Willingness to pay for reintroducing wolves in a divided voting base

Dana LK Hoag
Colorado State University - Fort Collins, dhoag@colostate.edu

Jesse Burkhardt
Colorado State University - Fort Collins

Benjamin Ghasemi
Colorado State University - Fort Collins

Stewart W. Breck
USDA/APHIS/WS National Wildlife Research Center, stewart.w.breck@aphis.usda.gov

Rebecca Niemiec
Colorado State University - Fort Collins

See next page for additional authors

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Dana LK Hoag[a,*], Jesse Burkhardt[a], Benjamin Ghasemi[b], Stewart Breck[d], Rebecca Niemiec[b], Kevin Crooks[c]

[a] Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, CO 80523, USA
[b] Department of Human Dimensions of Natural Resources, Colorado State University, Fort Collins, CO, USA
[c] Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, CO, USA
[d] USDA National Wildlife Research Center, Fort Collins, CO, USA

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A B S T R A C T

Wolves will soon be reintroduced in Colorado based on a statewide ballot initiative that narrowly passed in November 2020. Using an economic choice experiment, we estimate the benefits that wolf introduction might bring to Colorado. We calculated willingness to pay (WTP) for a sustainable wolf population by considering six program attributes: 1) state wolf population, 2) compensation for livestock-related losses, 3) cost-sharing for conflict reduction, 4) number of livestock killed statewide, 5) lethal government control of wolves, and 6) wolf hunting. Respondents who reported they voted yes on the ballot initiative had a positive WTP for a population of 200 wolves, referred to as the minimum sustainable population in the survey, but WTP diminished for larger populations. Preferences for a population of 200 wolves amounts to an annual WTP of approximately $31.1 million when extrapolating to all yes-voting households statewide. In contrast, respondents who reported they voted no would have to be paid to accept wolf populations. We also found statistically significant preferences for other attributes of the management program, such as cost sharing for conflict reduction measures to livestock producers or compensating livestock losses. When these attributes were included, the willingness to pay increased to $115 million statewide among yes-voting households. We estimated a $57.5 to $1 benefit-cost ratio for a sustainable wolf population. However, benefits and costs are not evenly distributed across urban and rural residents, which suggests that mechanisms to transfer resources from those willing to pay to those that incur costs would be needed to balance that distribution.

1. Introduction

The restoration of large carnivores to landscapes where they were extirpated can create direct conflicts with humans as well as social conflicts among stakeholders with differing opinions about carnivore recovery (Carter and Linnell, 2016; Venumière-Lefebvre et al., 2022). In particular, the restoration of wolves can elicit strong emotions because wolves often represent broader societal-level conflicts, such as socio-political identity, urban vs. rural values, and decision-making about contentious wildlife management issues

* Correspondence to: Department of Agricultural and Resource Economics, Box 1172, Colorado State University, Fort Collins, CO 80523, USA.
E-mail address: Dana.hoag@colostate.edu (D.L. Hoag).

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(Nie, 2002; Skogen et al., 2008; Wilson, 1997). In November 2020, citizens of the state of Colorado, U.S., narrowly approved a statewide ballot initiative to require the state wildlife agency to begin reintroducing gray wolves into the western portion of the state by the end of 2023 (Ditmer et al., 2022a; Niemiec et al., 2022). Wolves are native to Colorado and were historically distributed throughout the state in all major habitat types (Armstrong, 1972). Given perceived threats to livestock and game, wolves were extirpated from Colorado by the mid-1940 s via government-sponsored predator control, which similarly eliminated wolves throughout most of the western United States (Carhart, 2017). Prior surveys of Coloradans suggested a high level of support for wolf reintroduction (Meadow et al., 2005; Niemiec et al., 2020; Pate et al., 1996), but the 2020 ballot initiative passed by a slim margin with 50.9% support (Niemiec et al., 2022). This ballot measure was the first time voters were the decisive factor in restoring a native species in the U.S. (Ditmer et al., 2022) and provides a unique case of public decision-making for wildlife conservation.

The unprecedented vote to restore wolves to Colorado raises interesting questions. What benefit did a yes voter think they were getting, and did they consider costs to others? Would the value to yes voters cover the costs to those not wanting to reintroduce wolves, resulting in an net economic gain? Would people have voted differently if they had better understood the costs or if they had been responsible for some of the costs? A key to human-carnivore coexistence is the equitable distribution of benefits and costs among diverse stakeholders (Lute and Carter, 2020). Most people in Colorado will not experience losses from wolves (e.g., livestock or pets), creating an asymmetry in the distribution of benefits and costs. Livestock producers do seek assistance to prevent predation and compensation if they experience losses (Lee et al., 2017; Nyhus et al., 2005). However, due to a variety of logistical complications and disagreements about what is appropriate, there is a high degree of disparity in how much such compensation might or should be offered (Harris, 2020).

There is evidence, although limited, suggesting economic values associated with wolves substantially exceed costs (e.g., Duffield, 2019). For example, van Eeden et al. (2021) estimated that the benefits for a wolf management program in Washington state exceeded the costs to run the program by 150-fold. We add to that literature by computing how much Colorado voters value wolf reintroduction and whether their willingness to pay (WTP) is affected by demographics and different proposed management scenarios. Specifically, we estimate the benefits and costs of different wolf management programs in Colorado.

An innovation from this research is that we investigated how WTP for wolf reintroduction varies by support or opposition to reintroduction, as indicated by positive and negative votes on the 2020 ballot initiative. Conceptually, such analysis could help envisage an equitable distribution of costs and benefits, as evidenced by symmetry between economic winners and losers, associated with wolf reintroduction among interest groups. In general, we find that respondents who reported they voted yes on the ballot initiative have positive but diminishing preferences for wolves and that respondents who reported they voted no on the initiative have negative preferences for wolf populations (i.e., would have to be paid to accept wolves). We also find statistically significant preferences for other attributes of the management program, such as cost sharing conflict reduction measures for livestock producers or compensating livestock losses.

1.1. Previous wolf valuation studies

There are many potential costs and benefits associated with wolves, but research on the economic valuation of wolves is relatively limited. Loomis (2016) provided a contemporary and in-depth examination of economic results from literature that valued wolves. Hoag et al. (2022) built on that literature and provided a holistic understanding of the broad spectrum of different ways to value benefits. For example, having wolves can lead to increased expenditures by hunters and tourists. Hunters spend on license fees to hunt and trap wolves, for guided hunts, and gear, hotels and meals. The state of Montana, for example, collected $368,639 (all values expressed in 2022 dollars) from the sale of hunting and trapping licenses in 2020/2021 (Parks, et al., 2021). These values are considered consumptive. In contrast, Duffield (2019) found that non-consumptive expenditures, such as tourism, brought about $53.5 million per year through new visitation revenues to the Greater Yellowstone Ecosystem after wolves were reintroduced.

Hoag et al. (2022) also documented values not observed in markets. Non-market valuation focuses on the WTP for goods and services that are not exchanged in markets (see Champ et al., 2003). WTP is usually reported in dollars and represents the maximum amount of money someone would be willing to pay to obtain a good or service. The WTP literature divides WTP into use and non-use values. Use includes consumptive uses, like hunting, and non-consumptive uses, like tourism (Champ et al., 2003). Non-use values include existence (benefits reflected by a sense of wellbeing even if it is never directly experienced), bequest (value of ensuring availability to future generations), and option (having the option for using a good or service in the future). WTP is greater than expenditures, since not all values are priced. For example, non-resident hunters spent $6773 on travel and gear for a wolf hunting trip in Alaska (ECONorthwest, 2014) but this did not include the additional $613/day that they would be willing to pay above trip expenses for the ability to hunt wolves (Loomis, 2016). Likewise, people would need to spend about $700 on a trip to view wolves and would be willing to pay an additional $354 for that trip (studies summarized in Hoag et al., 2022). Expenditures represent money that people redirect from some other item, but WTP captures new value created by the good or service. When wolves were first reintroduced into the Greater Yellowstone Ecosystem, visitors spent $53.5 per person per trip to tour the region because wolves were reintroduced (Duffield et al., 2008). The value was at least $17.9 million more when adding in the existence or passive value (Duffield, 2019).

There have been few studies attempting to estimate the public value of a wolf population. Beyond the extensive work of Duffield and his colleagues concerning the reintroduction of wolves in the Greater Yellowstone Ecosystem (Duffield, 1991 and 2019; Duffield et al., 2008), one study found that Minnesota residents would be willing to pay a one-time tax of $42 million for a wolf management plan (Chambers and Whitehead, 2003). Residents in Washington state had a WTP of about $91 annually per household, or about $271 million per year across the state for funding a program to manage a sustainable population of wolves (van Eeden et al., 2019). One study found benefits through saved costs. In Wisconsin, wolves have a net positive economic impact by reducing deer-vehicle collisions by $427,690 per wolf-populated county per year, and by $12.4 million per year in aggregate across the 29 wolf-populated counties (Raynor et al., 2021).

2. Materials and methods

2.1. Survey design and distribution

We collected data through an online survey instrument hosted on Qualtrics®.[1] The instrument consisted of a choice experiment including questions about respondents' wolf reintroduction and management preferences, attitudes towards wolves and wildlife, and socio-demographics. Before launching the survey, we asked wolf experts (e.g., state and federal wildlife agency staff), Colorado Parks and Wildlife (CPW) staff, and various other stakeholders (e.g., ranchers, scholars, wolf advocacy NGO's) to review the survey instrument. We then revised and refined the instrument based on their comments. The survey instrument and procedure were approved by the Colorado State University Institutional Review Board (Protocol #2986).

We used an online panel, the KnowledgePanel® operated by Ipsos® (formerly owned by GfK®), to recruit a probability-based, representative sample of Colorado resident adults (18 years or older) for the survey. According to Ipsos, KnowledgePanel is the oldest and largest probability-based online panel in the U.S. (https://www.ipsos.com/en-us/solutions/public-affairs/knowledge-panel). Data collection was conducted in June and July 2022, approximately a year and a half after Colorado voters approved Proposition 114. At the time we administered the survey, CPW was in the process of developing a wolf reintroduction plan and there was a pack of wolves in northeast Colorado that arose from natural migration into the state. A total of 434 completed responses were used in the study. The median completion time of the survey was approximately 15 min. To achieve a representative sample of the Colorado population, Ipsos provided weights to adjust for Colorado's population demographics based on benchmarks obtained from the 2019 American Community Survey and the 2020 Census data (online supplemental files). The weighting was performed by KnowledgePanel using an iterative proportional fitting (raking) procedure (Battaglia et al., 2009) and incorporated gender, age, race-ethnicity, education, household income, and region (online supplemental files).

2.2. Choice experiment

WTP for non-market goods is elicited from surveys designed to elicit stated preferences for the good being considered. The two most common methods used for estimating WTP are the Contingent Valuation Method and Choice Experiments (Champ et al., 2017, Peterson, 2003, Train, 2009). We used a Choice Experiment because our intention was to elicit preferences for multiple attributes of a wolf reintroduction program. In addition, this is consistent with the only other similar survey, conducted in Washington by van Eeden et al. (2021). The weights reflect demographics described in the previous section.

We introduced six attributes in our choice experiment (Table 1): 1) state wolf population, 2) compensation for livestock-related losses, including direct losses (i.e., livestock killed by wolves) and indirect losses (e.g., reduced weight gain and reproduction due to stress caused by wolf activity), 3) cost-sharing to support livestock producers with conflict reduction, 4) number of livestock killed statewide, 5) lethal government control of wolves, and 6) regulated wolf hunting. Participants chose from one of three alternatives (i.e., management sets) with different combinations of the management conditions and a voluntary annual financial contribution (Table 2). They chose one of three sets in eight different scenarios. For example, Option 1 in Table 2 would yield a population of wolves equal to 200 animals, offer fair market compensation for livestock losses, offer no cost sharing to support producers with conflict reductions, result in moderate losses of livestock, not allow wolf hunting or the government to use lethal methods to control wolves, and cost $100 per year.

The attributes and attribute levels represent realistic ranges based on scientific literature and expert opinions. For example, the "status quo" scenario for wolf population assumes no active reintroduction by wildlife managers, but rather a population size of 10 representing the approximate size of a pack that had naturally colonized northern Colorado at the time of the survey (summer 2022). A wolf population of 200 was hypothetically suggested in the survey preamble as a minimal sustainable population, with relatively high probability of persistence into the future. Colorado Parks and Wildlife has proposed a minimum statewide population count of 200 wolves as a recovery metric for delisting wolves from the Colorado Threatened and Endangered Species List (Colorado Parks and Wildlife, 2022). We allowed for two other population levels, 400 and 600 wolves, spanning realistic ranges of the number of wolves Colorado could support. Multiple scientific studies have concluded that Colorado can sustain a viable population of wolves. For instance, a study published in 2006 predicted that, after forecasting increased human population growth and road development, Colorado could support at least 400 wolves by 2025 (Carroll et al., 2006), and a study published in 2022 found that western Colorado contained areas of ecologically and socially suitable habitat for wolves with relatively low conflict risk with humans (Ditmer et al., 2022b). Asking participants about populations that are greater than the minimum sustainable level allows us to evaluate whether there is a difference between a WTP for a minimally sustainable population and WTP for larger populations of wolves, which is a new contribution to the literature.

Given the complexity of wolf reintroduction, survey questions about economic values can differ. In Washington, for example, van Eeden et al. (2021) asked about a tax to pay for a wolf conservation program to manage wolves where government funding might

[1] Anonymous data and code are available at https://github.com/jbbcsu/Wolf-Valuation.

Table 1
Choice experiment attributes and attribute levels provided in the survey. Status-quo levels are bold and italicized.

Attribute	Attribute Descriptions	Attribute levels for survey
Wolf population	The total number of wolves expected to live in Colorado long-term.	***10 wolves;*** Minimal sustainable population 200, or 400 or 600 for an abundant population.
Compensation	A payment that a producer receives for confirmed livestock losses.	***No Compensation*** Fair Market Value Fair Market Value + indirect losses.
Cost Sharing	Financial assistance to livestock producers to offset their costs for the implementation of conflict reduction tools.	***No cost sharing*** 100% of the actual cost
Livestock killed	Number of livestock killed in Colorado in a single year by wolves.	Minimum (5 cows and 3 sheep per year) ***Low (15 cows and 18 sheep per year)*** Moderate (60 cows, 30 sheep per year) High (120 cows, 60 sheep per year)
Lethal government control of wolves	The number of "conflict" wolves that could be killed by the government under strict legal requirements due to preying on livestock or other problems.	***No wolves lethally removed*** Approximately 30 wolves per year. Approximately 50 wolves per year.
Wolf Hunting	Whether regulated wolf hunting is allowed once the population reaches a sustainable level.	***Not allowed,*** Allowed after wolf population is sustainable
Annual Voluntary Contribution per Household	The amount that your Colorado household would be willing to contribute every year to support the wolf management program.	***$0 per year*** $100 per year $10 per year $150 per year $50 per year $ 200 per year

Table 2
Example of choice set provided to survey participants. Each survey participant was provided with 8 sets of choices, described as referendums, with 3 choices containing attributes varied in an orthogonal design.

	Option 1	Option 2	Option 3
Wolf population	200 wolves	400 wolves	10 wolves
Compensation	Fair market value	Fair market value + indirect losses	No compensation
Cost sharing	No cost sharing	100% of the actual cost	No cost sharing
Livestock killed per year	Moderate (60 cows and 30 sheep per year)	High (120 cows and 60 sheep per year)	Minimum (5 cows and 3 sheep per year)
Government lethal control of wolves	No wolves lethally removed	Approximately 30 wolves per year (only kill wolves that consistently engage in conflict with livestock)	No wolves lethally removed
Wolf hunting	Not allowed	Allowed after wolf population is sustainable	Not allowed
Annual Voluntary contribution per household	$100	$150	$0
Check one circle	○	○	○

waiver as wolf populations recover. In our survey, participants were asked to make a hypothetical financial contribution, described as "*The amount that your Colorado household would be willing to contribute every year to support the wolf management program. This money would be used for management, compensation, and cost sharing,*" for a package of the six management attributes (Table 2). Participants were asked to choose one of the three options as if they were voting in a new referendum.

We ran 3 separate primary statistical mixed logit models. Model 1 of Table 3 used all the data provided by KnowledgePanel, including all respondents (yes voters, no voters, and non-voters). Yes and no voters are respondents that reported they voted yes or no on the statewide initiative or actual vote, not a response in our survey. There are two important functional form considerations. First, reintroducing wolves is highly controversial, and residents can have strong opinions. To address the division in support, we estimated models on respondents that reported they voted yes on the ballot initiative (Column 2 of Table 3) and on respondents that reported they voted no on the initiative (Column 3 of Table 3). Second, we included wolf population and wolf population squared in each of the models in Table 3 to allow preferences for wolf populations to be nonlinear, which would indicate whether preferences for wolves diminished when wolf populations increased beyond the hypothetical minimal sustainable level.

All specifications in this paper were estimated using mixed logit models with fully correlated random parameters in the gmnl package of the statistical software R. The response variable is an individual's choice of the 3 alternatives presented in Table 2. Therefore, the response variable is a vector of ones and zeros representing a respondent's choice. A benefit of the random parameter multinomial logit models, otherwise known as the mixed logit, is that we can estimate the standard deviations of the random parameters, which are reported in columns 4–6 of Table 3. The estimated standard deviations allow us to assess whether there is heterogeneity in preferences across respondents for each attribute. For instance, the standard deviation of the annual voluntary contribution parameter is 1.435 and statistically significant with a p-value less than 0.001. This means that we can reject a null hypothesis that respondents have identical preferences regarding annual voluntary contributions. We use standard mixed logit models with correlated random parameters as described in Train, Kenneth E, 2009, Champ et al., 2017, and Parthum et al., 2020. All models were weighted using probability weights provided by KnowledgePanel. Non-binary variables including cost, population, livestock, and government lethal were normalized to increase the likelihood that the models converge. The alternative specific constant (ASC) was coded as 1 for the non-status-quo alternatives and zero for the status-quo. This implies that positive values of the coefficient on the ASC

Table 3
Model 1, mixed multinomial logit results for all respondents, yes voters, and no voters[a].

Variable	Estimated Coefficients			Variable	Estimated Standard Deviations		
	All Respondents (1)	Yes Voters (2)	No Voters (3)		All Respondents (4)	Yes Voters (5)	No Voters (6)
Annual Voluntary Contribution	-1.007*** (0.081)	-1.350*** (0.150)	-2.249*** (0.434)	Std. Dev. Annual Voluntary Contribution	1.435*** (0.116)	1.942*** (0.234)	1.333*** (0.320)
Wolf Population	0.320* (0.167)	1.134*** 0.284)	-2.510** (1.202)	Std. Dev. Wolf Population	0.551** (0.223)	0.682 (0.430)	2.673*** (0.910)
Wolf Population Squared	-0.455*** (0.138)	-0.871*** (0.236)	1.609 (0.982)	Std. Dev. Wolf Population Squared	0.893*** (0.133)	-1.149*** (0.183)	2.477*** (0.589)
Compensation 100% FMV	0.762*** (0.149)	1.171*** (0.227)	1.059 (0.907)	Std. Dev. Compensation 100%	0.108 (0.092)	-0.239*** (0.092)	1.132*** (0.283)
Compensation 100% FMV + Indirect	0.986*** (0.158)	1.339*** (0.230)	-2.413** (1.051)	Std. Dev. Compensation 100% +	-0.949*** (0.174)	1.101*** (0.200)	0.973 (0.528)
Cost Sharing	-0.242** (0.108)	-0.516** (0.209)	-0.237 (0.852)	Std. Dev. Cost Sharing	0.729*** (0.071)	0.458*** (0.101)	1.723*** (0.297)
Livestock Losses	-0.271*** (0.062)	-0.445*** (0.122)	0.444 (0.356)	Std. Dev. Livestock	0.301** (0.129)	0.520** (0.207)	2.075*** (0.578)
Government Lethal Control	-0.325*** (0.064)	-0.484*** (0.114)	0.593 (0.444)	Std. Dev. Government Lethal Control	0.089 (0.074)	-0.022 (0.124)	1.049*** (0.228)
Wolf Hunting allowed	-0.340** (0.132)	-0.328 (0.250)	-3.047*** (0.896)	Std. Dev. Hunting allowed	-0.075 (0.080)	-0.353*** (0.127)	0.496*** (0.189)
ASC	1.548*** (0.413)	2.940*** (0.775)	-6.687** (3.040)	Std. Dev. ASC	1.225*** (0.136)	2.384*** (0.296)	2.863*** (0.516)
N Observations (respondents)	10392 (433)	4248 (177)	3120 (130)				
AIC	4443.7	2058.0	793.5				
Log Likelihood	-2156.9	-964.0	-331.8				

[a] . Coefficient estimates for each model are presented in columns 1–3 and standard deviation estimates for each coefficient are presented in columns 4–6. ASC stands for Alternative Specific Constant. Values in parentheses are standard error estimates. Variables that are non-binary are normalized to improve the model convergence. All models were estimated with fully correlated random parameters.
* $p < 0.1$,
** $p < 0.05$,
*** $p < 0.001$.

indicate preferences in favor of a wolf reintroduction program, whereas negative values indicate preferences against a wolf reintroduction program.

For additional context, we regressed each respondent's WTP on respondent characteristics including a dummy variable for the following: 1) whether the respondent reported they voted yes on the original initiative (the omitted category is all other voter types), 2) the respondent reported they were a Democrat, 3) the respondent reported they were an independent voter, and 4) the respondent lived in the Front Range of Colorado. We also included a categorical variable indicating the likelihood that the respondent would encounter a wolf (self-reported), a continuous variable ranging from 1 (no support) to 7 (fully support) indicating how much a respondent supports reintroduction, and the respondent's age and income and age and income squared.

To extrapolate these estimates to the broader population we downloaded the county voting results on the wolf initiative from the Denver Post. We then merged the county level percentages of yes votes with the county housing estimates from the Colorado State Demography Office (2022). Next, we multiplied the fraction of *yes* votes by the number of occupied housing units in each county to produce an estimate of the number of households that voted yes in each county. Finally, we multiplied these housing unit numbers by the average WTP of *yes* voters for each attribute. To assess the drivers of variation in WTP, we regressed individual WTP estimates on respondent characteristics (Table 5).

3. Results

3.1. Characteristics of respondents

The weighted sample was approximately evenly divided by male and female within the age categories 18–34, 35–55, and 55 + (Table AM1 in Supplemental Files). After weighting the data, 72.7% of respondents were white, 18.3% Hispanic, and 9.1% were black or other races. About 73% had college degrees or some college education and the rest had high school or a lower level of education. Of the weighted sample, 9.4% had annual household incomes under $25,000%, and 24% had incomes over $150,000 per year. Less than 4% lived on the Eastern Plains, 13.3% lived in the Western Slope, where wolves will be reintroduced, and 83.5% lived in the predominantly urban Front Range of Colorado. We also asked to what extent respondents identify as farmers or ranchers; on a scale of 1 (not at all) to 5, the average respondent was 1.7, consistent with most respondents living in the urban Front Range.

A total of 177 (40.8%) survey respondents indicated they had voted in favor of wolf reintroduction, 130 (30%) indicated they voted against reintroduction, 79 (18.2%) indicated they forgot how they voted, and 47 (10.8%) indicated they did not vote on the ballot initiative. We also asked respondents a series of questions regarding why they voted in favor or against reintroduction (online Supplemental Files). Affirmative (disapproving) reintroduction questions were only asked of those that indicated they voted in favor (against) of reintroduction. When evaluating preferences based on voting, we considered only those that indicated they voted in favor and those that indicated they voted against wolf reintroduction. For respondents who voted for wolf reintroduction, the most important reasons for their vote included: 1) Restore a balanced ecosystem/environment; 2) To keep wolves from going extinct; and 3) Protecting and returning wolves is the right thing to do. For respondents who voted against wolf reintroduction, the most important reasons for their vote included: 1) Negative impacts on livestock and agriculture; and 2) It is a waste of money to reintroduce wolves.

When asked "How likely do you think it will be that you see, hear, or otherwise have an encounter with wolves once a self-sustaining population is established in Colorado," most people found it relatively unlikely that they would encounter a wolf (mean =2.2, sd = 1.02 on a scale of 1, not at all likely, to 5, extremely likely). When asked about their participation in outdoor activities, nearly 70% of the respondents hiked, 47% viewed wildlife in some form, 9% rode ATVs, and 7% hunted in the past 12 months prior to taking the survey (online Supplemental Files).

3.2. Willingness to pay for wolves

The mixed mulitnomial logit analyses results of our choice experiment are presented in Table 3. Fig. 1 displays the distribution of each respondent's coefficient on the alternative-specific constant (ASC) from model 1. The bimodal nature of this distribution suggests there are two primary groups of respondents. Those with negative ASC coefficients tended to choose the status-quo (no active reintroduction) and those with positive coefficients tended to choose non-status-quo alternatives. The bimodality of this distribution is highly correlated with self-reported voting on the original ballot initiative. As such, columns 2 and 3 of Table 3 separate the data into voting groups. Column 2 reports mixed logit estimates on the subset of respondents who reported they voted yes on the initiative, while column 3 reports mixed logit estimates on the subset of respondents who reported they voted no on the initiative. The number of respondents across columns 2 and 3 does not sum to the number of respondents in column 1 because some respondents reported they did not remember how they voted or preferred not to say. The coefficients on the ASC in columns 2 and 3 align with the bimodal distribution in Fig. 1. Eighty respondents (61.5%) who voted no always chose the status-quo option (i.e., protest bidders), while only 16 respondents (9%) who voted yes always chose the status-quo option. We included these protest bidders in the analyses.

Respondents who voted yes on the initiative had positive but diminishing preferences for wolf populations, reflected by the positive coefficient on Population but the negative coefficient on Population squared (Table 3, column 2). The negative coefficient on the squared term indicates that respondents have diminishing preferences for wolves as wolf populations increase above the minimum

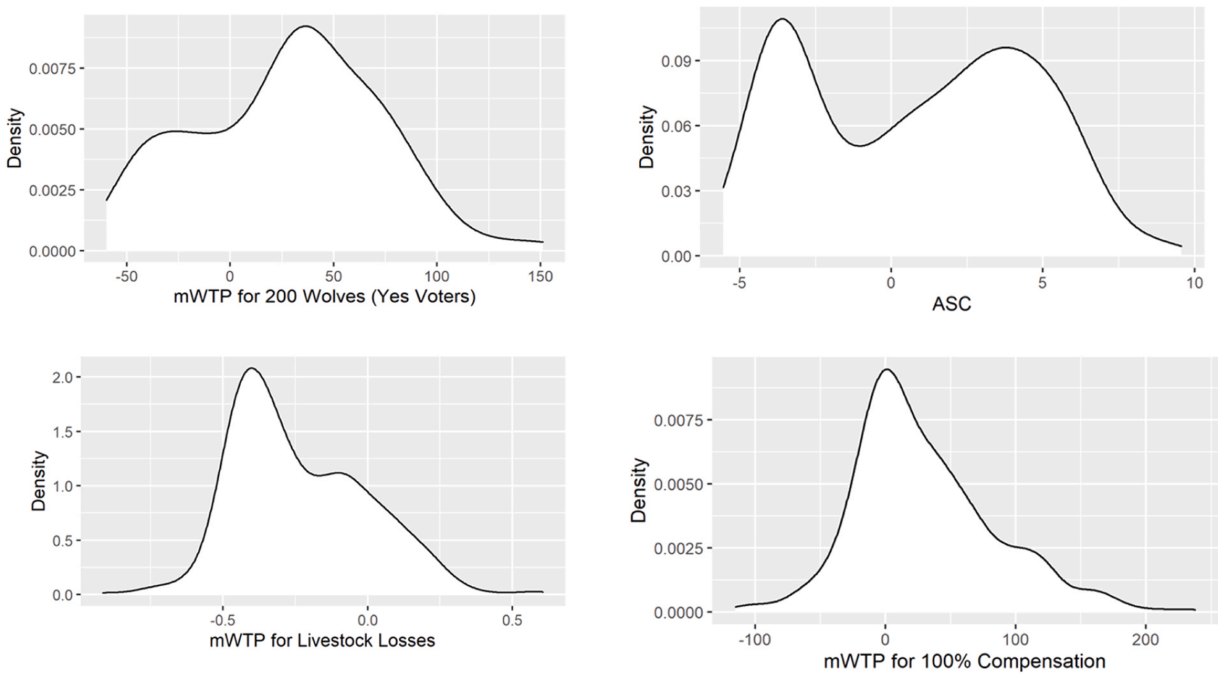

Fig. 1. Distribution of marginal willingness to pay for different attributes.

sustainable population. Yes voters had a WTP of approximately $26.94 per person for a population of 200 wolves, on average (Table 4). In contrast, the mean WTP across all voters for 200 wolves was $1.48 and statistically indistinguishable from zero due to including no voters who had negative WTPs (Table 4).

All respondents had negative preferences for cost sharing to support conflict reduction efforts, indicating a dislike or lack of understanding from our description. The standard deviations of the cost sharing coefficients across the three models were also statistically significant, indicating respondents varied in their preferences for cost sharing (Table 3, columns 4–6). Likewise, many of the other standard deviations were statistically significant, which corresponds with the diversity of preferences across respondent types. The average respondent had a WTP of $55.66 for compensation of direct livestock losses (Compensation 100% in Table 3) and $71.98 for compensation of direct and indirect livestock losses (Compensation 100%+ in Table 3). The average respondent was willing to pay $0.29 to avoid an additional livestock kill and $1.13 to avoid lethal control of the government euthanizing an additional wolf that has come into conflict with livestock producers. Finally, we found negative values for regulated wolf hunting across all three specifications, indicating disapproval. However, when we included only no voters that were strictly protest bidders (60 respondents), these respondents had a WTP of $196.84 for wolf hunting. These no voters also had a WTP of $54.97 for governmental lethal control of an additional wolf and were willing to compensate ranchers by $106.19 for direct losses and $75.49 for direct plus indirect losses.

Column 2 of Table 4 reports the results of the marginal WTP of each respondent and the marginal WTP extrapolated to the population of yes households in Colorado (square brackets). The average yes voter had a WTP of $26.94 for 200 wolves, which yields a total willingness to pay among yes voting households of $31.17 million. The average yes voter had a WTP of $63.7 for compensation of direct losses ($73.73 million across the estimated population of yes households) and a WTP of $72.88 for compensation of direct plus indirect losses ($84.32 million across yes households). The average yes voter had a WTP of $0.36 to avoid a livestock kill ($415,329 across types households) and a WTP of $1.25 to avoid governmental lethal control of an additional wolf at the margin. ($1.45 million yes households). The no voters tended to have strong preferences against wolf reintroduction and as such, selected the status-quo option 61% of the time. Consequently, we assume the no voters had zero benefit from a sustainable wolf population.

3.3. Determinants of WTP

The results of regressions on key each respondent characteristics, such as the way they voted, political affiliation, whether they lived on the Front Range, age, and income are shown in Table 5. The dependent variable in each model is each respondent's willingness to pay for 200 wolves, which we calculated using the coefficients estimated in Column 1 of Table 3. Columns 1–7 regress WTP on each variable individually because some of the variables are highly collinear (e.g., yes voters and Democrat). Column 8 includes all variables in one model. The results are generally intuitive, but we note that these estimates should be interpreted as correlations and not causal relationships. Column 1 indicates that yes voters were willing to pay $26.09 more than all other voter types on average for 200 wolves (Table 5, Column 1). Column 2 indicates that Democrats and Independents are willing to pay $28.62 and $20.87, respectively, more than Republicans or other voter types on average (Column 2). However, the coefficient on Democrat declines by roughly 50% when all variables are included in the model (Column 8). Voters in Colorado's Front Range are willing to pay more than voters elsewhere in Colorado, but the difference is statistically insignificant (Column 3). Respondents who feel they were more likely to encounter a wolf were willing to pay significantly less than respondents unlikely to encounter a wolf (Column 4). This finding suggests that the majority of the value elicited for wolves is non-use value or existence value. Respondents who have higher support for reintroduction were willing to pay $8.31 more for reintroduction (Column 5). Older respondents (Column 6) and respondents with higher incomes (Column 7) were willing to pay less ($2.80 and $16.56, respectively) for wolf reintroduction. Accordingly, the predominant drivers of WTP heterogeneity were political affiliation (Democrat or Independent), the degree to which a respondent supports reintroduction, and the respondent's age (Column 8). Finally, the low R squared values in each model indicate there is considerable unexplained residual variation in WTP.

Table 4

Example of choice set provided to survey participants. Each survey participant is provided with 8 sets of choices, described as referendums, with 3 choices containing attributes varied in an orthogonal design.

Variable	Willingness to Pay		
	All Respondents	Yes Voters	No Voters
Population (at 200 wolves)	1.477 (6.143)	26.943*** (7.889) [31,170,552]	-41.952* (19.596)
Compensation 100% FMV	55.663*** (11.058)	63.703*** (13.524) [73,698,392]	1.931 (29.623)
Compensation 100% FMV + Indirect	71.984*** (11.902)	72.882*** (13.431) [84,317,632]	-78.833* (35.197)
Cost Sharing	-37.492* (17.017)	-59.589*** (22.751) [− 68,938,880]	-16.408 (58.997)
Livestock losses	-0.293*** (0.071)	-0.359*** (0.103) [− 415,329]	0.0215 (0.180)
Government Lethal Control	-1.131*** (0.243)	-1.254*** (0.336) [− 1450,760]	0.923 (0.704)
Wolf Hunting Allowed	-24.792*** (9.805)	-17.866 (14.183)	-99.534*** (33.179)

a. Standard errors are estimated using the Delta method. Population WTP is estimated as $(\beta_{pop}/sd(pop) + 2*200*\beta_{pop^2}/sd(pop^2))/(-\beta_{cost}/sd(cost))*200$, where $\beta_{pop}, \beta_{pop^2}, and\ \beta_{cost}$ represent the coefficients on population, population squared, and cost or annual voluntary contribution in each model with each divided by the standard deviations of the variables. We divided by the standard deviation of the variables because the variables are normalized in the regression to facilitate model convergence. We multiplied by 200 because we are estimating the WTP for 200 wolves. Bracketed numbers in column 2 represent total WTP among yes voters for each attribute.

Table 5
Determinants of Willingness to Pay for Wolf Reintroduction: 1) yes voters, 2) Democrats and Independents, 3) Colorado's Front Range, 4) likelihood of encountering a wolf, 5) support for reintroduction, 6) age, 7) income, and 8) all covariates in a single model.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1(Voted Yes)	26.09***							6.418
	(5.512)							(7.190)
1(Democrat)		28.62***						10.66*
		(6.681)						(6.366)
1(Independent)		20.87***						9.830**
		(5.476)						(4.816)
1(Front Range)			8.535					6.210
			(7.754)					(6.347)
Encounter 2				-6.615				-6.552
				(7.425)				(6.697)
Encounter 3				-3.542				-3.490
				(9.572)				(7.937)
Encounter 4				-16.89*				-9.088
				(9.086)				(9.326)
Encounter 5				-31.09***				2.264
				(8.383)				(8.532)
Reintroduction Support					8.317***			5.807***
					(0.952)			(1.426)
Age						-2.800**		-1.806*
						(1.197)		(0.970)
Age Squared						0.0248**		0.0167*
						(0.0118)		(0.00946)
Income							-16.56*	-9.719
							(8.487)	(7.689)
Income Squared							1.738*	1.097
							(0.968)	(0.849)
Constant	-13.27***	-19.14***	-9.617	3.347	-41.66***	67.38**	31.81*	20.91
	(3.740)	(3.336)	(7.076)	(6.351)	(3.851)	(28.92)	(16.92)	(30.24)
Observations	10,272	10,272	10,272	10,272	10,272	10,272	10,272	10,272
R-squared	0.113	0.094	0.007	0.022	0.235	0.064	0.018	0.288

a. Dependent variable in each model is the individual specific WTP for 200 wolves calculated from model 1 in Table 3. There are slightly fewer observations than the primary model because some variables are null for a subset of respondents. Standard errors are clustered at the individual level
*** $p < 0.01$,
** $p < 0.05$,
* $p < 0.1$

4. Implications for policy and social welfare

4.1. Economic value of benefits

We can use the values from Table 4 to estimate the total willingness to pay for a reintroduction program with particular attributes by setting each attribute to a desired level and summing the values over the appropriate population (Parthum and Ando, 2020). The total economic value of introducing wolves includes the WTP for a given wolf population plus the WTP for any relevant management conditions that accompany reintroduction. For example, knowing that a compensation program will accompany reintroduction increases WTP, which implies that survey participants are willing to help offset the costs to livestock producers. Our results indicate that restoring a population of 200 wolves would add over $31 million per year to the state's non-market asset value, which increases by another $84 million if compensation for direct and indirect loss is included, as proposed in the state's wolf management and restoration plan (Colorado Parks and Wildlife. 2023). Therefore, the total annual value of restoring 200 wolves with compensation is estimated to be $99.8 per yes voting household or $115,488,184 across all yes voting households. For context, our estimated WTP of $99.8 is close to the WTP estimate of $91 for a wolf management program in Washington (van Eeden et al., 2021) Moreover, van Eeden et al. found respondents have a WTP of approximately $0.78 and $0.44 for an avoided cow or sheep death, while we found the average yes voter in Colorado had a WTP of about $0.40 for an avoided livestock kill.

How wolves are managed clearly affects value, with citizens placing more value on a program with compensation, small livestock losses, and low levels of lethal control. Another factor that affects value is the source of funding for wolf reintroduction. We asked respondents to tell us how much more, or less, they would have been willing to pay if the wolf reintroduction program had been funded from 1) the existing state agency budget (the state would have to defund some other activity equally), 2) special license plates focused on wolf reintroduction and management, or 3) state lottery funds (the state would have to defund some other activity equally already funded by lottery funds). We found that respondents were willing to pay approximately 15% less if the reintroduction was funded from the existing state agency budget, 20% more if the funds were from license plate sales, and about 8% more if the funds were from the lottery. These questions were asked after the initial choice experiment and therefore they could not bias our choice experiment results.

4.2. Benefits compared to costs

We estimated benefits to be approximately $115 million per year for a population of 200 wolves with compensation for livestock losses. We note that this benefit is primarily received by those who voted yes on the original ballot initiative. The cost of reintroduction is not yet known, but based on other states with wolves, annual costs will likely approximate $1–3 million. For example, $833,494 was budgeted for wolf management in Montana in 2021 (Parks et al., 2022), and $1.4 million in Washington (Washington Department of Fish and Wildlife, et al., 2022). Additionally, the USFWS estimated that, in 2015, almost $8.1 million was spent on managing wolves by state, federal, and tribal agencies in a region composed of northern Wyoming, Montana, North Dakota, the Idaho panhandle, Washington, and Oregon (Fish et al., 2015), averaging about $1.36 million per state. In Colorado, HB21–1243 appropriated $1.1 million for the wolf restoration and management program in FY 21–22.

For illustrative purposes, we can compare the estimated $115 million in annual benefits to a total annual cost of $2 million for wolf management in Colorado, which would yield $57.5 of benefit for each 1$ of cost. However, the benefits are unlikely to be distributed proportionately to those that incur costs (i.e., a spatial subsidy, Chester et al., 2022). For example, if the distribution of benefits is proportionate to where the yes voters reside, then 89.7% of the benefits would be in the Front Range where wolves are unlikely to occur, and only 5.4% percent of the benefits would be on the Western Slope which will incur most of the costs. We also emphasize that the estimated benefits of wolf reintroduction are based on hypothetical preferences for relatively small payments aggregated among many individuals across the state, whereas the predicted costs would be real losses incurred by a relatively few localized individuals where wolves occur. The high WTP also indicates that there was value lost during the period that wolves were gone, so not everyone is willing to pay to help them be reintroduced based on principle. Nevertheless, appropriate polices could harness the willingness to pay by members of the public that are willing to help mitigate losses that will likely be experienced by a small minority.

One challenge in estimating benefits and costs of wolf reintroduction was determining what might constitute a sustainable population of wolves in Colorado (i.e., one with high probability of long-term persistence) given population viability has not been estimated for the state. Further, at the time of the survey, Coloradoans had already voted to reintroduce wolves and a pack had naturally colonized the northwestern part of the state. We thus chose to focus on reintroduction with a status quo of a naturally colonized, small pack (10 individuals) of wolves with an uncertain future. However, some respondents who chose the status quo might have wanted wolves in Colorado but preferred natural recolonization over active reintroduction. If the status quo was instead set as no wolves in the state, this might have yielded higher WTP estimates for such people because reintroduction would have been their only option to restore wolves. We also did not investigate whether people for or against reintroduction would value naturally colonized wolves differently from those that would be reintroduced. Another limitation is that the no voters might hold some value for wolves, but the survey was not designed to parse out any positive portion of value held by a no voter.

5. Conclusions

Conflict related to conservation of large carnivores worldwide is escalated where the people calling for restoration and coexistence are not the same people living on landscapes with these animals. Valuing both human livelihood and sustainable carnivore populations will require that resources are available to help prevent conflict and, where appropriate, to compensate those impacted by carnivores. In the final Colorado wolf restoration and management plan, the state offers assistance for implementing wolf conflict minimization tools, and also proposes compensation for both direct and indirect livestock losses due to wolves (Colorado Parks and Wildlife, 2023). Colorado Parks and Wildlife will pursue a variety of funding sources to develop sustainable compensation and conflict reduction programs, including from other governmental agencies, NGO's, and the general public.

Our results indicate that WTP diminishes after a sustainable population of wolves is reached. This reduction is an important result that needs more nuanced research because it could be helpful to policy makers responsible for balancing wolf populations where stakeholders have diverse views. We demonstrate that there is a great deal of potential value that could be tapped to support efforts to restore wolves and mitigate conflict. While WTP represents the value of reintroduced wolves, it is only realized if it is collected. Not all of the estimated $115 million in benefits could be made available to apply towards wolf restoration, but our findings suggest that some of the voting public would support devoting more resources to restoration and coexistence programs if effectively asked. Innovative approaches, including public policies or private efforts, would be needed to find creative and accepted methods to leverage this untapped value from those willing to pay.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2023.e02576.

References

Armstrong, D., 1972. Distribution of Mammals in Colorado. Monogr. Mus. Nat. Hist., Univ. Kans. Number 3, 415.
Battaglia, M.P., Hoaglin, D.C., Frankel, M.R., 2009. Practical considerations in raking survey data. Surv. Pract. 2 (5), 2953.
Carhart, A., 2017. The Last Stand of the Pack: Critical Edition. University Press of Colorado.
Carroll, C., Phillips, M.K., Lopez-Gonzalez, C.A., Schumaker, N.H., 2006. Defining recovery goals and strategies for endangered species: the wolf as a case study. BioScience 56 (1), 25–37.
Carter, N.H., Linnell, J.D., 2016. Co-adaptation is key to coexisting with large carnivores. Trends Ecol. Evol. 31 (8), 575–578.
Chambers, C.M., Whitehead, J.C., 2003. A contingent valuation estimate of the benefits of wolves in Minnesota. Environ. Resour. Econ. 26 (2), 249–267.
Champ, P.A., Boyle, K.J., Brown, T.C., 2003 (eds.). A primer on nonmarket valuation, Vol. 3. Kluwer Academic Publishers, Dordrecht, pp. 72–82 (eds.).
Chester, C.C., Lien, A.M., Sundberg, J., Diffendorfer, J.E., Gonzalez-Duarte, C., Mattsson, B.J., Medellín, R.A., Semmens, D.J., Thogmartin, W.E., Derbridge, J.J., López-Hoffman, L., 2022. Using ecosystem services to identify inequitable outcomes in migratory species conservation. Conserv. Lett. 15 (6), e12920.
Colorado Parks and Wildlife. 2022. Colorado Wolf Restoration and Management Plan (Final). May 3, 2023. ⟨https://cpw.state.co.us/Documents/Wolves/2023-Final-CO-Wolf-Plan.pdf⟩.
Colorado State Demography Office. 2022. [last accessed September, 2022]. ⟨https://demography.dola.colorado.gov/assets/html/housing.html⟩.
Ditmer, M.A., Niemiec, R.M., Wittemyer, G., Crooks, K.R., 2022a. Socio-ecological drivers of public conservation voting: restoring gray wolves to Colorado, USA. Ecol. Appl. 32 (3), e2532.
Ditmer, M.A., Wittemyer, G., Breck, S.W., Crooks, K.R., 2022b. Defining ecological and socially suitable habitat for the reintroduction of an apex predator. Glob. Ecol. Conserv. 38, e02192.
Duffield, J., 1991. Existence and non-consumptive values for wildlife: application of wolf recovery in Yellowstone National Park. W-133/Western Regional Science Association Joint Session. Measuring NonMarket and Non-Use Values. Monterey, CA.
Duffield, J., 2019. Shopping for wolves: Using nonmarket valuation for informing conservation districts. In: Rasker, R. (Ed.), People and Public Lands. Headwaters Economics, Bozeman, MT.
Duffield, J.W., Neher, C.J. and Patterson, D.A., 2008, January. Wolf recovery in Yellowstone: park visitor attitudes, expenditures, and economic impacts. In The George Wright Forum (Vol. 25, No. 1, pp. 13–19). George Wright Society.
ECONorthwest. 2014. The Economic importance of Alaska's wildlife in 2011. Final report to the Alaska Department of Fish and Game, Division of Wildlife Conservation, contract IHP-12–052. Portland, Oregon.
U.S. Fish and Wildlife Service et al. 2015. Northern Rocky Mountain Wolf Recovery Program 2015. Interagency Annual Report. M.D. (Jimenez and S.A. Becker, eds) USFWS, Ecological Services, 585 Shepard Way, Helena, Montana, 59601.
Harris, R. 2020. Economic instruments to encourage coexistence between Montana livestock producers and large carnivores. Background and Discussion Paper, Montana Fish, Wildlife and Parks (April 24).
Hoag, D., Breck, S., Crooks, K., Niemiec, B., 2022. Economic consequences of the wolf comeback in the Western United States. In Western Economics. Forum Vol. 20 (No. 1), 61–70.
Lee, T., Good, K., Jamieson, W., Quinn, M., Krishnamurthy, A., 2017. Cattle and carnivore coexistence in Alberta: the role of compensation programs. Rangelands 39 (1), 10–16.
Loomis, J. 2016. Economic Values of Wolves in Denali National Park and Preserve (DNPP): Concepts, literature synthesis, data gaps and study plan. Available at IRMA Portal, National Park Service, U.S. Department of the Interior.
Lute, M.L., Carter, N.H., 2020. Are we coexisting with carnivores in the American West? Front. Ecol. Evol. 8, 48.
Meadow, R., Reading, R.P., Phillips, M., Mehringer, M., Miller, B.J., 2005. The influence of persuasive arguments on public attitudes toward a proposed wolf restoration in the southern Rockies. Wildl. Soc. Bull. 33, 154–163.
Nie, M.A., 2002. Wolf recovery and management as value-based political conflict. Ethics, Place Environ. 5 (1), 65–71.
Niemiec, R., Berl, R.E., Gonzalez, M., Teel, T., Camara, C., Collins, M., Salerno, J., Crooks, K., Schultz, C., Breck, S., Hoag, D., 2020. Public perspectives and media reporting of wolf reintroduction in Colorado. PeerJ 8, e9074.
Niemiec, R., Berl, R.E., Gonzalez, M., Teel, T., Salerno, J., Breck, S., Camara, C., Collins, M., Schultz, C., Hoag, D., Crooks, K., 2022. Rapid changes in public perception toward a conservation initiative. Conserv. Sci. Pract. 4 (4), e12632.
Nyhus, P.J., Osofsky, S.A. and Ferraro, P., 2005. the challenges of compensation schemes. People and wildlife, conflict or co-existence?, 9, p.107.
Parks, M., K. Podruzny, S. Sells, T. Parks, T. Smucker, N. Lance, and W. Cole 2022. Montana Gray Wolf Conservation and Management 2021 Annual Report. Montana Fish, Wildlife & Parks. Helena, Montana. 53 pages. ⟨https://fwp.mt.gov/binaries/content/assets/fwp/conservation/wolf/final-draft-2021-wolf-report-7.28.pdf⟩.
Parthum, Bryan, Ando, Amy W., 2020. "Overlooked benefits of nutrient reductions in the Mississippi River Basin.". Land Econ. 96 (4), 589–607.
Pate, J., Manfredo, M.J., Bright, A.D., Tischbein, G., 1996. Coloradans' attitudes toward reintroducing the gray wolf into Colorado. Wildl. Soc. Bull. (1973-2006) 24 (3), 421–428.
Peterson, L.George, 2003. In: Champ, Patricia A., Boyle, Kevin J., Brown, Thomas C. (Eds.), A primer on nonmarket valuation, Vol. 3. Kluwer Academic Publishers, Dordrecht.
Raynor, J.L., Grainger, C.A. and Parker, D.P., 2021. Wolves make roadways safer, generating large economic returns to predator conservation. Proceedings of the National Academy of Sciences, 118(22), p.e2023251118.
Skogen, K., Mauz, I., Krange, O., 2008. Cry wolf!: narratives of wolf recovery in France and Norway. Rural Sociol. 73 (1), 105–133.
Train, Kenneth E., 2009. Discrete choice methods with simulation. Cambridge university press.
van Eeden, L.M., Bogezi, C., Leng, D., Marzluff, J., Wirsing, A., Rabotyagov, S., 2021. Public willingness to pay for gray wolf conservation that could support a rancher-led wolf-livestock coexistence program. In: Biological Conservation, 260, 109226.
Venumière-Lefebvre, C.C., Breck, S.W., Crooks, K.R., 2022. A systematic map of human-carnivore coexistence. Biol. Conserv. 268, 109515.
Washington Department of Fish and Wildlife, Confederated Tribes of the Colville Reservation, Spokane Tribe of Indians, USDA-APHIS Wildlife Services, and U.S. Fish and Wildlife Service. 2022. Washington Gray Wolf Conservation and Management 2021 Annual Report. Washington Department of Fish and Wildlife, Ellensburg, WA, USA.
Wilson, M.A., 1997. The wolf in Yellowstone: Science, symbol, or politics? Deconstructing the conflict between environmentalism and wise use. Soc. Nat. Resour. 10 (5), 453–468.