Big Cats as Nature's Check Against Disease

A summary of theoretical, empirical, and experimental evidence supporting predator cleansing of CWD in deer and elk herds by mountain lions and wolves.

Cats Aren't Trophies
Protecting Colorado's mountain lions, bobcats & lynx

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Background

Predator cleansing is the idea or hypothesis that predators, especially apex carnivores sitting atop their ecosystem's food chain, can prevent or control the spread of infectious diseases in prey populations by hunting and killing the sickest and most infectious animals. In theory and perhaps in practice, this reduces the transmission, incidence, and prevalence of wildlife infections and improves the overall health, survival, and fitness of the prey population.

The predator cleansing concept, also sometimes referred to as disease sanitizing, is derived from the intuitive wildlife ecology notion that predators selectively target, pursue, kill, and consume sick, injured, weak, very young, very old, and otherwise vulnerable individuals—"the newly born and the nearly dead" — among the prey population. By carnivore calculus, these "less fit" individual prey might be easier to hunt (less energy expenditure by the predator) and be less likely to cause serious injury to the predator during the pursuit, takedown, and kill.

A prevailing idea in wildlife ecology is that coursing predators (such as wolves and coyotes) who approach their prey openly or pursue them for long distances will capture young, old, sick, weak, injured, or inexperienced individuals from prey populations in higher-than-expected (i.e., non-random) proportions. Whether stalking opportunistic predators (such as mountain lions and bobcats) also preferentially select ill prey remains to be tested. Even for coursing predators, despite its wide acceptance, this idea rarely has been tested and to our knowledge not for wolves.

Separate from whether predators preferentially select (deliberately target) diseased individuals, apex- and meso-carnivores, both predators and scavengers, are hypothesized to function as potential disease-sanitizing agents ("predator cleansers") by removing infected and infectious prey (or their dead but infectious remains). This reduces the infection or disease incidence across a prey population. The effectiveness of predators as sanitizers needs scientific evaluation with a long-term study of prey disease loads.

PART I

Predator cleansing of chronic wasting diseases by mountain lions and wolves

Predator cleansing is proposed as a possible natural solution for the biological control of chronic wasting disease (CWD), a slow-onset, long-incubation, and 100-percent fatal neurodegenerative and potentially zoonotic disease affecting deer, elk, moose, and other cervids. CWD is widespread and epidemic in deer and elk in much of North America, infecting and killing hundreds of thousands, perhaps eventually even millions, of free-ranging deer and elk in the United States and Canada. It is caused by a misfolded rogue infectious protein called the CWD prion.

CWD has proven to be almost completely intractable and uncontrollable in both farmed deer and elk and wild free-ranging cervids since its emergence in the late 1960s in farmed and free-ranging deer and elk in Colorado and Wyoming. The disease causes immense pain and suffering to hundreds of thousands, perhaps millions, of deer and elk. As CWD's geographic range continues to expand and infection prevalence continues to rise, the disease will have an ever-increasing impact on cervid populations, local economies, and ecosystem health. Without fear-mongering, it is fair to describe CWD as insidious and dire and "wicked" i.e., a problem that cannot be fixed, where there is no single solution to the problem, and "wicked" denotes resistance to resolution, rather than evil.

Can wolves and mountain lions be our allies in the fight against CWD?

Do ecological apex carnivore predators, particularly wolves and mountain lions, selectively prey on CWD-infected deer and elk? Can these apex predators be enlisted as our natural allies to prevent or limit the impact of this terrible disease on wildlife and people?

Princeton University disease ecologist Andrew Dobson and the late Canadian pro-hunting wildlife ecologist Valerius Geist theorize that killing off the wolf allowed CWD to take hold in the first place. In a turnabout, would re-introducing more wolves or re-establishing mountain lions in areas of the United States void of ecologically relevant apex predator populations serve to prevent or mitigate CWD?

Predator cleansing of CWD is unproven, but recent reports are highly suggestive that it is beneficial. Compared to other facets of CWD biology, epidemiology, and disease control, predator cleansing has been little studied by wildlife researchers. Given the magnitude of the CWD problem, there is a surprisingly modest amount of published primary research on either the theoretical (modeled) or observed (empirical) role of predators in chronic wasting disease ecology.

A comprehensive search and review of the wildlife disease literature identified 10 reports describing primary research evidence of predator cleansing of CWD in deer and elk by mountain lions, wolves, coyotes, and bobcats including eight peer-reviewed journal articles, one abstract of unpublished research, and one PhD thesis chapter.

- Two peer-reviewed papers theoretically modeled the effects of selective removal of (1) CWD-infected deer by wolf predation (Wild et al. (2011) and (2) infected deer by mountain lions and infected elk by wolves (Brandell et al. (2022). One grey literature government report modeled CWD eradication from a closed elk herd by selective wolf predation (Hobbs (2006).
- Four peer-reviewed papers reported empirical observational field studies of mountain lion predation on CWD-infected mule deer (Miller et al. 2008, Krumm et al. 2010, DeVivo et al. 2017, Fisher et al. 2022). All four studies supported selective predation on CWD-infected deer by mountain lions.

Three journal papers and one meeting abstract reported the near total inactivation of the CWD prion on passage through the carnivore (canid or felid) gastrointestinal tract.

Wolves and mountain lions are promoted as potential CWD sanitizing agents more often in the popular press than in the peer-reviewed scientific literature. The media messaging has probably overstated the idea that large apex predators, especially wolves, can curb CWD spread, ignoring the uncertainty and limited evidence in scientific literature. Nevertheless, while the predator cleansing literature is not vast, quality research has been conducted, especially for mountain lions.

There are large knowledge gaps that need to be filled to better understand the practical utility of CWD predator cleansing (**Table 0, Figure 1**, pgs. 5, 6). For example, there are no empirical field studies of selective predation by mountain lions on CWD-infected elk or selective predation on CWD-infected deer or elk by wolves. Further studies, including laboratory experiments, mathematical models, and field observational empirical investigations, are needed.

What is the proposed epidemiological mechanism of CWD predator cleansing?

Predators could reduce CWD prevalence and incidence by slowing transmission via three interacting mechanisms:

a. Shortening the life span of infected individuals which reduces the duration of infectiousness, thereby reducing the number of infections produced per infected individual.

b. Selectively removing the most infectious prey, which reduces transmission.

c. Decreasing the size of the susceptible prey population (reduced population density), which may reduce the number of potentially infectious contacts.

If these mechanisms cause the number of new infections produced per infected individual to fall below one (R_0 <1), then the disease will eventually (in theory) die out from the cervid population. These three mechanisms also lessen the duration and magnitude of the environmental spread of CWD by reducing prion contamination of deer or elk habitats. (**Figure 2C,** pg. 7)

Wolves come with challenges, but "it's still a lot easier to manage wolves than it is to manage (CWD) disease."

— Margaret Wild, National Park Service Biologist, 2022

What factors limit or permit the investigation of predator cleansing of CWD?

Mountain lions have been eco-functional and physically absent in the United States for at least a century from the East, Southeast, Great Plains, and Midwest where CWD is now epidemic (newly introduced) or endemic (well-established) in free-ranging deer and elk herds.

However, CWD is prevalent in deer and elk herds in the western mountain states with robust native mountain lion populations, especially Colorado and Wyoming.

Gray wolves. There have been no field or experimental studies of CWD predator cleansing by wolves. This is largely because gray wolves, like mountain lions, are absent in many North American ecosystems where CWD is present. No one has been able to study whether wolves single out CWD-infected animals because the range of predators and disease have never overlapped. But over the next few years, that will likely change as both the disease and wolves spread out.

Table 0

Nine published studies & one abstract report providing evidence in support of the predator cleansing hypothesis by mountain lions (seven studies) and wolves (two studies) for chronic wasting disease (CWD) in deer and elk

Proposed effect of predation	Type of evidence	Prey	Carnivore predator		
			Mountain lions	Wolves	Other predators
Preferential & targeted predation on CWD-infected cervids by apex predators	1 **Theoretical & mathematical models**	Deer	• Brandell et al. 2022	• Wild et al. 2011	None
		Elk	Knowledge gap – no studies	• Brandell et al. 2022; Hobbs 2006	None
	2 **Empirical observation** - field epidemiology	Deer	• Miller et al. 2008 • Krumm et al. 2010 • DeVivo et al. 2017 • Fisher et al. 2022	Knowledge gap – no studies	None
		Elk	Knowledge gap – no studies	Knowledge gap – no studies	None
CWD prion inactivation via passage through the carnivore (felid & canid) gastro-intestinal tract	3 **Laboratory experiments** - planned & controlled	Deer	• Baune et al. 2021 • Wolfe et al. 2022	Knowledge gap – no studies	• Peterson 2023: report on Davis et al. (2023) abstract (bobcats)
		Elk	• Wolfe et al. 2022	Knowledge gap – no studies	• Nichols et al. 2015 (coyotes)
Negative geo-spatial correlation of CWD & apex predator distributions	4 **Disease biogeography** - landscape epidemiology	Deer & elk	Knowledge gap – no studies	Knowledge gap – no studies – negative correlation noted informally	None
CWD incidence & rate of spread will be greatly slowed by apex predator presence	5 **Natural experiment** - unplanned & uncontrolled - field epidemiology	Deer, elk & moose	Mountain lions & wolves -CWD is now invading the Greater Yellowstone Basis & surrounds; this is the first time CWD will encounter intact predator guilds in a functional temperate mountain ecosystem with generally limited trophy hunting of apex predators		Grizzly bears, black bears, Canada lynx, coyotes, & wolverines

Key knowledge gaps (in red) are also indicated.

FIGURE 1

Evidence of predator cleansing of CWD in deer and elk by mountain lions and wolves.

Number in parentheses is no. of reports

1) Theoretical & math models • *How does CWD epidemiology change if predators target CDW-POS prey?*	**YES (1)** **YES (1)**	**NO DATA** **YES (2)**
2) Empirical observations • Field epidemiology • *Do predators selectively kill CDW-POS deer?*	**YES (4)** **NO DATA**	**NO DATA** **NO DATA**
3) Lab experiments • Planned & controlled • *Is the CWD prion inactivated via passage thru the felid & canid intestinal tract?*	**YES (2)** **NO DATA** **NO DATA** **YES (1)**	**YES (1)** **NO DATA** **YES (1)** **NO DATA**
4) Disease biogeography • Landscape epidemiology • *Is CWD absent where apex predators are common?*	**NO DATA** **YES (0)**	**NO DATA** **YES (0)** *Observed but not published*
5) Natural experiment • Unplanned & uncontrolled • Field ecology • *Will CWD spread in the Greater Yellowstone Basin?*	**NO DATA** **NO DATA**	**NO DATA** **NO DATA** *Experiment in progress*

This may change soon. Over the next few years, CWD, white-tailed deer, and wolves may begin to interact ecologically in the western Great Lakes region (northern Minnesota, northern Wisconsin, and Upper Peninsula Michigan). Similarly, CWD distribution has begun to overlap with areas containing suites of apex predators (wolves, coyotes, black bears, grizzly bears, mountain lions) in the northern intermountain west of the Greater Yellowstone Ecosystem at the intersection of Wyoming, Idaho, and Montana and in far southwestern Canada in North America.

Wolves may serve better as a gauntlet of protection from CWD incursions than by controlling (via wolf re-introductions) established endemic/high prevalence CWD regions. In other words, predator cleansing by wolves and mountain lions may function better as a prevention tool rather than as a mitigation or treatment for CWD in cervids.

Union of unlikely allies: Can environmentalists and the NRA unite? There are large cultural and policy gaps that must be bridged if apex predators are to have a chance at CWD predator cleansing success. This begins with the reintroduction and protection of wolves and mountain lions, and the elimination or reduction of mountain lion and wolf trophy-hunting in CWD-affected areas.

Wolves eat elk, mountain lions eat deer, and their predation regulates the numbers of elk and deer on the landscape.

Mountain lions and wolves occasionally attack, injure, and kill livestock. Big game deer and elk hunters see predators as competitors and blame them for low cervid prey populations. State game departments are also not infrequently unfriendly toward wolves, mountain lions, bears, and coyotes, because their primary constituents are deer and elk hunters who buy licenses and ranchers who control private lands on which much hunting takes place and where big game prey inhabit, so their predator concerns must be addressed.

A change of attitude is needed. Are our oft-maligned apex carnivore predators worthless vermin to kill or are they our important natural allies in battling CWD? Would the number of wolves or mountain lions necessary to control CWD be acceptable to humans, particularly to ranchers, farmers, and hunters?

Patience will be required to ascertain if predator cleansing by wolves and mountain lions "works" for CWD. This slow-moving epidemic disease may have a devastating effect on cervid populations for as long as 50-100 years or more; 50 years is considered the early stage of a CWD epidemic. Thus, the combined effects of wolves and mountain lions on CWD, for example in the Greater Yellowstone Ecosystem, may not be empirically estimable for decades.

Many consider CWD the biggest single threat to wildlife in North America while others

dismiss or are apathetic towards the disease, including many big game hunters. **For more than 150 years, government agencies and the public waged a relentless war on predators of every size and species across North America. This mentality is slowly changing. Elk hunters and conservationists who still believe that predator removals help deer and elk may wish to rethink their positions.**

Some wildlife managers believe the solution to CWD is to raise the number of deer or elk that hunters can kill in areas where CWD is prevalent. However, the track record of this approach is dismal. Wolf or mountain lion predation, on the other hand, could remove CWD-infected deer from a population more effectively (non-randomly, with a bias towards infected deer or elk) than human harvest, as human hunters are more likely to randomly kill deer by CWD status compared to a wolf or mountain lion. Apex predators are predisposed, by instinct and learned behavior, to focus first on prey animals that are easier to kill rather than those living at the height of their physical strength. They are efficient at detecting and exploiting weaknesses in prey that humans cannot detect because their survival depends on it.

Photo credit: Thomas D. Mangelsen

"Mother Nature always bats last, and she always bats 1.000."

Rob Watson, 2010

PART II

Epidemiology of CWD in a nutshell

- CWD is a uniformly 100% fatal slow onset neuro-degenerative disease of free-ranging and farmed deer, elk, moose, and other cervid species. The Teddy Roosevelt Conservation Partnership, a non-profit coalition working to preserve hunting and fishing, calls CWD "the biggest threat to the future of deer hunting".
- CWD is caused by a prion, a highly infectious misfolded rogue pathogenic protein. CWD belongs to a group of similar animal and human prion diseases called transmissible spongiform encephalopathies (TSEs) that include sheep scrapie and bovine spongiform encephalopathy (BSE, or "Mad Cow"). Unlike viruses and other pathogens, prions lack a specific nucleic acid genome.
- The CWD prion, like all prion pathogens, causes normal prion proteins ($PrP^{cellular}$) to convert to the abnormal PrP^{CWD} in tissues throughout the body and eventually in neurological tissue. These abnormal prions accumulate in the brain, spinal cord, and lymphoid tissues (e.g., spleen, tonsils, lymph nodes), and eventually cause neurological disease, emaciation, and death.

Transmission. CWD spreads among deer and elk in two ways (**Figure 2A**, pg. 10):

- Deer and elk are highly social herding species. Direct deer-to-deer CWD spread happens via social contact, grooming, fighting, and mating via blood, saliva, urine, feces, semen, and milk.
- Indirect spread occurs when uninfected animals encounter environmental fomites that were previously contaminated by prions released by infected animals, e.g., when deer have contact with a CWD-prion-contaminated feces, urine, blood, milk, mucus, or saliva.
- The excreted or secreted PrP^{CWD} in urine, feces, or saliva, as well as PrP^{CWD} in the decomposing remains of a dead CWD-infected cervid, are extremely infectious and resistant to degradation so that PrP^{CWD} can be readily transmitted to other naïve cervid hosts by ingestion via direct contact with live deer or indirect contact with a PrP^{CWD}-contaminated environment.
- Most infections occur via direct contact during the early stages of an outbreak or epidemic and via the indirect route once the disease becomes endemic as the deer's territory becomes increasingly contaminated with built-up CWD prions.
- Although the CWD prion infectivity titer (infectious load) in excreta (feces and urine) is low, their repetitive excretion and accumulation lead to a massive release of infectious prions into the environment. A CWD-infected deer sheds a higher amount of prions through excreta during its extended incubation period and clinical disease vs. the level of infectious agent present in the brain at the terminal disease stage.

Environmental persistence. Depending on your preferred meme, the CWD prion is either the "Chuck Norris" or the "tardigrade" of infectious materials, i.e., extremely environmentally resistant. Since they are not alive, CWD prions cannot be killed, unlike bacteria, fungi, or other typical pathogens. They can only be "inactivated," which is no easy feat. Sewage treatment and cooking of harvested venison do not inactivate CWD prions.

Box 1

Chronic Wasting Disease (CWD) in game-farmed & free-ranging wild cervids

Best evidence suggests CWD originated in a confined research mule deer herd in ~1967 in Fort Collins CO (perhaps from deer exposure to scrapie-infected sheep) that then spread largely anthropogenically locally, regionally, nationally and internationally via:

(a) *Intra-state and inter-state shipments (translocations)* of CWD-infected privately-owned farmed deer and elk (for breeding and hunting) and wild deer and elk movements by wildlife agencies;

(b) *Fence-line infectious contacts* between infected farmed deer and wild free-ranging deer;

(c) *Environmental spread* via CWD-contaminated deer carcasses or hunter-translocated infected deer carcasses

(d) *Deer and elk bait stations and winter-feeding programs* that artificially congregate deer and elk at high densities and promote CWD spread

- To date, *there are no confirmed cases of zoonotic CWD infections of humans* from infected deer contact or deer meat ingestion although this may change as the CWD prion protein could mutate to become human-adapted.

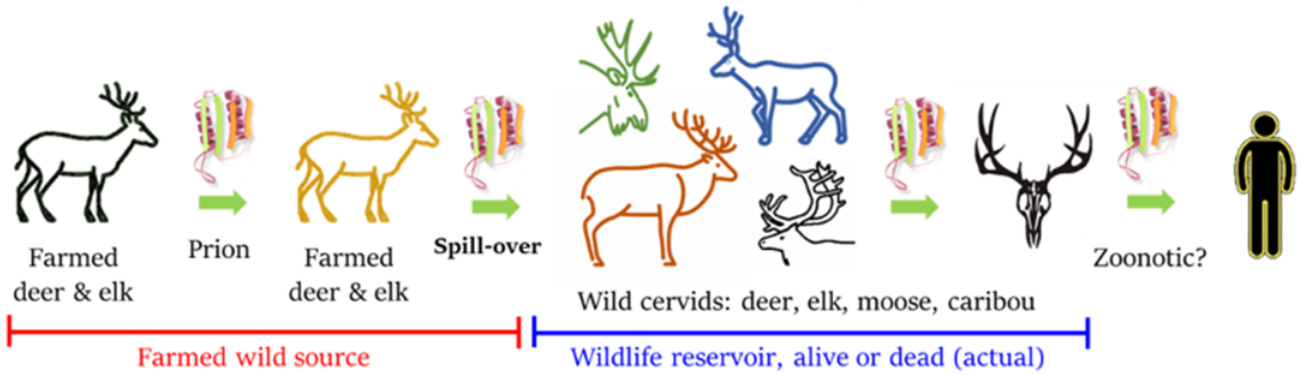
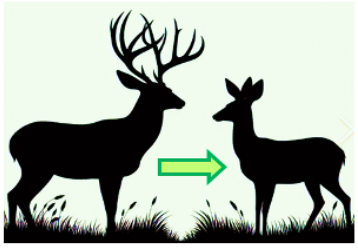


FIGURE 2A

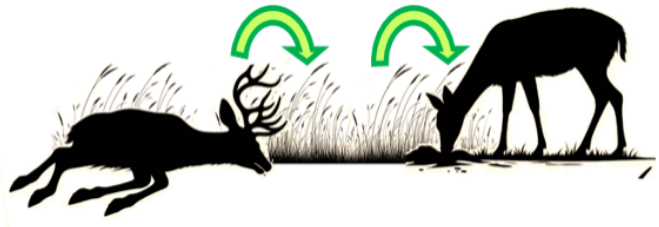
CWD is spread among deer & elk in two basic ways.

1) ***Direct deer-to-deer spread*** via social contact, grooming, fighting & mating via blood, saliva, urine, feces, semen & milk

2) ***Indirect spread*** occurs when uninfected deer encounter CWD prions in environment previously seeded by infected animals via urine, feces, blood, saliva or carcasses
   - Prions are extremely resilient & stable in the environment for years
   - Decomposing CWD-infected carcasses create contaminated *"CWD super-sites"*
   - Indirect spread seven-fold more important vs direct spread



Prions in saliva, urine, feces,& mucus infect deer & elk during social contacts e.g. grooming, fighting, mating,



Excretions of infected live deer & *carcasses* of deer that died from CWD pollute & seed deer habitats with prions

Uninfected deer ingest CWD prions via soil, water, plants, etc

FIGURE 2B

Carnivore predators reduce the probability of both types of CWD spread.

1) Apex predators (e.g. wolves & mountain lions) & meso-predators (e.g. coyotes & bobcats) may **selectively kill cervid prey infected with CWD** and ***remove sick or infectious animals*** from herd

Apex carnivore targets, kills & eats CWD-infected deer & elk
- Stops direct CWD spread
- Predators can detect infected prey that would be imperceptible to humans

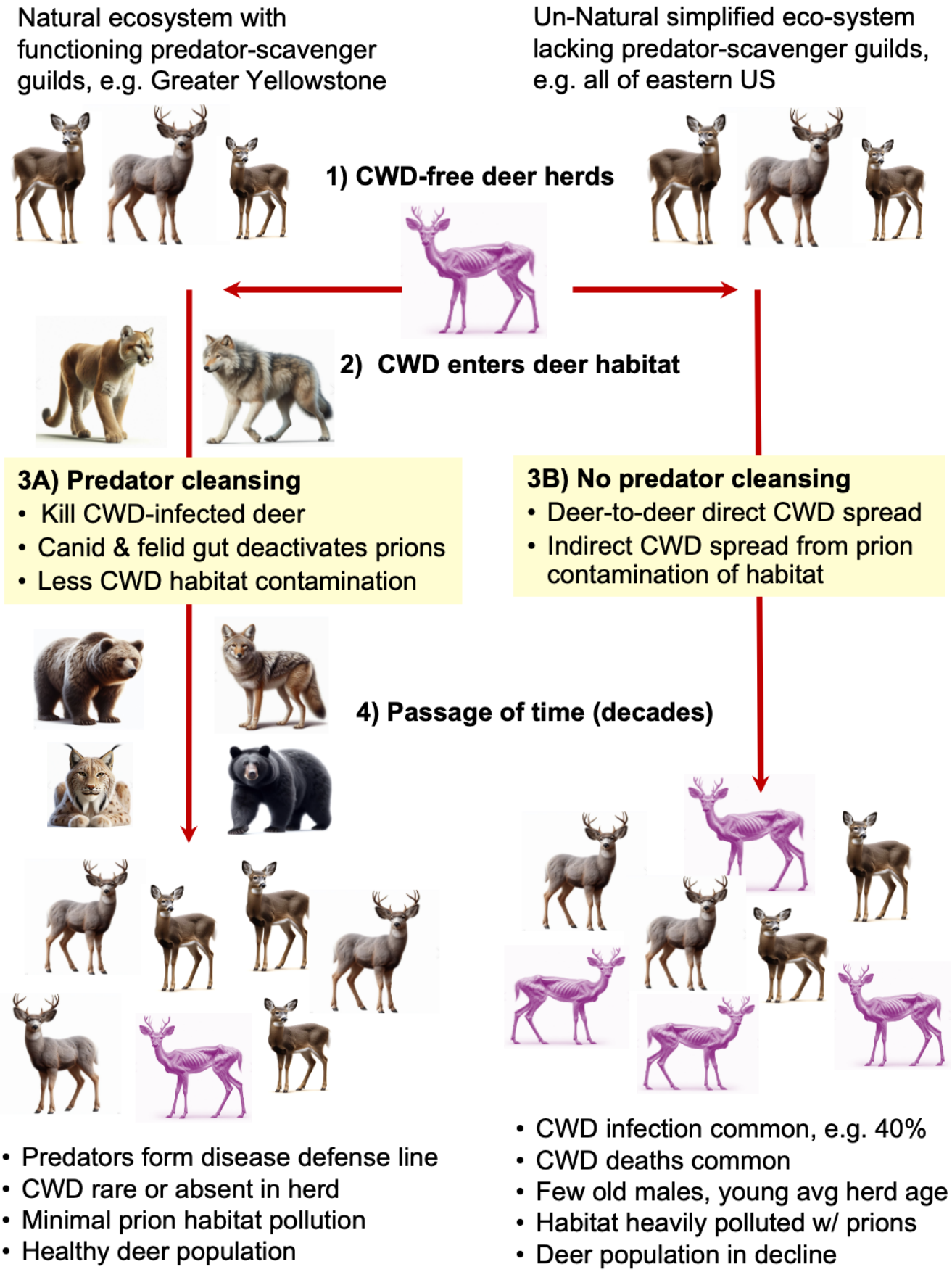
2) Passage of CWD-contaminated deer carcasses thru the felid or canid carnivore gastro-intestinal tract, via an unknown mechanism, **greatly reduces the infectious titer** ("infectiousness) of CWD prions, thus *reducing the CWD environmental load*

High CWD prion titer when predator ingests CWD-infected deer or elk tissues
- Canids & felids resistant to CWD infection (species barrier)

(Mountain lion, wolf, coyote, bobcat)

Low or absent CWD prion titer excreted in feces after gut passage
- Limits prion contamination
- Lessens indirect CWD spread

FIGURE 2C A tale of two deer herds with and without apex predators.



- CWD prions persist and remain infectious (even in trace amounts) in outdoor deer habitats for years, perhaps indefinitely. Prions resist disinfectants, alcohol, formaldehyde, detergents, proteolytic enzymes, desiccation, radiation, freezing, and incineration up to 1800 ^{0}F.
- The only known methods that reduce (but not eliminate) prion infectivity are incineration at high temperatures (above 900°F) for several hours; soaking in 40% bleach; saturation with sodium hydroxide (lye) for 24 hours, or "super autoclaving" at 132°C for 4.5 hours. None of these methods are of any practical utility to decontaminate natural outdoor deer habitats.

Clinical disease. During the terminal late stages of CWD after an incubation period of at least 1.5 to two years in deer and longer in elk, the built-up abnormally folded prion protein aggregates lead to severe brain injury causing both drastic physical changes and extremely abnormal behavior. Experienced hunters in CWD endemic areas readily recognize these diseased deer.

- Physical changes: Progressive weight loss ("wasting") leading to emaciation, a shaggy ungroomed hair coat, drooping ears, and an inability to hold the head up.
- Peculiar behaviors: Stumbling, incoordination, loss of fear of humans, confusion, listlessness, lethargy, excessive urination and salivation (drooling), extreme thirst (remaining near water), and a telltale "blank stare".

History & disease bio-geography. CWD emerged in the late 1960s in a captive mule deer research herd at the Colorado Division of Wildlife Foothills Wildlife Research Facility in 1967 in Fort Collins. These herds were captured cervids from different wild populations, including pregnant females that were released after parturition. The herds had contact with scrapie-infected sheep, but it is so far undetermined if a scrapie variant caused CWD. Scrapie is closely related to CWD. The epidemiology of CWD is most compatible with a single strain that originated in mule deer and then infected elk and white-tailed deer.

- Over the past half-century, this alien-like pathogenic protein infection has slowly but relentlessly spread north, south, east, and west from its northeastern Colorado and southeastern Wyoming epicenters. CWD geo-expansion occurred and continues from a combination of translocation and sale of silently infected farmed deer and elk, the natural migrations and movements of free-ranging deer and elk, and human movements of carcasses and parts (e.g., gut piles) of infected deer by hunters.
- The past 24 years have seen a rapid spread and expansion of the disease from Western states, with new regions testing positive each year. CWD is now epidemic at high prevalence in the major deer and elk hunting havens in Wisc., Mich., Colo., Wyo., Mont., W. Va., Tenn., and Pa.
- According to Colorado Parks and Wildlife (CPW), CWD is prevalent across much of Colorado and continues to negatively impact deer, and to a lesser extent, elk populations. As of 2022, CWD has been detected in 40 of 54 deer herds, 16 of 43 elk herds, and 2 of 9 moose herds. CWD infection rates vary by herd and location but may exceed 25% (1 in 4 deer).
- CWD now infects (and eventually causes premature death of) hundreds of thousands, perhaps millions, of deer, elk, and moose in free-ranging deer and elk in 34 US states and five Canadian provinces. Farmed deer and elk in 18 states and four Canadian provinces are infected. The pathogenic protein has reached both Canada and South Korea via the farmed deer trade.

Control. The approach of most state wildlife agencies to control CWD is to increase the number of deer that can be killed or hunted in

places where the disease prevalence is increasing based on surveillance of hunter-killed deer. This approach has failed. CWD has so far proven impossible to eradicate with current tools especially when environmental prion contamination is significant. At present, the best option is to minimize the spread to new areas and naïve cervid populations.

With the beginning spread of CWD into the Greater Yellowstone Area which is occupied by several large predators (i.e., wolves, grizzly bears, and mountain lions), the role of predators in prion transmission dynamics may soon become more relevant and apparent. A multi-predator system may have a greater impact on an emerging CWD epidemic, especially before significant prion contamination occurs in the environment.

No shortage of money. Notably, the many knowledge gaps in the CWD predator cleansing literature occur despite almost a billion dollars in federal and state funding directed at CWD surveillance and control since 2000.

- The federal government spent over $284.1 million on CWD-related efforts between 2000 and 2021, with $200 million going to the USDA APHIS. In fiscal year 2020, state natural resources agencies and state agriculture/animal health agencies spent over $25.5 million and $2.9 million, respectively, on CWD-related work.
- The ($490 million total) in new funding for CWD. These monies are split evenly between research and management of CWD, with $35 million per year for each purpose. It is not known whether any of these new funds will investigate CWD predator cleansing.
- State wildlife agencies in 16 CWD-positive states spent $773,000 annually in 2021 on CWD disease management. This includes sample collection and disposal, testing, salaries, supplies, and logistics. Across 32 wildlife agencies including states where CWD has yet to be detected, the annual costs associated with CWD ranged from just under $8,000 (Oklahoma Department of Wildlife Conservation) to more than $2 million (Texas Department of Parks and Wildlife), for an average of $503,000 per state.

PART III

Evidence supporting predator cleansing of CWD in cervids by wolves and mountain lions.

Five lines of evidence support the predator cleansing hypothesis for CWD by wolves and mountain lions. There is more evidence for mountain lions than wolves. The available evidence suggests that predators reduce both direct and indirect transmission (**Figure 2B,** pg. 11). The evidence is summarized in great detail in **Tables 0** (pg. 5), **1A**, **1B**, and **1C** (pgs. 19, 20, 21).

1) Predator-prey ecologic theory & predator-prey CWD disease modeling

Hypotheses:

- Apex predators preferentially target sick prey, i.e., wolves and mountain lions target and kill deer and elk infected with CWD.
- The killing of CWD-infected deer or elk will lower the prevalence of CWD in deer and elk herds over time.

Approach: Use predator-prey theory and infectious disease mathematical models of CWD in a deer or elk herd.

Importance: Given the slow onset and spread of CWD, an advantage of mathematical models is that various assumptions can be tested (e.g., variable CWD prevalence) and long-time periods can be assessed.

Problems: "All models are wrong, some are useful" (British statistician George Box, 1976). This means that all s**tatistical or mathematical models** always fall short of capturing the full complexities, intricacies, and nuances of reality. However, despite these imperfections, some models are incredibly valuable in providing insights. Models tend to be parsimonious, i.e., simple and concise compared to the reality that they approximate. Models are used to both describe and analyze past events and to predict future outcomes.

Status: See **Table 0** and **Table 1A** (pgs. 5, 19). Three reports mathematically modeled CWD in the presence of mountain lions and wolves.

Gaps: No models yet of mountain lions preying on CWD-infected elk herds. See **Table 0** and **Figure 1** (pgs. 5, 6).

Conclusion: All three reports generated models showing mountain lion or wolf predation of elk or deer greatly decreased or even eliminated CWD, but the time frame was long i.e., it took 20 to 50 years. To simplify the models, it was assumed the herds were closed, i.e., no deer or elk immigration.

2) Empirical observations

Hypotheses (same as for No. 1 above):

- Apex predators preferentially target sick prey, i.e., wolves and mountain lions target and kill deer and elk infected with CWD
- The killing of CWD-infected deer or elk will lower the prevalence of CWD in deer and elk herds over time

Approach: Use field epidemiology methods to ascertain if predators selectively target and preferentially kill CWD-infected deer or elk in the field.

Importance: Real-world evidence for or against predator cleansing theory. Can inform or ground truth mathematical models; identifies CWD risk factors and drivers.

Problems: No one has been able to study whether wolves single out CWD-infected animals because the range of predators and the disease have never overlapped until very recently in the Greater Yellowstone Basin and the western Great Lakes region in northern Minnesota, Wisconsin, and Upper Peninsula Michigan.

Status: See **Table 0** and **Table 1A (**pgs. 5, 19). Four reports examined if mountain lions appeared to target CWD-infected deer. In all four reports, CWD-positive mule deer were 3.5 to 8 times more likely to be killed by mountain lions vs. uninfected deer or human hunters.

Gaps: No observational studies yet of mountain lions preying on CWD-infected elk herds or wolf predation on CWD-infected deer or elk. See **Table 0** and **Figure 1** (pgs. 5, 6).

Conclusion: Four studies support predator cleansing of CWD by mountain lions in mule deer herds.

Comments: No one has been able to study whether wolves single out CWD-infected animals because the range of predators and disease have never overlapped. To date and in general, CWD has not thrived where wolf populations are active, although CWD has

appeared on the margins of these populations. Just as mountain lions are absent from the United States east of the Rocky Mountains, gray wolves are absent from many North American ecosystems where CWD is present. (Of course, it may be that gray wolves have prevented the expansion of CWD into their domains via predator cleansing). Over the next few years, CWD and wolves should begin to interact as both the disease and wolves spread out.

3. Laboratory experiments

Hypotheses:

- Wild canids and felids are resistant to CWD infection, i.e., CWD cannot cross the canid or felid species barrier.
- A mechanical basis for this CWD resistance is that carnivore predators inactivate all or most ingested CWD prions when they consume CWD-infected or diseased prey.

Approach: Short- to long-term, planned, controlled feeding trials. Determine if the CWD prion is inactivated during passage through the felid and canid gastrointestinal tract by titrating CWD infectivity over time. In a confined setting using tame animals, feed predators or scavengers known infectious doses of CWD prion (brain, lymph nodes, or muscle) from CWD-infected deer or elk.

Outcome: What was the titer (level) of infectious CWD after passage through the predator's or scavenger's gastrointestinal tract?

Importance: If wild canid and felid predators decontaminate CWD from cervid prey tissues, this reduces prion environmental contamination, lessening the risk of indirect CWD spread to cervids. Furthermore, all prions, including CWD prions, are incredibly resistant to physical and chemical inactivation. Prions resist disinfectants, alcohol, formaldehyde, detergents, proteolytic enzymes, desiccation, radiation, freezing, and incineration up to 1800 ^{0}F. Understanding how felid and canid carnivores can deactivate all or most prion infectivity at body temperature and over a short time frame (1 to 3d) could provide insights into the decontamination of prion-polluted environments.

Status: See **Table 0** and **Table 1B** (pgs. 5, 20). All four studies showed high-level inactivation of 96% to 100% of prion infectivity after passage in coyotes, mountain lions, and bobcats. Mountain lions resisted CWD infection after many years of experimental exposure to CWD.

Gaps: No studies conducted yet that test if wolves destroy most or all CWD prions they consume. One can assume the wolf's response would be very similar to the closely related coyote.

Conclusion: Mountain lions, coyotes, and bobcats (but not ravens) effectively destroy 965 to 100% of the CWD prions they consume when infected deer or elk tissue passes through their intestines, by an unknown mechanism. This helps to reduce CWD prion pollution of deer habitats and is an extremely valuable ecosystem service.

4. Disease biogeography

Hypotheses:

- CWD will be absent or at low prevalence where apex predators, mountain lions, and wolves, are common
- There is a negative spatial correlation between apex predator abundance and CWD prevalence at large (continental), medium (state-level), and small (game management units) spatial scales.

Approach: Use landscape epidemiology techniques to analyze **risk patterns** and **environmental risk factors** related to diseases across time and space; explore the relationship between CWD risk and the presence, absence, or density of carnivores, to provide insights into CWD prevention and control efforts by natural predation.

Outcome: Maps of the co-distribution of CWD (occurrence or prevalence) and apex predator

distributions or densities (mountain lions or wolves) with or without statistical analysis.

For this document, we created the following simple maps without any statistical analysis:

For gray wolves and CWD in North America, the continental United States, and Wisconsin:

Figure 3A (pg. 22). Negative spatial correlation: gray wolf range vs. CWD distribution in North America

Figure 3B (pg. 23). Co-distribution of CWD in free-ranging cervids & gray wolves in lower 48 US

Figure 4A (pg. 24). Cumulative CWD prevalence in free-ranging Wisconsin deer from 1999 to 2023 by Deer Management Zone

Figure 4B (pg. 25). Predator cleansing? Negative spatial correlation between wolf pack distribution and CWD prevalence in Wisconsin

Figure 4C (pg. 26)**.** Cumulative distribution of CWD-POS free-ranging deer in Wisconsin Northern Forest Zone

Figure 4D (pg. 26). Cumulative distribution of CWD-POS free-ranging deer in Wisconsin Southern Farmland Zone

For mountain lions and CWD in North America and Colorado:

Figure 5A (pg. 27). Negative spatial correlation: mountain lion range vs. CWD occurrence in North America

Figure 5B (pg. 27). Approximate range of mountain lions in Colorado counties

Figure 5C (pg. 28). CWD prevalence in mule deer and elk vs. mountain lion distribution in Colorado

Tables 3 and 4 (pgs. 29, 30). As relevant background data, Table 3 shows estimates of cervid populations and cervid deaths from human causes and different predators in Colorado in 2022. Table 4 shows estimated predator populations and human causes of their deaths in Colorado in 2022.

Importance: Disease biogeography can assess correlations at multiple spatial scales from small (e.g., game management unit), to state levels to large continental scales.

- **Continental-scale:** compare CWD distribution in deer and elk vs. occurrence of gray wolves and mountain lions in North America. See **Figures 3A**, **3B**, and **5A** (pgs. 21, 22, 23).
- **State-level e.g., gray wolves in Wisconsin; and mountain lions in Colorado:** See **Figures 4A**, **4B**, and **5C** (pgs. 23, 24, 27).
- **Deer Management Unit for gray wolves in Wisconsin and mountain lions in Colorado:** See **Figures 4C** and **5C** (pgs 25, 27).

Status: See **Table 0** and **Table 1B** (pgs. 5, 20). Ecologically functional gray wolf populations are found in the western Great Lakes region in northern Wisconsin, northern Minnesota, and Upper Peninsula Michigan. CWD prevalence is lower in those regions of these states where wolves are present compared to areas in these states where wolves are absent.

There are no studies, to our knowledge, that have formally tested for a negative spatial correlation between apex predator abundance and CWD prevalence. However, wildlife ecologists have noted the absence of CWD where wolves are abundant:

American-Canadian mammal biologist Paul Paquet has monitored the geo-expansion of CWD vs. the presence of established wolf populations since the disease was first confirmed in the wild decades ago: "To date and in general, CWD has not thrived where wolf populations are active, although the disease has appeared on the margins of these populations. A simple mapping of the distribution of wolves and CWD is very instructive. I have not mapped the distribution of all large predators and CWD, but that would be an instructive exercise. In particular, a comparison of diverse multi-prey and multi-predator systems like Yellowstone with simpler systems like the Great Lakes would be of interest, as well as comparing the mix and densities of predators with establishment of CWD."

Conclusions:

Visual inspection of the co-distributions of wolves and CWD in North America, the continental US, and Wisconsin, moderately to strongly suggest a negative spatial correlation between CWD and wolves.

In Colorado, visual inspection of mountain lion distributions and CWD prevalence in deer and elk suggests that mountain lions may be preventing or delaying CWD incursions into south-central Colorado's Game Management Units.

Correlation is not proof that wolves prevent or limit CWD incursions but strongly supports it when observed at many locations or different spatial scales.

Table 1A

Summary of evidence supporting predator cleansing of CWD in cervids

Approach & hypothesis	*Mountain lion & wolf examples*	*Comments*
1A) Predator-prey ecologic theory **1B) Mathematical models of infectious disease** ***Approach:*** Use mathematical, statistical & computational methods (w/ or w/out real demographic & disease incidence data) to *describe & predict* how an infectious disease will spreads in a population & to evaluate potential interventions ***Hypotheses:*** • Predators may create healthier ("*cleansed*" or "*sanitized*") prey populations by selectively hunting & removing infected or diseased individuals • For predator cleansing to be efficient, prey species vulnerability to disease must overlap with vulnerability to predation & predators must select for infectious individuals • Changes in predation rates or predator-prey dynamics may affect patterns of disease emergence, reemergence & persistence • There is targeted & selective predation on CWD-infected deer & elk by **wolves** & **mountain lions**	Hobbs (2006) – Dynamic model with direct & indirect CWD transmission suggests that presence of 20 **wolves** would eradicate chronic wasting disease from **elk** in Rocky Mountain NP in two to three decades if **elk** population closed to infection in from outside sources Wild et al. (2011) – In a dynamic model with selective mortality where CWD-positive **deer** had 4× higher mortality from **wolves** with 15% annual predation, the **deer** population decreased modestly while CWD prevalence decreased rapidly. This resulted in CWD elimination in ~60 yrs from a simulated closed **deer** herd. Brandell et al. (2022) – Deterministic model of (1) **cougar-deer** & (2) **wolf-elk** predator-prey systems in a simulated Greater Yellowstone Ecosystem • Used actual **deer, elk, mountain lion & wolf** population estimates • Model showed that both **mountain lions** & **wolves** can reduce CWD outbreak size via biological control of the prion infection under moderate yet realistic predation pressure.	• Predator cleansing theory is generally supported for coursing predators e.g., **wolves** that chase down their prey based on fitness. • There is less general support for ambush & opportunistic predators e.g., **mountain lions** (*Adrian Treves, personal communication*) • "As CWD distribution & **wolf** range overlap in the future, **wolf** predation may suppress CWD disease emergence or limit prevalence." Wild et al. (2011) • Ecosystems altered by removal of natural predators by humans may respond differently to endemic or novel pathogens than intact more natural ecosystems with predators • "*All models are wrong, but some are useful*." *George Box 1978* i.e., no model can capture the full complexity of reality, but some models provide useful insights
2) Field observational epidemiology ***Approach:*** Investigate a naturally-occurring infection or disease outbreak or event to understand patterns, causes & risk factors for the infection or disease. This empirical data is critical to ground-truth predictive models. ***Hypothesis***: CWD-positive **deer & elk** are more likely to be selectively targeted & killed by predators vs uninfected cervids or vs human hunters **Mountain lions** can detect & actively target subclinically-affected CWD-infected **deer**	• Miller et al. (2008) – CWD-infected **deer** four times more likely to be killed by **mountain lions** vs. uninfected **deer** • Krumm et al. (2010) – CWD-POS female **mule deer** 8.5-times & CWD-POS male **mule deer** 3.2 times more likely to be killed by **mountain lion** vs. same sex **deer** killed in same vicinity & time by a hunter • DeVivo et al. (2017) – CWD-POS **mule deer** more susceptible to **mountain lion** predation, hunter harvest & illegal harvest. **Mountain lion** predation no. 1 cause of mortality followed by clinical CWD • Fisher et al. (2022) – CWD-POS **deer** had 4.5-fold higher **mountain lion** predation vs CWD-NEG **deer**; same herd as Miller et al. (2008) but ten years later w/ similar results	• CWD epidemics may alter predator-prey dynamics by enabling **mountain lion** hunting success • *Knowledge gap*: No field studies conducted yet that test if **wolves** selectively prey on CWD-POS **deer** or **elk**. • CWD-infected **deer** appear less vigilant or fit & are relatively vulnerable to 'attack' e.g., by predation, hunting, or vehicle collision • CWD-infected **deer** have high vulnerability to **mountain lion** predation

TABLE 1B

Summary of evidence supporting predator cleansing of CWD in cervids (cont'd.)

Approach & hypothesis	*Mountain lion & wolf examples*	*Comments*
3) Laboratory experiments ***Approach:*** Employ captive confined (usually tame) wildlife in a controlled setting to address a problem that would be difficult, expensive or even impossible to conduct in a field setting. May entail challenging the animal e.g., with a pathogen ***Hypotheses:*** • Felid & canid apex & meso-predators are evolutionarily resistant to CWD infections • Felid & canid predators neutralize CWD prions during gut passage of ingested infected cervids • Carnivores play minor role in prion envt'l contamination vs CWD-infected cervids & human hunters e.g., leave deer gut piles	• Nichols et al. (2015) – Four captive **coyotes** removed most CWD prion infectivity from elk brains during gut passage; prions not detected one to three days post-ingestion • Baune et al. (2021) – Two captive **mountain lions** destroyed 96% of consumed mule deer CWD prions in brain spiked muscle • Wolfe et al. (2022) – Three captive **mountain lions** fed 432 CWD-tainted deer & elk carcasses (14K kg) in 2K feedings over 18 yrs failed to show any evidence of prion-infection; 133 wild **mountain lion** brains & lymph nodes had no prion infections • Peterson (2023) – Four captive **bobcats** eliminated 98% of ingested CWD prions (from deer & elk brains & lymph nodes) in one day; 100% in 3 days; Davis et al. (2023) meeting abstract	• Good quality evidence for **mountain lions** & **coyotes** from a small number of studies. • Felid & canid scavengers & carnivores esp **bobcats** & **mountain lions** may be removing infectious prions from the landscape, lowering CDW risk for **deer** & **elk** • No known prion diseases affect canids; BSE ("Mad Cow" prion) infects all felids • **Mountain lions**, **coyotes** & **bobcats** effectively destroy most of the CWD prions they consume. • *Knowledge gap*: No studies conducted yet that test if **wolves** destroy most or all CWD prions they consume
4) Landscape epidemiology or disease biogeography ***Approach –*** Examine spatial variation in disease risk or incidence as influenced by landscape characteristics & environmental factors that affect the distribution & dynamics of hosts, vectors, predators & pathogens ***Hypotheses:*** • **Deer & elk** CWD prevalence or incidence will be negatively spatially correlated with **wolf** & **mountain lion** distribution, density or predation pressure • CWD distribution only recently began to overlap with areas containing suites of apex predators (**wolves, coyotes, black bears, grizzly bears, cougars**) in North America. CWD ecology in these diverse multi-prey & multi-predator systems like Greater Yellowstone may contrast sharply w/ simpler ecosystems (often apex predator-free) e.g., western Great Lakes in northern WI, MN, & MI	• There are no good examples of **mountain lions** vs CWD geo-spatial correlation. This is b/c, outside of California, **mountain lions** are trophy hunted & CWD is not yet present in California. • There is a general negative spatial correlation between **gray wolf** range & CWD occurrence in North America at small (game mgmt. unit) to large (continental) scales. *Example:* In WI, 98% of 10.7K CWD cases from 1999-2023 occurred in the Southern Farmland Zone where **wolves** are absent. Only 78 (0.7%) of CWD cases were detected in Northern & Central Forest Zones where **wolves** are common. **Deer** are abundant thru-out the State. • A *negative geo-spatial relationship* between **wolf** distribution & CWD is observed: (1) in **deer** in WI; (2) in **deer** & **elk** in the inter-mountain Rocky Mountain West (e.g., CO) & western Canada	• *Knowledge gap:* The apparent negative geo-spatial relationship between CWD & **wolves** & **mountain lions** has not yet been formally tested or analyzed • There are parts of the Western slope in south-central CO where CWD has not yet been detected where **mountain lions** are hunted but still abundant. • These **mountain lions** may be an unseen defensive wall against CWD incursion in certain CO game mgmt units. • To date & in general, CWD has not thrived where **wolf** populations are active, although CWD has appeared on the margins of wolf populations

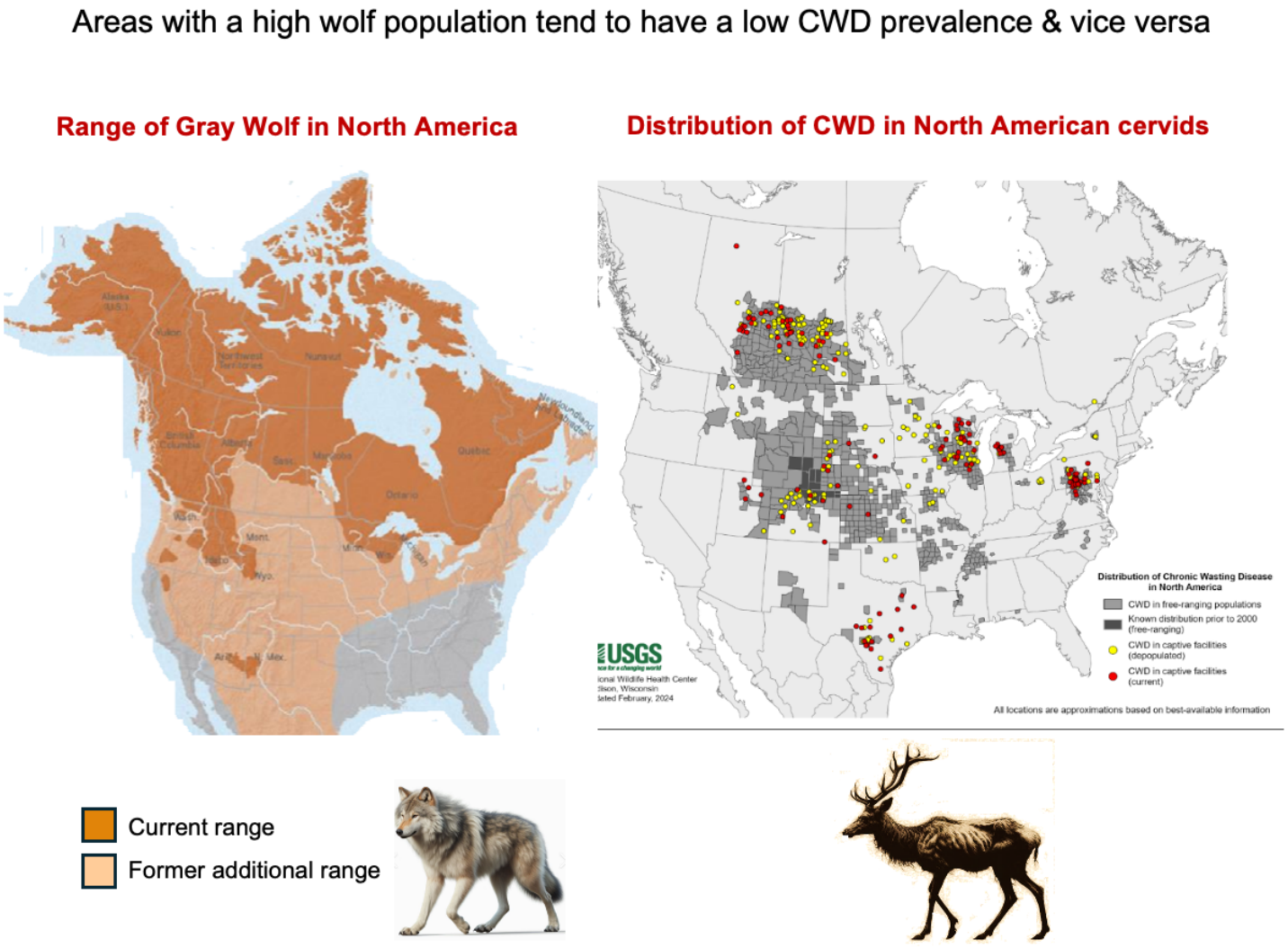
TABLE 1C

Summary of evidence supporting predator cleansing of CWD in cervids (cont'd.)

Approach & hypothesis	Mountain lion & wolf examples	Comments
5) Natural experiments ***Approach:*** Investigate an unplanned or unexpected event not under control of the researcher that creates an exposure or outcome of interest. ***Example:*** The atomic bombing of Hiroshima & Nagasaki in 1945 was a "natural experiment" permitting study of adverse health effects of radiation on a large population. ***Hypothesis:*** CWD was detected for the first time in a **mule deer** in Yellowstone NP in Nov 2023. CWD was earlier found in the adjacent Grand Teton NP in a **mule deer** in 2018 & an **elk** in 2020. • A high-profile unintended *natural experiment* on how CWD spreads is about to unfold in the Greater Yellowstone Basin (GYB) • Due to predator cleansing by a functional apex predator guild in the GYB within a resilient large intact temperate forest mountain ecosystem: (1) CWD spread in **deer, elk** & **moose** in the GYB will be *much slower* & (2) CWD incidence & prevalence will be *much lower* vs other areas of the U.S. (e.g. CO, eastern States) with CWD that lack an intact apex predator guild.	• CWD will likely spread throughout the GYE in coming decades. • This is first time CWD has entered an ecosystem with an intact apex predator guild (**gray wolves, mountain lions, grizzly bears, coyotes, lynx**) where human interference (e.g., trophy hunting) of predators & prey is minimal. • This will in some ways be a real-world test of the CWD infectious disease models of Wild et al. (2011) & Brandell et al. (2022) i.e., to compare the models to future empirical CWD epidemic data • CWD spreads slowly & only recently invaded areas inhabited by abundant large predators (e.g. the GYE), so empirical effects of selective predators on CWD invasion & spread may not be evident for years to decades. • Reintroduction & protection of **wolves** in CWD-affected areas, although controversial, could be very efficient for the natural bio-control of this disease. • Predator cleansing may be more efficient at *preventing CWD* establishment in the GYB than "treating" an already CWD-infected area by introducing predators.	• CWD has slowly encroached on the GYB from the north in Montana & from the south & east in Wyoming • Predator cleansing may represent the best long-term defense of cervids in the GYB against CWD • The CWD course in cervids in the GYE will be well-studied b/c cervid prey & apex predators are closely monitored year-round. • In Yellowstone, **wolves** primarily kill **elk**, while **cougars** kill **elk** & **mule deer** at almost equal rates • CWD ecology in diverse multi-prey & multi-predator systems like Yellowstone may contract sharply with simplerecosystems (often apex predator-free) like the western Great Lakes region. • *Knowledge gap:* The effectiveness of predators as *disease sanitizers* needs scientific evaluation with long-term studies. • *Knowledge gap:* Whether predators can significantly improve control of CWD is unknown but deserves deeper exploration.

FIGURE 3A

Negative spatial correlation: gray wolf range vs. CWD distribution in North America



https://www.usgs.gov/media/images/distribution-chronic-wasting-disease-north-america-0

The negative spatial correlation between gray wolf distribution and CWD occurrence in deer and elk is apparent at several geographic scales.

Figures 3A and **3B** (pg. 23) show the mostly negative spatial correlation between gray wolf distribution and CWD in free-ranging deer and elk in North America (Figure 3A) and the continental US (Figure 3B).

Figures 4A, **4B** and **4C** (pgs. 24, 25, 26), and **Table 3** (pg. 29) show this same phenomenon in Wisconsin at the state level, see **Figures 4A** and **4B** (pgs. 24, 25), and by Deer Management Zone, see **Figures 4C** and **4D** (pg. 26) .

Table 2 (pg. 24) shows the numbers of deer, CWD cumulative (1999-2023), and predators for each of Wisconsin's four Deer Management Zones.

FIGURE 3B

Co-distribution of CWD in free-ranging cervids & gray wolves in lower 48 U.S.

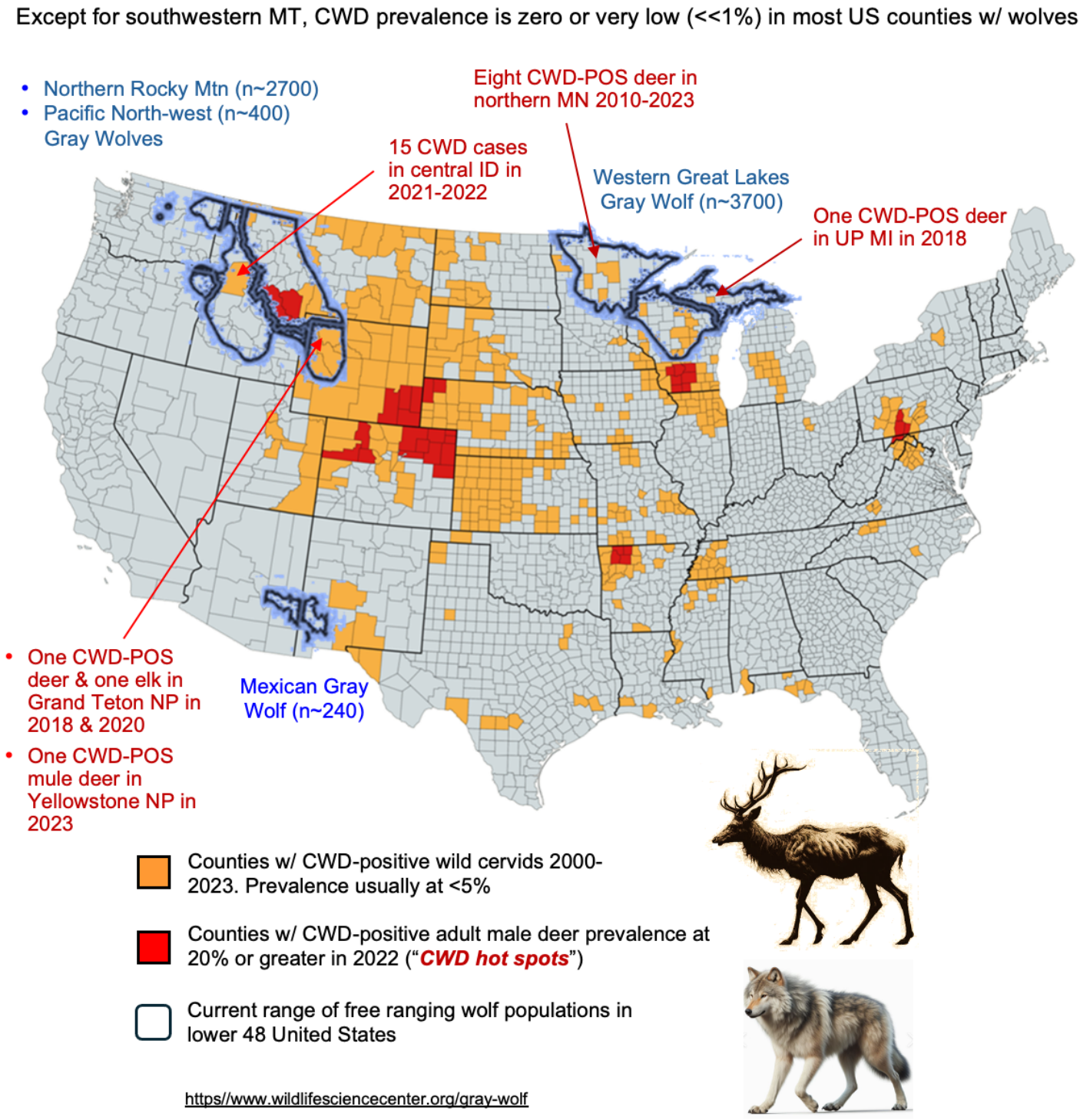
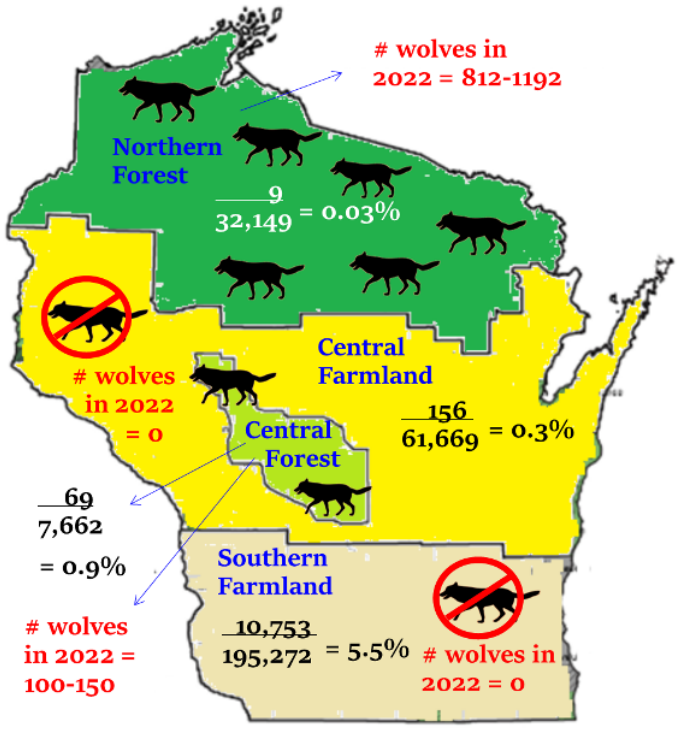


Figure 4A

Cumulative CWD prevalence in free-ranging Wisconsin deer from 1999 to 2023 by Deer Management Zone



- *97.8%* of CWD cases occurred in *Southern Farmland Zone where wolve are absent*
- *0.71%* of CWD cases occurred in *Northern Forest & Central Forest Zones where wolves are common*

Overall cumulative CWD prevalence
= 10,987/296,752
= 3.70%

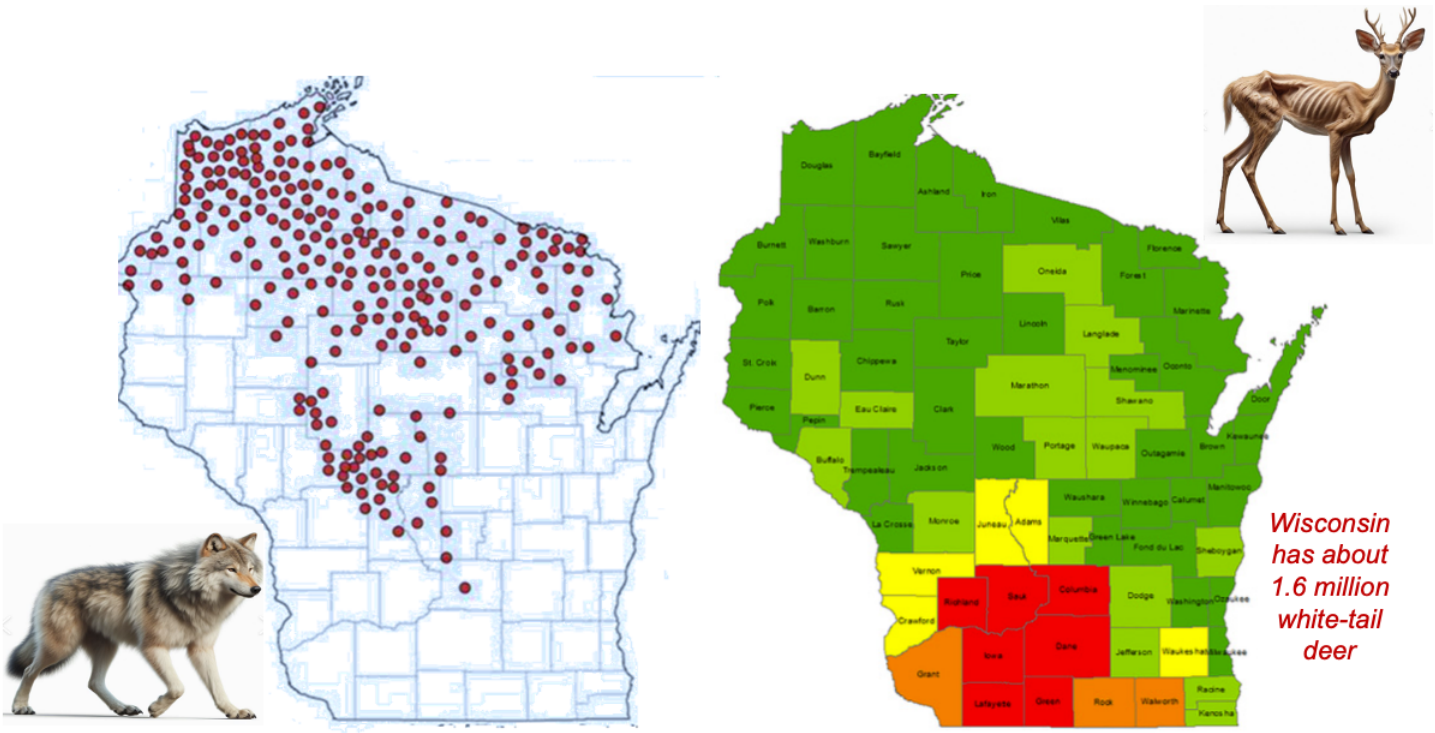
Table 2

White-tailed deer, CWD prevalence, predator & scavenger numbers, Wisconsin 2022

Deer Mgmt Zone	No. deer	CWD cumulative prevalence 1999-2022	No. wolves	No. coyotes	No. bobcats	No. black bears	No. deer vehicle collisions
Southern Farmland	500,000	5.5%	0	45,000	300-500	2,500	4,600
Central Farmland	500,000	0.9%	0	33,000	500-700	3,500	5,910
Central Forest	250,000	0.3%	100-150	25,000	800-1100	5,000	8,088
Northern Forest	300,000	0.03%	812 to 1,193	50,000	1400-1700	13,000	10,399
Totals	**1,550,000**	**3.7%**	**912-1343**	**153,000**	**3000-4000**	**24,000**	**28,997**

FIGURE 4B

Predator cleansing? Negative spatial correlation between wolf pack distribution & CWD prevalence in Wisconsin



Known Wisconsin gray wolf packs, 2020

- Estimated 292 packs; ~1034 wolves
- Avg pack size 3.8 wolves
- Wolf trophy hunting permitted until recently in WI but not currently

CWD prevalence in hunter killed deer in 2022 in Wisconsin

- At or above 20% in 7 counties (red)
- 10% to 19.4% in 3 counties (orange)
- 5% to 9.9% in 5 counties (yellow)
- less than 5% in 16 counties (light-green)
- "not found" in 41 counties (dark green)

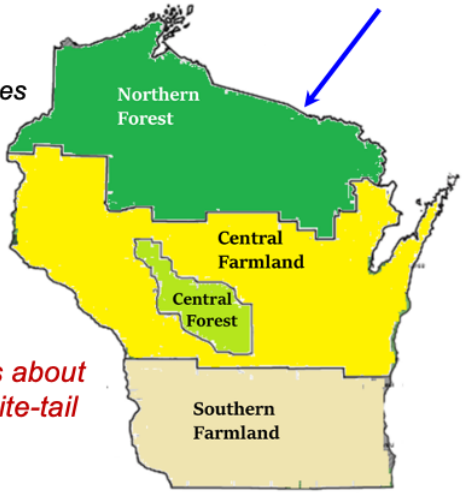
https://www.reddit.com/r/wisconsin/comments/psla17/wisconsin_wolf_pack_map/

FIGURE 4C

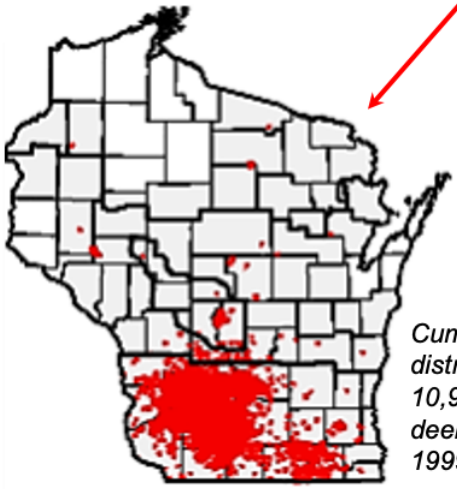
Cumulative distribution of CWD-POS free-ranging deer in WI Northern Forest Zone

- Nine CWD-POS deer from 1999-2023 of 32,149 samples
- **0.028% prevalence**
- CWD prevalence *196 times higher* in southern WI w/out wolves vs. northern WI where wolves are common
- Wolves & black bears abundant
  - No. wolves in 2022 = 812-1192
  - No. black bears in 2022 = 13,000

Four deer management zones in Wisconsin



Wisconsin has about 1.6 million white-tail deer



Cumulative distribution of 10,987 CWD-POS deer in Wisconsin 1999-2023

FIGURE 4D

Cumulative distribution of CWD-POS free-ranging deer in WI Southern Farmland Zone

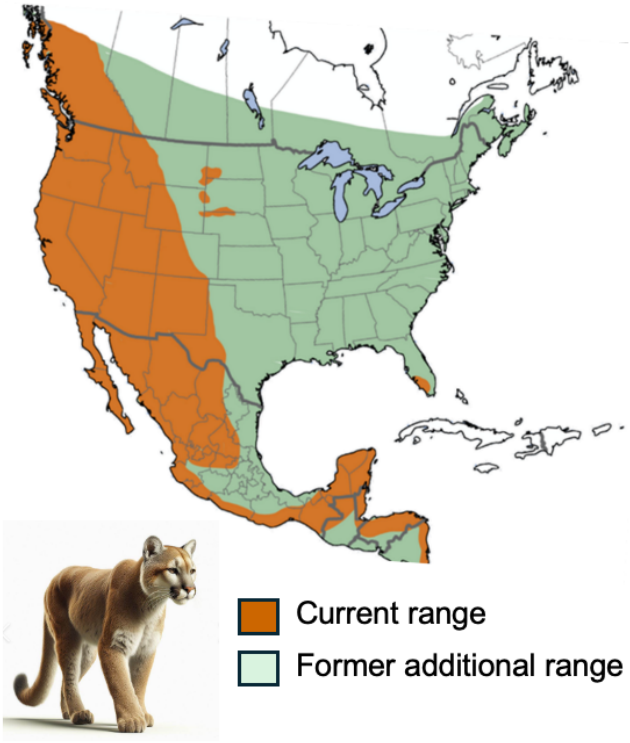
- 10,753 deer CWD-POS out of 195,244 samples from 1999-2023 in southern Wisconsin = **5.5% prevalence**
- Some scientists predict *eventual extinction* of wild deer in southwestern Wisconsin due to CWD
- Wolves absent from southern WI since early 1900s (more than a century)

Figure 5A

Negative spatial correlation: mountain lion range vs. CWD occurrence in North America

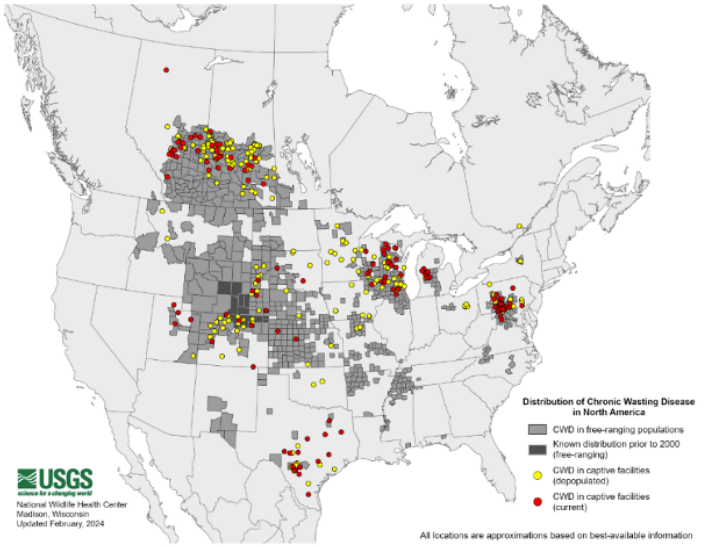
- Areas with a mountain populations tend to have a low CWD prevalence
- There are 20,000 to 30,000 mountain lions in the U.S. largely in 15 western states

Range of mountain lions in North America



https//www.wildlifesciencecenter.org/cougar

Distribution of CWD in North America



https://www.usgs.gov/media/images/distribution-chronic-wasting-disease-north-america-0

Figure 5B

Negative spatial correlation: mountain lion range vs. CWD occurrence in North America

- According to Colorado Parks and Wildlife, there are an estimated approximately **3,800 to 4,400 adult mountain lions**. This estimate does not include kittens, focusing only on independent-aged lions.
- About **500 mountain lions are killed each year** by trophy hunters in Colorado

https://mountainlion.org/wp-content/uploads/2021/01/CO-Cougar-

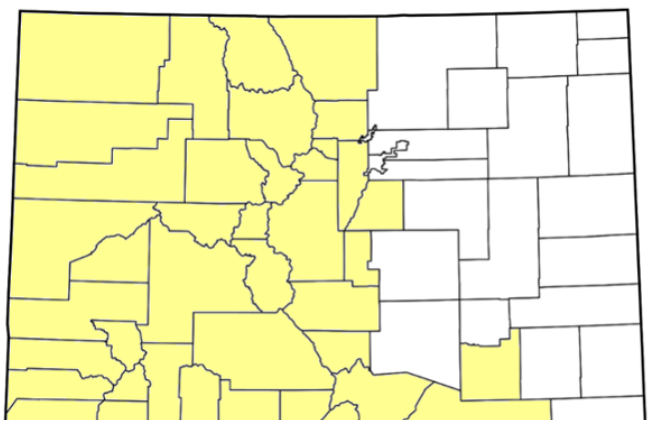
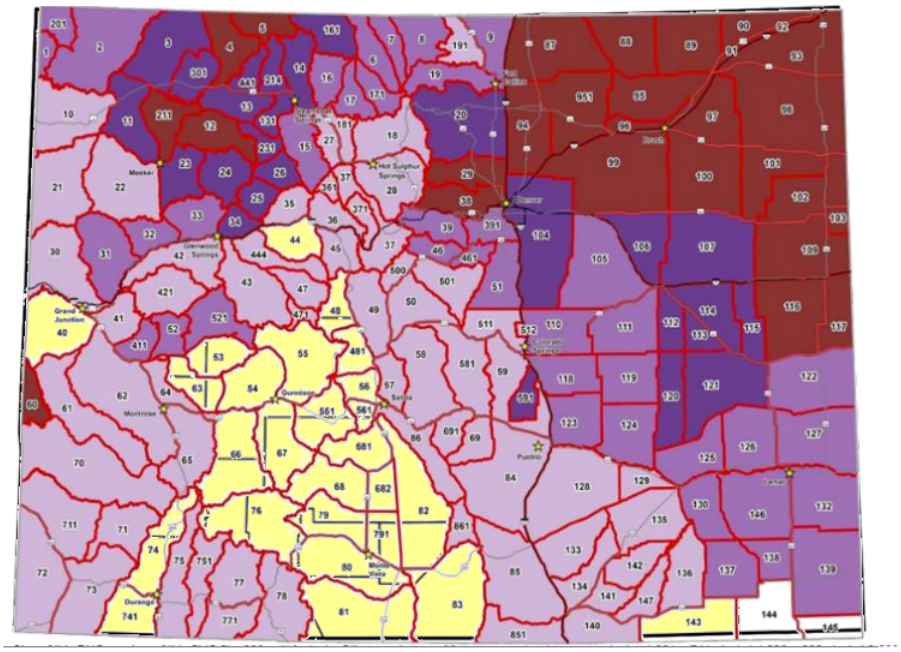


FIGURE 5C

CWD prevalence in mule deer and elk vs. mountain lion distribution in Colorado

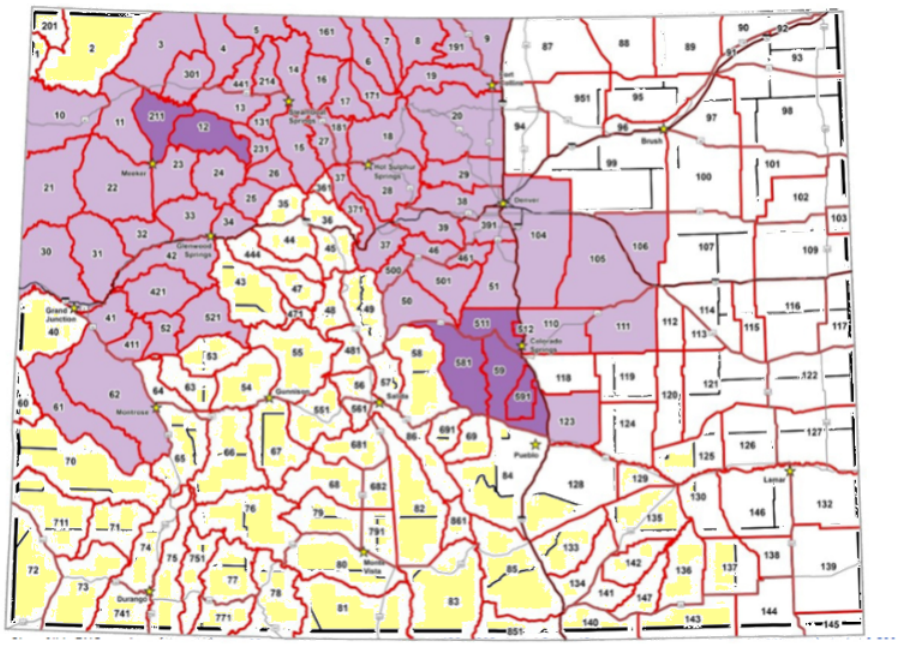
- CWD is well established and at high prevalence in mule deer and elk in Colorado
- Mountain lions in south-central and south-western Colorado could be providing "predator cleansing" eco-services as a predator buffer to slow CWD geo-spread



Areas in Yellow represent mountain lion habitats 0verlapping with mule deer range that are currently test-negative for deer CWD

CWD prevalence 2017-2021

Not detected	Detected under 5%	Detected 5-10%	Detected >10%	Detected >20%



Areas in Yellow represent mountain lion habitats overlapping with elk range that are currently test-negative for elk CWD

Table 3

Estimated cervid populations & deaths from humans vs. predators in Colorado, 2022

- Mountain lions kill 156,000 to 200,000 deer per year in Colorado, far more than any other predator or human hunters.
- Given the high CWD prevalence in deer and elk in Colorado, it is likely that many deer and elk killed by mountain lions are CWD-infected, especially since there is good evidence that mountain lions preferentially kill CWD-infected mule deer.
- Thus, mountain lions are likely slowing CWD spread in deer and elk in Colorado and lessening habitat contamination with CWD prions. This is an invisible eco-system service provided by lions.
- Since CWD-infected deer and elk are easier prey to hunt and kill vs. uninfected deer and elk, and since mountain lions are resistant to CWD infection, CWD may be, paradoxically, aiding mountain lion conservation and survival.

Prey		***Annual no. killed by humans***				***Annual no. killed by predators***				
Cervid	***Pop.***	***No. of licensed hunters***	***Hunters***	***Vehi-cles***	***Poach-ed****	***3K-4K adult mtn lions***	***20K black bears***	***60K coyotes***	***12K bob cats***	***150 lynx***
Elk	280K	220K; 17% hunter success	40K; 13.1% harvest	630	3,000	200-300 0.05 elk per lion	50-100 0.002 elk per bear	0	0	0
Mule deer	400K to 500K	84K; 30% hunter success	27K; 6% harvest	1,265	1,000	156K to 200K; 1 deer per wk	500 to 100; mostly fawns	50-100; mostly fawns	5-10	36 (?)
White-tailed deer	75K to 100K	100K; 30% hunter success	4K; 20% harvest	2,885	800	400	100 to 20; mostly fawns	100-200	10-20	36 (?)
Moose	3,000	589; 4% hunter success	16 bulls; 7 cows; 0.8% harvest	123	13	10-20	0 (?)	0 (?)	0	0

* Likely a large underestimate

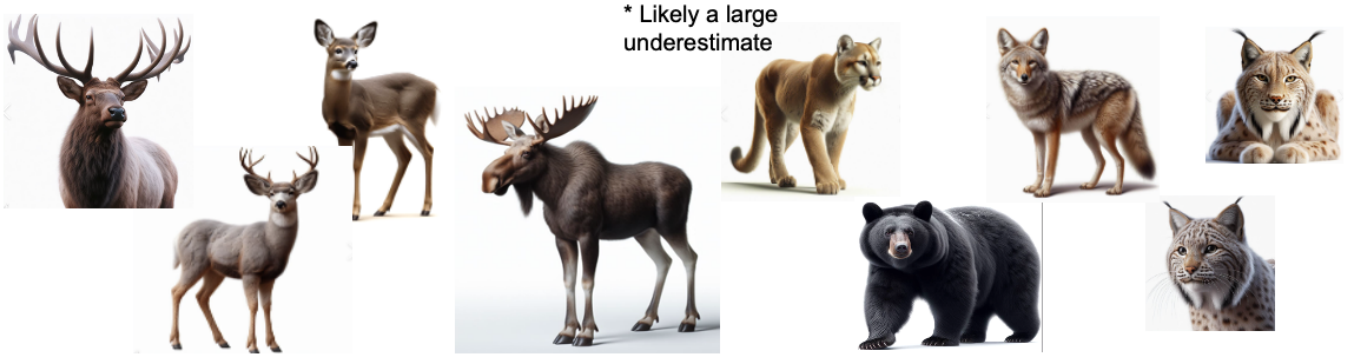


TABLE 4

Estimated predator populations & human-caused deaths in Colorado, 2022

- Killing of these five apex predators by humans, especially trophy hunting of mountain lions, is likely counter-productive in the fight against CWD.
- Mountain lions are only Colorado apex predator that primarily kills adult deer of which many are likely to be CWD-infected or diseased.

Predator species		No. killed by human activity				
Predator	Colorado population	No. of licensed hunters	Hunters or trappers	Vehicle collision	Poache[1]	USDA Wild-life Services[2]
Black bears	17,000 to 20,000	17,000; 12% hunter success	2,000; 6% harvest	60	25	64
Mountain lions	3,000 to 5,000	5,000; 10% hunter success	500; 11% harvest	30	10	12
Coyotes	60,000 to 80,000	12,000; 86% hunter success	10,300; 17% harvest	200	50	1,581
Bobcats	12,000	7,000; 28% hunter success	1,978; 16% harvest	10	10	2
Lynx	150-250	0 (illegal)	0	5	2	0

[1] Likely large underestimate

[2] Nuisance or dangerous animals

5. Natural experiments

Hypotheses: The first known case of CWD in Yellowstone National Park was reported in a radio-collared dead mule deer in Nov 2023, a discouraging but not unexpected occurrence. The wild-life-rich Greater Yellowstone Basin (GYB) was a rare CWD-free oasis surrounded by a high CWD force of infection in Montana to the north and Wyoming to the south and east. In the adjacent Grand Teton National Park, CWD was found for the first time in a hit-by-car mule deer in 2018 and in a dead elk in 2020.

Given the complete functioning predator guilds (wolves, mountain lions, lynx, grizzly bears, black bears, wolverines) in Yellowstone NP, Teton NP and the GYB surrounds, CWD invasion will be stopped or greatly slowed compared to other regions of the US which lack apex predator guilds.

Approach: Use field epidemiology methods to determine if predators selectively target and preferentially kill CWD-infected deer or elk in the GYB.

Outcome: Highest quality real-world evidence for or against the predator cleansing theory. Data will inform and/or ground truth mathematical models and identify CWD risk factors and drivers

Importance: If CWD predator cleansing does show benefits in the GYB, it is unlikely to be of value anywhere. There is minimal predator hunting in Yellowstone and Teton NPs, although there is some hunting of wolves and mountain lions in some surrounding areas.

Status: See **Table 0** and **Table 1C** (pg. 5, 21). Yellowstone National Park recently initiated field studies of predator cleansing of CWD, although this work will take decades to complete given the slow pace of CWD spread. Preliminary results in Yellowstone have shown that wolves can delay outbreaks of chronic wasting disease in their prey species and can decrease outbreak size. In addition, field research has been initiated in northern Wisconsin on how effectively wolves remove a carcass with CWD from the landscape.

Conclusion: Over the coming years, the value of wolves (in particular), and predator-scavenger carnivore guilds (in general) will determine if predators are an effective biocontrol for CWD in free-ranging cervids.

Comments: Only recently did the CWD distribution begin to overlap with areas containing suites of apex predators (wolves, coyotes, black bears, grizzly bears, mountain lions) in the Greater Yellowstone Basin and far western Canada in North America. To date and in general, CWD has not thrived where wolf populations are active, although the disease has appeared on the margins of these populations.

Of great ecologic concern among the wildlife conservation community is, "What will happen and how do we respond when CWD has breached the Greater Yellowstone Basin?" That time has arrived. A radio-collared mule deer that died of clinical CWD was found in Yellowstone National Park in October 2023. This was a fortuitous if ominous discovery that would have gone unnoticed if not for telemetry. CWD was first detected in the Grand Teton National Park adjacent to Yellowstone NP in 2018 in a sick mule deer struck by a vehicle and again in 2020 in a dead elk. A CWD outbreak among the 60,000 to 100,000 elk in the GYB, the largest concentration of free-ranging elk in North America, is an impending eco-disaster.

CWD may have already made serious inroads in deer and elk herds in both Yellowstone and Grand Teton National Parks and surrounds since it takes at least 1.5 to four years of silent infection before a mule deer or elk clinically presents with CWD neurologic signs.

The GYB elk are concentrated in the winter months on 23 State and Federal elk feeding grounds in Wyoming to reduce conflicts

with livestock and private landowners. These crowded elk feeding grounds are a near-perfect setting to create a heavily CWD-contaminated environment and rapidly disseminate CWD, analogous to private deer and elk game farms that were devastated by, and widely disseminated, CWD across North America. A high-profile, high-stakes, and unintended "natural experiment" in how CWD disease spreads in the wildlife-rich GYB is about to unfold.

The combined effects of wolves and mountain lions on CWD in the GYB and other parts of the Rocky Mountain West may not be empirically estimable for decades given that CWD is a slow-moving epidemic with multi-year incubation times. The ecology of CWD in diverse multi-prey and multi-predator systems like Greater Yellowstone may contrast sharply with simpler ecosystems that are often apex predator-free.

PART IV

CWD predator cleansing conclusions

The presence of apex predators on the North American wilderness landscape is a sign of a healthy, natural, and functioning ecosystem. CWD has sickened many of these forest and mountain ecosystems across the US and Canada, most often where apex predator mountain lions and or gray wolves are absent.

The future of many cervid populations in North America with CWD appears grim from a long-term perspective. The CWD prion puts the longstanding survival of our nation's 35 million white-tailed deer, 5 million mule and black-tailed deer, and 1.2 million elk, and the industries that rely on them, at risk. **Big game deer and elk hunters and wildlife conservationists who still believe that predator removals help deer and elk should rethink their positions. Without healthy cervid populations, entire forest ecosystems could collapse.**

Our efforts to control CWD in free-ranging deer and elk have failed. CWD continues to expand geographically towards our western and eastern borders as CWD prevalence steadily increases. If the CWD prion evolves into a new strain that is adapted to and can infect people, a public health disaster will ensue.

It is time to confront our anti-predator bias, reduce or eliminate trophy hunting of mountain lions and wolves, and offer them protection from hunting. Wolves and mountain lions may not be a magic cure, but they offer our best chance to halt CWD's march. It is time to enlist wolves and mountain lions as our allies in the fight against CWD.

As biologist Gary Wolfe, former Montana wildlife commissioner and former CEO/president of the Rocky Mountain Elk Foundation, said in 2107, "While I don't think any of us large carnivore proponents are saying that wolf predation will prevent CWD, or totally eliminate it from infected herds, it is ecologically irresponsible to not consider the very real possibility that wolves can slow the spread of CWD and reduce its prevalence in infected herds. We should consider wolves to be 'CWD border guards,' adjust wolf hunting seasons accordingly, and let wolves do their job of helping to cull infirm animals from the herds."

References

Bartz JC, Benavente R, Caughey B, et al., 2024. Chronic Wasting Disease: State of the science. *Pathogens.* 13(2):138. https://www.mdpi.com/2076-0817/13/2/138

Holz CL, Darish JR, Straka K et al., 2022. Evaluation of Real-Time Quaking-Induced Conversion, ELISA, and Immunohistochemistry for Chronic Wasting Disease Diagnosis. *Front Vet Sci*. 8:824815. https://www.frontiersin.org/articles/10.3389/fvets.2021.824815/full

Mallikarjun A, Swartz B, Kane SA et al., 2023. Canine detection of chronic wasting disease (CWD) in laboratory and field settings. *Prion*. 17(1):16-28.

> "This study is the first to demonstrate that trained detection dogs can be used as an antemortem test for CWD… dogs can be trained to differentiate CWD-positive feces from CWD-negative feces in both laboratory and field settings."
>
> If dogs can detect CWD-infected by smell, there can be little doubt that wolves could also detect CWD-infected deer and elk by scent.

Schwabenlander MD, Rowden GR, Li M, et al., 2022. Comparison of chronic wasting disease detection methods and procedures: Implications for free-ranging white-tailed deer (*Odocoileus virginianus*) surveillance and management. *J Wildlife Dis*. 58(1):50-62. https://meridian.allenpress.com/jwd/article/58/1/50/472442/COMPARISON-OF-CHRONIC-WASTING-DISEASE-DETECTION

1) Predator-prey ecologic theory & predator-prey CWD disease modeling references

Hobbs NT (2006). A model analysis of effects of wolf predation on prevalence of chronic wasting disease in elk populations of Rocky Mountain National Park. Report submitted to the National Park Service. **https://wolfwatcher.org/wp-content/uploads/2019/06/Hobbs_wolf-cwd-report.pdf**

Hobbs developed a simulation model suggesting that the presence of 20 wolves would eradicate chronic wasting disease from elk in Rocky Mountain National Park in two to three decades.

Wild MA, Hobbs NT, Graham MS, Miller MW (2011). The role of predation in disease control: A comparison of selective and non-selective removal of prion diseases in deer. *J Wildlife Diseases* 47(1):78-93. **https://meridian.allenpress.com/jwd/article/47/1/78/121161/THE-ROLE-OF-PREDATION-IN-DISEASE-CONTROL-A**

> "*We review theoretic relationships between predation and host-parasite dynamics and describe a mathematical model to evaluate the potential influence of random removal through harvest or culling and selective predation by wolves (Canis lupus) upon CWD dynamics in deer (Odocoileus spp.) populations. We suggest that as CWD distribution and wolf range overlap in the future, wolf predation may suppress disease emergence or limit prevalence.*"
>
> *From* **Uehlinger et al. 2016**: *"The role of predation in control of CWD was evaluated by Wild et al. in a deterministic predictive model. Imposing non-selective mortality (any deer) from wolves decreased population size and CWD prevalence, resulting in the persistence of CWD within the simulated population. Imposing selective mortality (where CWD-positive deer had 4× higher mortality) from wolves decreased population size more modestly while rapidly reducing CWD prevalence, resulting in disease elimination from a simulated closed population. Based on this model, CWD prevalence could be halved within a decade and eliminated within the century if a pack of wolves consistently and selectively removed 15 % of deer in a closed population. Furthermore, the model predicted that CWD emergence in new areas could be limited through selective predation.*

However, authors acknowledge that prey vulnerability, the nature of population compensation, and factors affecting disease transmission greatly affect precise estimates of the time required to attain results. The demonstrated beneficial effect of predation on CWD control was considered to be underestimated by the authors as they did not account for carcasses as a potential source of CWD. They concluded that carcasses infected with CWD would likely be removed by predators, thereby further decreasing the risk of CWD spread. The authors concluded that CWD prevalence consistently and robustly decreased in deer populations exposed to predation, and more so when exposed to selective predation."

Brandell EE, Cross PC, Smith DW, et al. (**2022**). Examination of the interaction between age-specific predation and chronic disease in the Greater Yellowstone Ecosystem. *J Anim Ecol*. 91(7):1373-1384. https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2656.13661

"Our modeling exploration shows that predators (wolves and cougars) have the potential to reduce prevalence in prey populations when prey age and disease severity are considered, yet the strength of this effect is influenced by predators' selection for demography or body condition. Current CWD management focuses on increasing cervid hunting as the primary management tool, and our results suggest predators may also be a useful tool under certain conditions, but not necessarily without additional impacts on host abundance and demography. Protected areas with predator populations will play a large role in informing the debate over predator impacts on disease."

In this paper, Brandell et al. develop a model to evaluate the predator cleansing effect given age-based variation in pathogens and predation. The model was developed for Chronic Wasting Disease (CWD) infections in deer and elk facing predation by cougars and grey wolves in the Greater Yellowstone Ecosystem. The results indicate that predators can reduce CWD outbreak size, especially if selecting for infected individuals.

"Our model results suggest that under moderate, yet realistic, predation pressure from cougars and wolves independently, predators may decrease CWD outbreak size substantially and delay the accumulation of symptomatic deer and elk. The magnitude of this effect is driven by the ability of predators to selectively remove late-stage CWD infections that are likely the most responsible for transmission, but this may not be the age class they typically select."

Brandell, Ellen. "Do predators create healthier prey populations?" **#StoryBehindThePaper (blog) for the paper "Examination of the interaction between age-specific predation and chronic disease in the Greater Yellowstone Ecosystem". *Animal Ecology in Focus***. Jan 25, 2022.

https://animalecologyinfocus.com/2022/01/25/do-predators-create-healthier-prey-populations/

Clear explanation and discussion of Brandell and colleagues (2022)."There is no vaccine" for CWD, researcher Ellen Brandell told the New York Times. "Can predators potentially be the solution?"

2) Empirical observation references

Miller MW, **Swanson HM, Wolfe LL et al**. (**2008**). Lions and prions and deer demise. *PLoS ONE*, 3(12). https://doi.org/10.1371/journal.pone.0004019

"Using a cohort study design, we found that prion infection dramatically lowered survival of free-ranging adult (>2-year-old) mule deer (Odocoileus hemionus): estimated average life expectancy was 5.2 additional years for uninfected deer but only 1.6 additional years for infected deer.

Prion infection also increased nearly fourfold the rate of mountain lions preying on deer, suggesting that epidemics may alter predator–prey dynamics by facilitating hunting success. Despite selective predation, about one-fourth of the adult deer we sampled were infected. High prevalence and low survival of infected deer provided a plausible explanation for the marked decline in this deer population since the 1980s."

Krumm CE, Conner MM, Hobbs NT et al. (**2010**). Mountain lions prey selectively on prion-infected mule deer. *Biol Lett*. 6(2):209-211. https://doi.org/10.1098/rsbl.2009.0742

"We examined whether mountain lions selectively prey upon mule deer infected with chronic wasting disease, a prion disease. We located kill sites of mountain lions in the northern Front Range of Colorado and compared disease prevalence among lion-killed adult (⩾2 years old) deer with prevalence among sympatric deer taken by hunters in the vicinity of kill sites. Hunter-killed female deer were less likely to be infected than males (odds ratios (OR) = 0.2, 95% confidence intervals (CI) = 0.1–0.6; p = 0.015). However, both female (OR = 8.5, 95% CI = 2.3–30.9) and male deer (OR = 3.2, 95% CI = 1–10) killed by a mountain lion were more likely to be infected than same-sex deer killed in the vicinity by a hunter (p < 0.001), suggesting that mountain lions in this area actively selected prion-infected individuals when targeting adult mule deer as prey items."

DeVivo MT, Edmunds DR, Kauffman MJ, et al. (**2017**). Endemic chronic wasting disease causes mule deer population decline in Wyoming. *PLoS One.* 12(10):e0186512. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0186512

"Mule deer were captured from 2010–2014 in southern Converse County Wyoming. We documented 97 mortalities of radio-collared deer. Mule deer that were CWD-positive were more susceptible to mountain lion predation (n=20; p=0.01), hunter harvest (n=4; p<0.01), and illegal harvest (n=2; p=0.05). Mountain lion predation was the number one cause of mortality followed by clinical CWD (n=14). Other natural causes of mortality of radio-collared mule deer included vehicle collision (n=3), coyote predation (n=1), fence entanglement (n=1), drowning (n=1), and winter kill (n=1). Thirteen deer died due to injuries sustained during captures and we were unable to determine the cause of death in 37 cases due to severe autolysis and scavenging.

Natural selection in favor of less susceptible CWD Prnp genotypes may be assisted with selective predation by mountain lions and harvest by hunters of prion-infected deer. While CWD-positive deer were more likely to be killed by mountain lions compared to uninfected deer, it is not clear if this source of mortality regulated or influenced the observed CWD epidemic. Selective predation of CWD-positive deer in Table Mesa, Colorado did not appear to control CWD transmission (Miller et al. 2008) and it also did not appear to curtail CWD prevalence in the current study herd. At this time, empirical evidence that supports a predator's influence on CWD epidemics does not exist.

However, with the expected spread of CWD into areas such as the Greater Yellowstone Area that is occupied by several large predators (i.e., wolves [Canis lupus], grizzly bears [Ursus arctos], and mountain lions), the role of predators in prion transmission dynamics may soon become more relevant. A multi-predator system may have a greater impact on an emerging CWD epidemic, especially before significant prion contamination occurs in the environment.

Fisher MC, Prioreschi RA, Wolfe LL *et al.* (2022). Apparent stability masks underlying change in a mule deer herd with unmanaged chronic wasting disease. *Commun Biol* **5**:15. https://doi.org/10.1038/s42003-021-02951-z

Here we describe unexpected stability in prevalence and abundance in the Table Mesa mule deer herd in southwest Boulder, Colorado USA, where CWD has been left unmanaged. High apparent prevalence (~30%) since at least 2005 likely drove observed changes in the proportion and age distribution of wild-type native prion protein (PRNP) gene homozygotes among deer sampled. Predation by mountain lions (Puma concolor) may be helping keep CWD in check.

3) Laboratory experiment references

Nichols TA, **Fischer JW, Spraker TR, et al. (2015**). CWD prions remain infectious after passage through the digestive system of coyotes (*Canis latrans*). *Prion*. 9(5):367-375. https://www.tandfonline.com/doi/full/10.1080/19336896.2015.1086061

"In this study, we evaluated the ability of CWD-infected elk brain material to pass through the gastrointestinal tract of coyotes (Canis latrans) following oral ingestion and be infectious in a cervidized transgenic mouse mode [i.e., the tg12 mouse model expressing elk prion protein]. Results from this study indicate that coyotes can pass infectious prions via their feces for at least 3 days post-ingestion, demonstrating that mammalian scavengers could contribute to the translocation and contamination of CWD in the environment."

Among all mammals, canids are probably the most resistant to prion diseases, with the amino acid residue 163 of canine PrPC conferring protection. There are no known prion diseases affecting canids. Oral exposure of captive coyotes in this study to elk prions demonstrated the presence of prions in the coyote fecal material during the first days after consumption. However, even after a large volume of infectious brain homogenate was inoculated, only 50% of exposed coyotes had detectable infectivity in feces between 1- and 4-days post-exposure (dpe) as evaluated by bioassay in tg12 mice (expressing elk PrPC), while the other half lacked detectable prions or were only recovered in feces after 1 day. No evidence of CWD accumulation in the coyote lymph tissue was detected. These results suggest that coyotes were capable of degrading CWD infectivity. Consistent with this interpretation, the attack rates were incomplete in tg12 mice inoculated with feces collected at various times following exposure.

Baune C, Wolfe LL, Schott KC et al. (**2021**). Reduction of chronic wasting disease prion seeding activity following digestion by mountain lions. *mSphere.* 6(6):e0081221\ https://journals.asm.org/doi/10.1128/msphere.00812-21.

Mountain lions may have some potential to distribute CWD prions within their home ranges but they also effectively eliminate most of the CWD prions they consume. The National Institute of Allergy and Infectious Diseases in Montana did a study where two mountain lions, cougars, were fed mule deer meat spiked with CWD prions. Only 2.8 to 3.9 percent of the CWD prions survived the gastrointestinal tract of the cougars and could be recovered in the cougar's feces.

Wolfe LL, Fox KA, Griffin KA, Miller MW (2022). Mountain lions (*Puma concolor*) resist long-term dietary exposure to chronic wasting disease. *J Wildlife Dis*. 58(1):40-49. **https://meridian.allenpress.com/jwd/article/58/1/40/473661/MOUNTAIN-LIONS-PUMA-CONCOLOR-RESIST-LONG-TERM**

"For nearly 18 years, we evaluated the susceptibility of captive mountain lions (*Puma concolor*) to chronic wasting disease (CWD) in the face of repeated exposure associated with consuming infected cervid carcasses. Three mountain lions with a monomorphic prion protein gene (*PRNP*) sequence identical to that described previously for the species had access to parts of ⩾432 infected carcasses during ⩾2,013 feeding occasions, conservatively representing >14,000 kg of infected feed material, from May 2002 to March 2020. We observed no clinical

signs suggestive of progressive encephalopathy or other neurologic disease over the ~4.5-17.9 yr between first known exposure and eventual death. Similarly, none of the 133 free-ranging mountain lion carcasses sampled opportunistically during 2004-20 showed immunostaining consistent with prion infection in sections of the brainstem or lymph node. These findings align with prior work suggesting that CWD-associated prions face strong barriers to natural transmission among species outside the family Cervidae".

Davis M, Van Wick P, Allen S, Hashem B, et al., 2023. "Abstract #20 – Using real-time quaking-induced conversion (RT-QuIC) to detect prion seeding activity in bobcat (*Lynx rufus*) scat after the consumption of CWD-positive tissue". **4th International Chronic Wasting Disease Symposium**, Denver, CO, May 30, 2023

Four captive bobcats eliminated 98% of ingested CWD prions (from deer & elk brains & lymph nodes) in one day; 100% were eliminated in 3 days.

Peterson, Christine. "Carnivores and scavengers could help reduce CWD". *WyoFile*. Dec 29, **2023**. *https://wyofile.com/carnivores-and-scavengers-could-help-reduce-cwd/*

A follow-up study to Baune et al. (2021). Bobcats may only deposit a fraction of the infectious prions on the landscape that they eat, early study results show. Only 2% of the chronic wasting disease prions that go into a bobcat's mouth can be detected in the bobcat's poop. And that's day one. By day two there's less than 1%, and by day three there's none at all.

4) Disease biogeography references

Wilkinson, Todd. "Part 4: The undeniable value of wolves, bears, lions, and coyotes in battling disease". *Mountain Journal*. Dec 11, 2017. **https://mountainjournal.org/predators-and-chronic-wasting-disease**.

Will the fairy tale mentality of Western states against predators hamper their ability to slow CWD?

"*While I don't think any of us large carnivore proponents are saying that wolf predation will prevent CWD, or totally eliminate it from infected herds, it is ecologically irresponsible to not consider the very real possibility that wolves can slow the spread of CWD and reduce its prevalence in infected herds. We should consider wolves to be 'CWD border guards,' adjust wolf hunting seasons accordingly, and let wolves do their job of helping to cull infirm animals from the herds." - biologist Gary Wolfe, former Montana wildlife commissioner and former CEO/ president of the Rocky Mountain Elk Foundation".*

5) Natural experiment references

Bence, Susan. "Can the gray wolf help control CWD-infected deer? Great Lakes tribes and UW scientists team up to find out." *WUWM 89.7 FM* (*National Public Radio*). Oct 26, 2023. **https://www.wuwm.com/2023-10-26/can-the-gray-wolf-help-control-cwd-infected-deer-uw-scientists-and-indigenous-knowledge-collaborate. *Accessed 1.24.24***

Brookshire, Bethany. "Can wolves help hunt disease?". *Sierra*. Oct 12, 2022. https://www.sierraclub.org/sierra/wolves-cwd-chronic-wasting-predation-science

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