents, three (4%) *probable* incidents, 20 (30%) *possible/unknown* incidents, and 20 (30%) *other* incidents. USDA Wildlife Services assisted with field investigations.

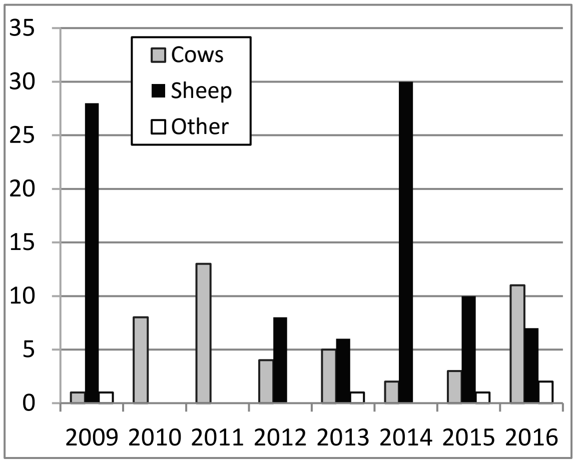

Figure 6. Number of confirmed livestock losses by year (2009-2016).

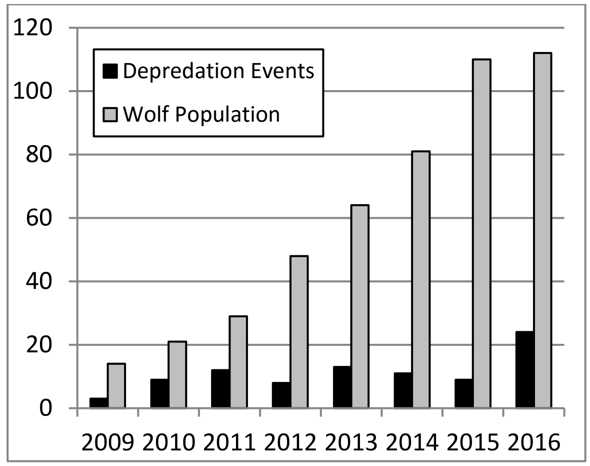

Figure 7. Number of depredation events and wolf population (2009-2016).

**Options to Minimize Depredation**

The Wolf Plan mandates focusing on non-lethal efforts before lethal removal is considered in all phases of wolf management. Though the wolf population has increased significantly over the last eight years, depredation events and livestock losses have not increased at the same rate (Figure 7).

Non-Lethal Options: Effective proactive non-lethal measures vary by the type of livestock being protected and the size of the pasture. Reducing attractants by carcass and bone pile removal may be the single best action to keep from attracting wolves to areas of livestock. There are no non-lethal measures which are 100% effective in preventing livestock depredation by wolves. The Department and USFWS continued to support producers with fladry, electromesh fencing, solar chargers, and RAG boxes.

In 2016, wolf program personnel designated, posted, or revised 17 Area of Known Wolf Activity maps in order to inform livestock producers of resident wolf activity. District wildlife biologists informed producers when wolves were near their livestock and worked with them to implement non-lethal strategies. In response to depredation, five Areas of Depredating Wolves and four Conflict Deterrence Plans were also developed and posted on the Department's wolf website.

Lethal Options: Within the federally listed portion of Oregon, west of Highways 395/78/95, all lethal take is regulated by the USFWS and no lethal removal was conducted in this area. Within the federally delisted portion of Oregon east of Highways 395/78/95 and under Oregon Administrative Rule 635-110-0020 (Phase II), there are two options for lethal control in response to wolf-livestock conflicts.

One option available to livestock producers east of Highways 395/78/95 is to lawfully shoot a wolf caught in the act of biting, wounding, killing or chasing livestock or working dogs without a permit in certain circumstances. In May, a sheep herder shot a wolf that he saw killing a sheep and fighting with a livestock protection dog. The Department confirmed that the ewe had been killed by wolves.

Second, in chronic depredation situations and under certain conditions the Department may lethally remove wolves or issue a limited duration permit for a livestock producer to kill a wolf or wolves to minimize further depredation. In March, four wolves of the Imnaha Pack were lethally removed in response to a chronic depredation situation after five depredations were confirmed in a 3-week period. The Department also lethally removed two wolves from the Imnaha Pack during 2011. Between 2010 and 2016, the Imnaha Pack was responsible for 38 confirmed depredations with 45 dead or injured livestock.

### Compensation for Wolf-Caused Losses

The Oregon Department of Agriculture's Wolf Depredation Compensation and Financial Assistance County Block Grant Program was again implemented in 2016. The program provides four types of financial assistance options; 1) direct depredation payment, and 2) missing livestock payment, and 3) preventative measures, and 4) program implementation costs. The Department's primary roles are determining if wolf depredation has occurred and to delineate areas of known wolf activity. The Department was also asked by some counties to provide input on appropriate non-lethal and preventative measures. A total of 13 counties were awarded $129,664 in grant funds (Table 5).

Table 5. Funds awarded through the County Block Grant Program in 2016 (source; Oregon Department of Agriculture)

| County | Death/Injury | Missing | Prevention | Admin | Total |
|---|---|---|---|---|---|
| Baker | 0 | $11,793 | $10,000 | $495 | $22,288 |
| Crook | 0 | 0 | $2,000 | 0 | $2000 |
| Jackson | 0 | 0 | 0 | $495 | $495 |
| Klamath | $3,796 | 0 | $5,000 | 0 | $8,796 |
| Lake | 0 | 0 | $3,000 | 0 | $3,000 |
| Malheur | 0 | 0 | 0 | $495 | $495 |
| Morrow | 0 | 0 | $3,000 | $675 | $3,675 |
| Sherman | 0 | 0 | $750 | $500 | $1,250 |
| Umatilla | $2,931 | $25,172 | $24,000 | $675 | $52,778 |
| Union | 0 | 0 | $5,000 | 0 | $5,000 |
| Wallowa | $3,887 | $5,250 | $17,000 | $750 | $26,887 |
| Wasco | 0 | 0 | $1,000 | $750 | $1,750 |
| Wheeler | 0 | 0 | $750 | $500 | $1,250 |
| **Award Amount** | **$10,614** | **$42,215** | **$71,500** | **$5,335** | **$129,664** |

## WOLF RESEARCH

The Oregon State University/ODFW wolf-cougar research project in northeastern Oregon continued in 2016. This project is primarily focused on understanding competitive interactions and prey selection between wolves and cougars in the Mt Emily Unit.

Since summer 2014, researchers have collected data by monitoring 11 GPS radio-collared cougars and 11 wolves from four packs using area in the Mt Emily Unit. Researchers used GPS location cluster analysis methods to identify potential prey acquisition sites and document prey species selection and acquisition rates. To date, project researchers have investigated 456 potential wolf prey acquisition sites during winter months and 115 prey items were identified at these sites. Elk remains were identified at approximately 60% of acquisition sites and mule deer at 22% of the sites. White-tailed deer (7%), unknown deer (9%), and non-ungulate prey (2%) were present at the remainder of sites. Of the elk remains where age of animal could be determined, 49% were calves, 46% were adults, and 5% were yearlings. Out of all deer (mule deer and white-tailed deer) remains where age class could be identified, 59% were adults, 32% were fawns and 9% were yearlings.

Prey remains were also located at 43 of 200 potential wolf prey acquisition sites during summer months with elk comprising 64% and mule deer 17% of the prey remains. White-tailed deer (3%), deer unidentifiable to species (3%), and non-ungulate (13%) prey were present at the remainder of sites. The age of the elk prey identified during summer months were calves (83%), adults (13%), and yearlings (4%). Out of all deer remains where age class could be identified 57% were adults, 29% were yearlings, and 14% were fawns.

The most common wolf-cougar interaction documented was wolves at prey remains of cougar kills (70%). Using elements at the scene and the GPS data for both predators three classes of wolf-dominated interaction have been identified at cougar kills; wolves feeding on prey remains from cougar (seven cases), visiting prey already abandoned by cougar (four cases), or usurping prey before/during time periods cougar were actively feeding on remains (three cases). Other interactions include two cases where wolves chased cougars up trees, two cases of where cougar visited a wolf kill, and one case of wolves killing young cougar kittens.

Fieldwork investigating prey acquisition sites concluded in November 2016 for the Mt Emily wolf-cougar research project. Data collection will continue through summer 2017 where the project will continue to; 1) collar additional wolves, and 2) monitor GPS collared cougars within the study area to investigate competitive interactions between the two species. Data analysis and the project are expected to be completed in 2018.

## INFORMATION AND OUTREACH

The Department continued to rely on its internet-based wolf webpage (http://www.odfw.com/wolves) as the primary information distribution tool in 2016. Throughout the year, the online wolf pages received 176,833 views. The wolf program home page alone received nearly 47,000 views. Currently, 6,049 people subscribe to the Department's wolf update page. Its subscribers increased by 621 (11%) during 2016.

In 2013, the Department added a Wolf-Livestock update page that focuses on the needs of livestock producers and the requirements of Phase I Oregon Administrative Rules. Since this page was launched, 4,203 people subscribed to receive updates on confirmed depredations, maps of Areas of Known Wolf Activity and Areas of Depredating Wolves, Conflict Deterrence Plans and other information.

The Department also shared wolf-related content on its social media channels (Facebook, Instagram, and Twitter), including photos and infographics about the population, which generated significant engagement. It also regularly responds to wolf-related questions and comments on these channels.

In addition to web-based information, the Department conducted numerous media interviews to print, radio, and television reporters. The Department presented at three workshops that focused on educating livestock producers about successful implementation of non-lethal methods. Presentations were given to schools, universities, other agencies, agriculture meetings and organizations, sportsman organizations, and conservation groups. Wolves were also a popular topic for students of all levels writing papers or articles, and the Department responded to a variety of questions from these students.

## WOLF PROGRAM FUNDING

Wolf program funding during the 2015-2017 biennium consists of federal funds from the Pittman-Robertson Grant Program and support grants from the US Fish and Wildlife Service. These federal sources provide 80.6% of the wolf program funding. Some of these federal grants require state match which comes from a combination of Oregon Department of Fish and Wildlife license dollars (6.6%) and Lottery Funds (12.8%). Two full time employees are associated with the program. The total budget allocation for the 2015-2017 biennium is $793,282.

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