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Grizzly bear and American black bear interactions with people in Yellowstone National Park

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Abstract: In North America, polar bears (*Ursus maritimus*), grizzly bears (*U. arctos*), and American black bears (*U. americanus*) occasionally injure or kill humans. Although bear-inflicted human injuries are uncommon, they generate media attention that can lead to fear and unreasonable perceptions of the risk of bear attacks. Information on the behavioral responses of grizzly and black bears during interactions with people can provide a factual basis regarding the risks associated with recreating in bear habitats and assist land managers in developing and prioritizing bear safety messages. To address those objectives, we collected 17,171 reports of grizzly and black bear reaction behavior during interactions with people in Yellowstone National Park, USA, between 1991 and 2022. We used Bayesian Multinomial Logistic Regression models to examine the odds of attack, agitation and/or warning, flight, or curious behavioral reactions versus neutral responses in bear–human interactions. We found that reaction behavior depended on both the species involved and the location of the interaction. In developed areas and along roadsides, neutral responses were most likely for both species. On front-country trails, odds of curious or flee reactions were greater than neutral responses for both species. The odds of agitation and/or warning reactions from grizzlies were also greater in this setting. In backcountry campsites, there were marginally higher odds of black bears attacking; whereas, grizzlies had marginally higher odds of attacking during off-trail backcountry interactions. Although bear attacks were uncommon in all locations, grizzlies were ~3.9× more likely than black bears to injure people in backcountry areas. Bear interactions with people were generally predictable; grizzly and black bears exhibited neutral behaviors or fled during most interactions. Curious approaches, agitation and/or warning behaviors, physical contact, and attacks were uncommon. Safety messages encouraging calm, confident responses during bear–human interactions are warranted, and may have better efficacy than those that generate fear and apprehension.

Key words: American black bear, bear attacks, bear–human encounters, bear–human interactions, camping, grizzly bear, hiking, off-trail travel, outdoor recreation, *Ursus americanus*, *Ursus arctos*, Yellowstone National Park

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Ursids (Ursidae) have ferocious reputations (Moment 1968, Olson 1969, Cramond 1981, Lapinski 2005, Snow 2016) that instill fear in many people throughout the world (Hastings et al. 1986, Herrero 2002, Balciauskas and Kazlauskas 2012, Debata et al. 2016, Støen et al. 2018). In North America, polar bears (*Ursus maritimus*), grizzly bears (*U. arctos*), and American black bears (hereafter, black bear [*U. americanus*]) do occasionally injure people and in rare incidents kill and consume humans (McCullough 1982, Herrero and Fleck 1990, Herrero et al. 2011, Stirling 2011, Penteriani et al. 2017). In Yellowstone National Park (YNP), USA, most grizzly bear–inflicted human injuries occur in backcountry areas and involve unintentional encounters at close distances when bears react defensively to protect themselves, their offspring, or their food from perceived threats (Gunther and Hoekstra 1998). Most black bear–inflicted human injuries in YNP occur in campsites and involve curious nips on sleeping people that may be tests of humans as potential prey (Gunther 2023).

Although bear-inflicted human injuries are uncommon, they often generate world-wide media attention (Craighead and Craighead 1972, Kellert 1994, Bombier et al. 2019). Sensational media coverage of bear attacks often leads to public fear and unreasonable public perceptions of the risk of being attacked by bears (Craighead and Craighead 1972, Miller and Tutterrow 1999, Herrero 2002, Penteriani et al. 2016, Smith and Herrero 2018, Støen et al. 2018, Bombier et al. 2019, Conover 2019, Nanni et al. 2020). Knowledge of the range of behavioral responses exhibited by grizzly bears and black bears during interactions with people can

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provide fact-based information regarding the actual risks associated with recreating in bear habitats and assist public land managers in developing and prioritizing effective bear safety messages. To address those objectives, we collected information on grizzly bear and black bear interactions with people in YNP during the 32-year period 1991–2022.

Study area

Yellowstone National Park was established in 1872 and encompasses 8,991 km^2 in the states of Wyoming (96%), Montana (3%), and Idaho (1%), USA. Most (~99%) of YNP is relatively pristine, undeveloped land; 92% of the park has been recommended for wilderness designation and by National Park Service policy is managed so as not to preclude that designation in the future (U.S. Department of the Interior, National Park Service 1974, 2006). Only ~1% of the park's natural landscape has been significantly altered through construction of roads and developments.

Yellowstone National Park has 5 major developed areas containing hotels, lodges, and rental cabins that provide overnight accommodations for park visitors. These developed areas contain 2,170 overnight lodging units (U.S. Department of the Interior, National Park Service 1991) that can accommodate ~8,300 guests per night (U.S. Department of the Interior, National Park Service 1974). Annual overnight stays in hotels, lodges, and rental cabins average ~577,000 overnight stays per year. Additionally, YNP has 11 roadside campgrounds and a recreational vehicle park that contain 2,265 campsites and accommodate from 566,000 to 792,000 overnight stays per year.

There are 499 km of paved roads and 251 km of gravel roads in YNP. Park roads are typically open to the public from mid-April through early November. Park roads provide visitor access to the major developed areas, campgrounds, front-country trails, and backcountry trailheads.

The park has 24 km of front-country trails providing access to geysers, thermal features, and other scenic attractions. Front-country trails are short walking trails located adjacent to roads and developments that contain interpretive signs providing visitors with information about geysers, wildlife, fire ecology, and other natural features. Front-country trails provide a stable walking surface with gentle grades or steps to travel up and down hills allowing use by visitors of wide-ranging ages, physical abilities, and hiking experience. Hundreds to thousands of visitors walk the front-country trails each day from mid-May through mid-October.

Additionally, the park has 1,609 km of maintained backcountry trails; 92 roadside trailheads provide access to the backcountry trail system. An additional 21 backcountry trailheads along the park's wilderness boundary allow access to YNP trails from adjacent U.S. National Forest Service lands. Yellowstone National Park's backcountry trails provide access to backcountry campsites, lakes, rivers, mountain peaks, and scenic vistas.

Yellowstone National Park has 301 designated backcountry campsites. The backcountry campsites have a total maximum capacity of 3,112 people and 1,665 stock animals per night. Each backcountry campsite provides a bear-resistant food-storage device (food hanging pole or steel food storage locker) to make food storage easy and convenient for backcountry recreationists. The backcountry campsites receive ~40,000–45,000 overnight stays per year.

During the study period (1991–2022), total park visitation ranged from 2.75 to 4.86 million visits and averaged 3.3 million visits per year. The majority (>96%) of park visitation occurred from May through October, the same period when most grizzly bears and black bears of all sex and age classes were out of winter dens and active on the landscape (Haroldson et al. 2002).

Yellowstone National Park has sympatric populations of grizzly bears and black bears. Bear densities in the region are estimated at approximately 1.9 grizzly bears (calculated from Gould et al. 2023; 965 grizzly bears within the 49,931-km^2 Yellowstone Demographic Monitoring Area) and 20.0 black bears (Bowersock et al. 2023) per 100 km^2. Topography in YNP is characterized by high-elevation plateaus and the mountain ranges that encircle them. Elevations range from 1,590 to 3,360 m; timberline occurs at 3,000 m. Approximately 80% of YNP's landscape is covered by forest and 20% by sagebrush–grasslands and grass–forb meadows (Despain 1990).

Methods

Information on bear–human interactions was gathered from Bear Sighting Reports that were self-reported by YNP visitors, concession employees, and YNP staff at visitor information centers, the Bear Management Office, and via telephone and e-mail during the 32-year period of 1991–2022. The bear sighting report form had prompts for people to fill in the species (grizzly, black bear, or unknown), number of bears, family groups (females with

cubs, yearlings, or 2-yr-olds), coloration, date, time, location, activity of the bear, whether or not the bear noticed the observer, and the bears reaction to the observer. The bear sighting form also had space for the observer to write in a description of the sighting, interaction, or incident. Bear Sighting Reports were entered into a computer database stored in the YNP Bear Management Office. Based on the information provided by the observers, YNP Bear Management Technicians filled out fields in the database for location, bear behavior during the interaction (no overt reaction, flee, curious response, agitation and/or warning behaviors, or attack), and other variables. For analysis, we grouped bear–human interactions into 6 broad categories based on the locations where they occurred: (1) within front-country developments, (2) along roads, (3) along front-country trails, (4) along backcountry trails, (5) within backcountry campsites, and (6) in off-trail backcountry areas. We included all bear–human encounters where the person reporting the incident believed that the bear was mutually aware of their presence. We censored data from 377 bear–human interactions where the people involved were unable to determine the species of bear with which they had an interaction. We also censored the data from 289 grizzly bear and 347 black bear interactions with people where the bears' behavioral response to the encounter was not reported. Additionally, we censored the data from 7 bear-inflicted human injuries that occurred to YNP and other partner agency employees while conducting job-related work activities (e.g., trapping and handling bears, moving injured bears, approaching ungulate carcasses) that put staff at greater risk of bear attack than park visitors are generally exposed to.

Definitions of terms

- *Agitation and/or warning behavior*: Incidents where bears reacted to encounters with people by blowing, huffing, woofing, vocalizing, teeth-clacking, paw-slap lunging, hop-charging or charging without contact.
- *Backcountry*: All lands in YNP proposed for wilderness designation and all other undeveloped lands >250 m from developments, roadside campgrounds, paved or gravel roads, and front-country trails. Areas classified as backcountry include backcountry trails, backcountry campsites, and off-trail backcountry areas.
- *Bear attack*: Any incident where grizzly or black bears initiated intentional physical contact with recreationists during encounters and interactions, including noninjurious contact and fatal or nonfatal injuries to people (from life threatening to minor cuts, scratches, and contusions).
- *Bear–human encounter*: Incidents where people observed bears or bears detected people, but they were not mutually aware of the others' presence. There are likely many incidents where bears detect the presence of recreationists and move away without being detected themselves. There are also incidents where people observe bears and move away without the bear being aware of the people's presence.
- *Bear–human interaction*: Bear–human encounters where bears and people were both mutually aware of the others presence.
- *Curious behavior*: Incidents where bears slowly approached or followed people they encountered.
- *Flight behavior*: Incidents where bears ran or walked away from people after encountering them.
- *Front-country*: All areas ≤250 m from the impacted footprints of developments, roadside campgrounds, paved or gravel roads, roadside pullouts, and front-country trails.
- *Neutral behavior*: Incidents where bears exhibited no overt response during interactions with people.
- *Off-trail backcountry areas*: All areas in YNP proposed for wilderness designation and all other undeveloped lands >250 m from developed areas, road corridors, front-country trails, and backcountry trails.
- *Overt reaction*: Readily observable behavioral responses exhibited by bears during interactions with recreationists. This definition does not infer that unobserved internal reactions without overt responses do not also occur (Herrero et al. 2005).

Statistical analysis

We explored initial variable importance through Multinomial Logistic Regression (MNL) models executed using the nnet package (Venables and Ripley 2002) using the Program R version 4.3.1 (R Core Team 2023). We examined the importance of the main explanatory variables of location, species, and the location:species interaction term for the full bear–human interaction data set. We compared initial MNL models containing each main variable and the interaction against simplified models by the difference between Akaike Information Criterion values (ΔAIC). When ΔAIC >2, we considered the removed term significant and left it in the model. In this initial run, both main variables and the interaction were significant (Likelihood Ratio Test, $\chi^2_{48,20} = 43.571$, $P < 0.002$). However, MNL models can underestimate the occurrence of rare events in

Table 1. Grizzly bear (*Ursus arctos*) behaviors reported during interactions with people in different locations of Yellowstone National Park, USA, 1991–2022.

Location of interaction with people	Total no. reported	Bears' behavior during interaction with people									
		Flee		Neutral		Curious		Agitation and/or warning		Attack	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%
Development	723	346	48	346	48	17	2	13	2	1	<1
Road corridor	4,132	979	24	3,020	73	58	1	75	2	0	0
Front-country trail	46	32	70	1	2	6	13	6	13	1	2
Backcountry campsite	208	88	42	89	43	20	10	11	5	0	0
Backcountry trail	1,521	750	49	481	32	114	8	160	11	16	1
Backcountry off-trail	460	254	55	140	30	16	4	41	9	9	2
Total	7,090	2,449	35	4,077	58	231	3	306	4	27	<1

imbalanced data (King and Zeng 2001), and bear attack events are quite rare in our data set, so we opted to shift to a Bayesian framework for our final analysis.

To assess the probability of each grizzly and black bear reaction type in different encounter locations, we used Bayesian multinomial logistic regression models executed with the Program R package UPG (Zens et al. 2023a) in R version 4.3.1 (R Core Team 2023). This package provides for Bayesian implementation of multinomial logit models based on Gibbs sampling with Markov chain Monte Carlo algorithms (MCMC) as described in Zens et al. (2023b), and is well-suited to imbalanced data sets.

We first ran Bayesian MNL models with all data combined to generalize the effect of species on reaction outcomes when the effect of location was held constant for both grizzly and black bears. However, initial data exploration suggested a significant interaction between species and location on the outcome of behavior; therefore, we stratified data by species and modeled them again to determine effect size when allowing the coefficients of each location category to vary for each species separately. Multinomial logit regression models estimate the effect of variables on the odds of observing each outcome as compared with a reference level. Neutral was the most common reaction behavior observed and therefore served as the reference level. Model coefficients are the change in likelihood of each behavior compared with neutral, expressed in log odds.

We based analysis for all models on 25,000 posterior draws following an initial burn-in of 5,000 iterations of the MCMC chain. We plotted results from the posterior distributions to display mean estimated effect-size coefficients with credible intervals for each location covariate. Species was an additional covariate in the model where both black and grizzly bear encounters were combined. We considered posterior estimates where the 95% credible interval for a given covariate did not include zero as significant. We exponentiated posterior mean coefficients post hoc to obtain odds ratios (OR) for each encounter behavior in each location type. Model specification and complete summaries are reported in Tables S1–S3 (*Supplemental material*).

Results

We collected 17,171 reports of interactions between bears and people in YNP from 1991 to 2022 that listed species and bear reaction behavior during the interaction. Reports included 7,090 grizzly bear–human interactions (Table 1) and 10,081 black bear–human interactions (Table 2). Grizzly bears made physical contact with people in 27 of the interactions and black bears in 5 of the interactions. Bear-inflicted human injuries occurred within developments, along front-country and backcountry trails, in backcountry campsites, and in off-trail backcountry areas. No bear attacks were reported along roads during the study period. For each location type, there were significant differences in the odds of bears reacting with behaviors other than "Neutral" in both the stratified and combined models.

Grizzly bear–human interactions

In 7,090 interactions between grizzly bears and people where the bears' behavior was reported, grizzlies reacted with neutral behaviors in 58%, by fleeing in 35%, with curious behaviors in 3%, and with agitation and/or warning behaviors in 4% (Table 1). Grizzly bears attacked people in <1% of the interactions. Grizzly bear attacks occurred at a slightly higher rate during off-trail backcountry encounters (2%, 9 attacks in 460 interactions) than during on-trail interactions (1%, 16 attacks in 1,521 interactions).

Table 2. American black bear (*Ursus americanus*) behaviors during interactions with people in different locations of Yellowstone National Park, USA, 1991–2022.

Location of interaction with people	Total no. reported	Bears' behavior during interaction with people									
		Flee		Neutral		Curious		Agitation and/or warning		Attack	
		n	%	*n*	%	*n*	%	*n*	%	*n*	%
Development	1,110	562	51	519	47	22	2	9	1	0	0
Road corridor	7,229	1,992	28	5,092	70	111	2	34	<1	0	0
Front-country trail	29	23	79	1	3	5	17	0	0	0	0
Backcountry campsite	161	64	40	71	44	17	11	6	4	3	2
Backcountry trail	1,242	652	53	478	39	74	6	35	3	2	<1
Backcountry off-trail	310	175	56	108	35	12	4	15	5	0	0
Total	10,081	3,468	34	6,269	62	241	2	99	1	5	<1

Grizzly bears rarely attacked during encounters with people in areas where human presence was frequent, concentrated, and spatially predictable to bears, such as along primary roads (0 attacks), within developments (1 attack), along front-country trails (1 attack), and in backcountry campsites (0 attacks). Along roads, grizzly bears mostly (73%) had neutral reactions to people, whereas flight was the most common response during front-country trail (70%) and backcountry off-trail interactions (55%).

Posterior means and credible intervals from the Bayesian MNL model and post hoc odds ratios estimate that grizzly bears encountered in developed areas were ~82% less likely (OR = 0.176; Table 3) to exhibit an agitated and/or warning reaction type than a neutral reaction (log odds = −1.74, 95% credible interval [CI]: [−3.32, −0.17]; Fig. 1A). Along roads, grizzly bears were ~88% less likely to react with agitation and/or warning (OR = 0.118; log odds = −2.14, 95% CI: [−3.68, −0.62]), ~98% less likely to attack (OR = 0.018; log odds = −4.01, 95% CI: [−6.11, −1.98]), and 90% less likely to display curious behavior (OR = 0.100; log odds = −2.30, 95% CI: [−3.83, −0.78]; Table 3, Fig. 1A) than a neutral behavior. On front-country trails, the model-estimated odds of grizzly bears fleeing were ~8.1× the odds of a neutral reaction (OR = 8.085; log odds = 2.09, 95% CI: [0.36, 3.84]; Table 3, Fig. 1A). Odds of curious behavior reactions were ~9.2× the odds of neutral responses (OR = 9.207; log odds = 2.22, 95% CI: [0.37, 4.13]), and the odds of agitation and/or warning reactions were ~8.4× greater than the odds of neutral behavior (OR = 8.415; log odds = 2.13, 95% CI: [0.29, 4.04]; Table 3, Fig. 1A). For all backcountry locations (backcountry campsites, backcountry trails, or backcountry off-trail) grizzly bears were neither significantly more nor less likely to respond with agitation and/or warning, attack, curious, or flee reactions than a neutral reaction at the 95% credibility level, but did show a trend toward attack behavior when interactions occur in backcountry off-trail locations (OR = 3.706, 95% CI: [−0.48, 3.11]; Table 3, Fig. 1A).

Black bear–human interactions

In 10,081 interactions between black bears and people where the bears' behavior was reported, black bears reacted with neutral behaviors in 62%, by fleeing in 34%, with curious behaviors in 2%, and with agitation and/or warning behaviors in 1% (Table 2). Black bears made physical contact and/or attacked people in <1% of the interactions. Black bears were more likely to injure people in backcountry campsites (2%, 3 attacks in 161 interactions) than on backcountry trails (<1%, 2 attacks in 1,242 interactions) or off-trail backcountry areas (0 attacks in 310 interactions). No black bear attacks were reported within developed areas, along roads, or on front-country trails. Like grizzly bears, black bears were most (70%) likely to exhibit neutrality to interactions along roads and most likely to flee during encounters along front-country trails (79%) and in off-trail backcountry areas (56%). All 5 black bear attacks occurred in backcountry areas, 3 in campsites and 2 along trails. One of the trail incidents involved a person taking a mid-day nap next to a trail. The second trail incident involved a surprise encounter at very close range between hikers (mother and 2 children) and a black bear with a cub in thick lodgepole pine (*Pinus contorta*) forest regeneration (26 yr postfire). In that incident the bear charged and made contact (wrapped its forelegs around the woman's waist) but did not injure the person.

Posterior means and 95% credible intervals from the Bayesian MNL model and post hoc odds ratios estimated that black bears were ~88% less likely to exhibit agitation and/or warning reactions (OR = 0.115; log odds = −2.16, 95% CI: [−3.74, −0.56]), ~98% less likely to

Table 3. Bayesian multinomial logistic regression model-estimated odds ratios for the occurrence of bear response behaviors separated by location for grizzly bears (*Ursus arctos*), American black bears (*U. americanus*), and both species combined in Yellowstone National Park, USA (data derived from interactions with people, 1991–2022).

	Grizzly bears				Black bears				All (combined)			
Location	**Agitation**	**Attack**	**Curious**	**Flee**	**Agitation**	**Attack**	**Curious**	**Flee**	**Agitation**	**Attack**	**Curious**	**Flee**
Development	**0.176**	0.172*	0.257**	0.726	0.289*	0.165*	0.223**	0.771	**0.165**	**0.106**	0.226**	0.719
Road corridor	**0.118**	**0.018**	**0.100**	0.235**	**0.115**	**0.023**	**0.115**	0.275**	**0.091**	**0.009**	**0.105**	0.250**
Front-country trail	**8.415**	5.755	**9.207**	**8.085**	0.487	0.670	**12.680**	**9.488**	**7.003**	4.690	**13.177**	**10.090**
Backcountry campsite	0.571	0.122*	1.162	0.719	1.336	7.243**	1.221	0.631	0.572	0.867	1.145	0.661
Backcountry trail	1.553	2.014	1.221	1.127	1.246	0.932	0.811	0.970	1.135	1.015	0.979	1.015
Backcountry off-trail	1.363	3.706*	0.577	1.310	2.270	0.249	0.560	1.150	1.195	1.833	0.559	1.208
Species												
Grizzly									**3.223**	**3.797**	1.066	**0.906**
Black									REF	REF	REF	REF

Bold numbers indicate statistical difference where 95% credible intervals do not overlap zero while a ** denotes the same for 90% credible intervals and a * for 80% credible intervals. REF denotes that black bears were the reference level in the combined model.

attack (OR = 0.023; log odds = −3.78, 95% CI: [−6.22, −1.51]), and 88% less likely to exhibit curious behavior (OR = 0.115, log odds = −2.16, 95% CI: [−3.66, −0.64]) than neutral reactions along roads within the park (Table 3, Fig. 1B). In encounters on front-country trails, the odds of black bears fleeing were ∼9.5× the odds of a neutral reaction (OR = 9.488; log odds = 2.25, 95% CI: [0.45, 4.15]) and the odds of curious behavior were ∼13× the odds of neutral behavior (OR = 12.680; log odds = 2.54, 95% CI: [0.57, 4.54]; Table 3, Fig. 1B). Like grizzly bears, black bears were neither more nor less likely to respond with agitation and/or warning, attack, curious, or flight behaviors than with neutrality in all backcountry locations (Table 3, Fig. 1B). There was a moderately well-supported trend toward the odds of black bear attack reactions being ∼7.2× greater than the odds of a neutral response when encountered in backcountry campsites (OR = 7.243, log odds = 1.98, 95% CI: [−0.06, 4.04]), which warrants some attention. This finding was supported within the 90% CI, but not the 95% CI (Table 3, Fig. 1B).

All bear–human interactions

All 17,171 encounters modeled in the above individual species models were combined to estimate a generalized effect of species in observed encounter reaction behaviors. This model provided a location-adjusted species effect estimate for grizzly bears versus black bears, but does not account for the significant species:location effect modification that the species-stratified models estimate. Thus, location coefficients are likely underestimates for some behaviors and overestimates for others.

In developed areas, posterior distributions for all combined bear encounters estimated that agitation and/or warning (OR = 0.165; log odds = −1.80, 95% CI: [−3.34, −0.26]) and attack (OR = 0.106; log odds = −2.25, 95% CI: [−4.22, −0.43]) reactions were significantly less likely to occur than neutral reactions (Table 3, Fig. 1C). Along roads, agitation and/or warning (OR = 0.091; log odds = −2.39, 95% CI: [−3.88, −0.88]), attack (OR = 0.009; log odds = −4.75, 95% CI: [−6.64, −2.89]), and curious (OR = 0.105; log odds = −2.25, 95% CI: [−3.77, −0.73]) responses were significantly less likely to occur than a neutral reaction (Fig. 1C). On front-country trails, agitation and/or warning (OR = 7.003; log odds = 1.95, 95% CI: [0.13, 3.75]), curious (OR = 13.177; log odds = 2.58, 95% CI: [0.82, 4.35]), and flee (OR = 10.090; log odds = 2.31, 95% CI: [0.62, 4.04]) reactions were significantly more likely to occur than neutral reactions (Table 3, Fig. 1C). In all backcountry

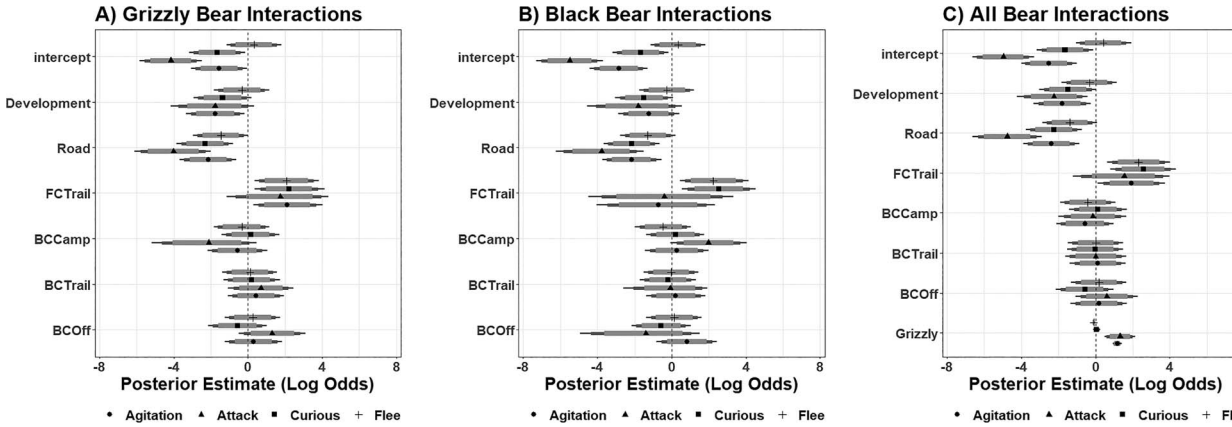

Fig. 1. Posterior means and credible intervals from Bayesian Multinomial Logistic Regression models for bear reactions to encounters in different park locations in Yellowstone National Park, USA (data derived from interactions with people, 1991–2022). Points are posterior mean effect size in log odds. Thick grey bands represent 80% credible intervals, mid-thickness bands represent 90% credible intervals, and thin dark bands represent 95% credible intervals. Values where 95% credible intervals include zero were not considered to have a significant effect on reaction outcome. Panel A shows grizzly bear (*Ursus arctos*) encounters only. Panel B shows American black bear (*U. americanus*) encounters only. Panel C shows combined grizzly and black bear encounters with species included as an explanatory variable to directly contrast species effects on bear behavior during encounters.

locations, agitation and/or warning, attack, curious, and flee reactions were not significantly more likely to occur than a neutral reaction (Table 3, Fig. 1C). Species had a significant effect in determining reaction type. Model estimated odds of encounters with grizzly bears were ~3.2× greater for agitated and/or warning behavior (OR = 3.223; log odds = 1.17, 95% CI: [0.93, 1.41]), ~3.8× greater for attack reactions (OR = 3.797; log odds = 1.33, 95% CI: [0.49, 2.14]), and 10% less for flight responses (OR = 0.906; log odds = −0.10, 95% CI: [−0.17, −0.03]) than the odds of a neutral response compared with black bears (Table 3, Fig. 1C).

Chances of bear attack

Most grizzly bear (93%, 25 of 27) and all black bear (5 of 5) attacks in YNP from 1991 to 2022 occurred in backcountry areas, so we calculated the chances of being attacked by bears while recreating in the backcountry. From 1991 to 2022, there were 2,189 interactions reported between backcountry recreationists and grizzly bears, of which 25 resulted in an attack, yielding a rate of 1 grizzly bear attack per 88 backcountry interactions. During the same period, there were 1,713 interactions between black bears and backcountry recreationists, resulting in 5 attacks and yielding a rate of 1 black bear attack per 343 backcountry interactions. Therefore, grizzly bears were ~3.9× more likely than black bears to attack people during backcountry interactions.

Discussion

Grizzly bear

Despite their ferocious reputations, long-term monitoring of grizzly bear–human interactions in YNP indicates that grizzlies were tolerant of recreationists in most interactions and rarely attacked people. Low rates of brown bear–inflicted human injury have also been reported in Alaska (Middaugh 1987, Smith and Herrero 2018), Austria (Rauer 1999), Canada (Herrero and Higgins 1999), and Scandinavia (Swenson et al. 1999, Støen et al. 2018). In YNP, grizzly bears were especially tolerant of people during interactions in areas where human activity was spatially predictable, such as along park roads and within developments. Grizzlies in YNP were significantly less likely to exhibit agitation and/or warning behaviors than neutrality when interacting with people in developed areas and along roads. This is consistent with Jope's (1982) suggestion that grizzly bears are less likely to react with defensive aggression when they encounter people in a predictable manner. Management of roadside bear viewing opportunities by YNP staff makes human behavior in road corridors more predictable to bears (Haroldson and Gunther 2013, Gunther et al. 2018) and may have

contributed to the high rate of neutral responses from bears along roads.

Overall, grizzly bears exhibited neutrality in more than half of all reported interactions with recreationists parkwide. Neutral responses to encounters may be more common in National Parks and protected areas where bear–human interactions are frequent and rarely result in the bear being harmed or killed, leading to higher levels of habituation to people in National Parks and protected areas compared with nonprotected areas (Albert and Bowyer 1991; Aumiller and Matt 1994; Gunther et al. 2004, 2018; Herrero et al. 2005; Smith et al. 2005). The habituation of some bears to people in YNP and other protected areas throughout the world is inevitable, and likely to increase with successful bear conservation programs and the increasing popularity of human recreation in natural areas (Gunther et al. 2018, Penteriani 2023). Thus, sustaining and expanding as necessary the people management programs that have made management of habituated bears successful to date, such as those at the McNeil River State Game Sanctuary, and Katmai, Yellowstone, and Grand Teton National Parks (Aumiller and Matt 1994, Gunther et al. 2004, 2018), is likely to be a growing challenge for managers of protected areas throughout the world.

Avoidance through flight was the second-most common grizzly behavior exhibited during interactions with people in YNP. Grizzly bears fled at a higher rate during off-trail backcountry interactions than during encounters in most other areas of the park. Human presence and activity are likely to be less predictable to grizzlies in off-trail areas (Herrero 2002).

Grizzly bears seldom displayed threat or warning behaviors toward people and only occasionally made contact and/or injured people during interactions occurring in YNP. However, in incidents where grizzly bears make physical contact, injuries can be severe or fatal (Herrero 1970, Gunther 2022).

In comparison with black bears, grizzly bears were significantly more likely to react to encounters with people with agitation and/or warning behaviors or attack than to exhibit neutrality in our combined model. However, our species-stratified results suggest that this effect likely depends on the context of the location of the interaction. Grizzlies were less likely to exhibit aggression during interactions in areas where human activities were spatially predictable, and more likely to exhibit aggression during interactions in areas where human activities were less predictable in space and time.

During our study, almost all grizzly bear attacks on people occurred in backcountry areas. The rate of grizzly bear attack was slightly higher during off-trail backcountry interactions than on-trail interactions. Off-trail travel may increase the risk of surprise encounters (Jope 1982, Herrero and Fleck 1990, Herrero 2002). The danger of unintentional surprise encounters with grizzly bears and associated defensive attacks decreases if bears know where to expect people (Jope 1982, Herrero 2002). Most hikers in YNP stay on designated trails (Coleman et al. 2013), so bears are less likely to anticipate encounters with people who are traveling off-trail, and therefore, more likely to react with defensive aggression to off-trail encounters (Gunther and Hoekstra 1998, Herrero 2002).

Black bear

Like grizzly bears, black bears were tolerant of people in most interactions, especially those that occurred in areas where human activity was spatially predictable, such as along roads. Overall, black bears exhibited neutrality in over half of all interactions with people parkwide. Flight was the second most common behavior reported during black bear–human interactions. As with grizzly bears, black bears also exhibit behavioral plasticity and will readily habituate to people in protected areas (Gunther et al. 2018).

All the reported black bear attacks during our study occurred in backcountry areas. This contrasts with YNP's early history, when from 1931 to 1969 most black bear–inflicted human injuries involved food-conditioned bears being recreationally hand-fed by park visitors in frontcountry areas (Gunther and Hoekstra 1998, Garshelis et al. 2017). Implementation of a new bear management program in 1970 (Leopold et al. 1969) has mostly eliminated the recreational hand feeding of black bears along roads and within developments in YNP, resulting in significant declines in black bear–inflicted human injuries (Meagher and Phillips 1983, Gunther 1994, Gunther and Hoekstra 1998, Garshelis et al. 2017).

Herrero and Higgins (1999) reported that almost all serious injuries inflicted by black bears in British Columbia, Canada, were possible predatory attacks. All the black bear–inflicted human injuries during our study were very minor and most (4 of 5) involved people that were sleeping or resting in a prone position. Most (3 of 5) also occurred in backcountry campsites. Only one incident involved an unintentional surprise encounter with hikers. These factors suggest that the incidents involving sleeping or resting people in prone positions in YNP may have been tests of people as potential prey. However, in all the incidents with

sleeping or resting people, the bears disengaged with the victims after they yelled, sat up, stood up, or the bear was driven off by a companion. In most documented diurnal predatory attacks on people, black bears are extremely focused on their intended prey and not easily dissuaded (Herrero 2002, Smith 2006). Therefore, the black bear incidents involving people in prone positions during our study may have been curious soft bites to determine how the people would respond, before deciding whether or not to pursue them as potential prey. The circumstances of black bear attacks in YNP during our study (5 attacks in 32 yr, no major injuries, 4 of 5 involved sleeping or resting people, 3 of 5 occurred in campsites) are very similar to those reported in New York state, USA, where during a 20-year period (1960–1980) only 3 people were injured by black bears, all minor injuries, with all 3 injured people being bitten or swiped through a tent while sleeping or resting (Herrero 2002).

Estimating the chances of bear attack

Our estimates of 1 grizzly bear attack per 88 interactions with backcountry recreationists and 1 black bear attack per 343 backcountry interactions in YNP are likely biased high. We believe benign interactions where bears fled or behaved in a neutral or unaggressive manner were less likely to be reported than injurious or aggressive interactions. Therefore, our data are likely skewed toward more aggressive interactions, possibly by a considerable margin. Despite this bias, our data indicate that both grizzly bears and black bears rarely reacted aggressively, made physical contact, or attacked people during interactions in YNP.

Although aggression and attacks were uncommon in all locations, grizzlies were ~3.9× more likely than black bears to attack people during backcountry interactions. This calculated rate is similar to our model-derived estimate. However, the models indicate that the likelihood of attack might vary by the type of backcountry location, with highly predictable human locations such as designated backcountry campsites showing significantly lower odds of grizzly attack compared with backcountry off-trail travel. Our calculated rate is similar to the rate reported for British Columbia, where grizzly bears inflicted about 3× as many human injuries as black bears (Herrero and Higgins 1999).

Grizzly bear evolutionary history makes them much more aggressive than black bears in defending themselves, high-quality foods (such as ungulate carcasses), and their cubs from perceived threats (Herrero 1972, Sterling and Derocher 1990). The distribution of black bears has been correlated with forested habitats (Jonkel and Cowan 1971, Rogers 1987, Bowersock et al. 2021). Black bears forage within forests, in small forest openings, and along forest edges. They have adaptations well-suited to forested habitats including short, curved claws that aid in tree climbing (Herrero 1978). Black bears are proficient tree climbers, and often use trees for shelter, sleeping, nursing, playing, and protection from threats (Herrero 1972). When threatened, black bears and their cubs often climb trees or escape into forest cover, minimizing the need to directly engage potential predators (Herrero 1978, Sterling and Derocher 1990). In contrast, grizzlies spend considerable time foraging in large nonforested valley bottoms, wet meadows, sagebrush-steppe, and arctic and alpine tundra (Herrero 1972), where they can be long distances from the nearest trees. Grizzly bears claws are long and gently curved, better suited to digging foods from the soil than climbing trees (Herrero 1978). Grizzly bears are frequently without nearby trees for escape, and therefore often defend themselves and their cubs from predators and perceived threats on the ground with explosive aggressiveness (Herrero 1978, Sterling and Derocher 1990). During their evolutionary history, highly aggressive mother grizzlies were likely the most successful at raising cubs (Herrero 1972).

Statistical analysis and credible intervals

We used the 95% credible interval to denote statistical difference in our analysis in order to present the most conservative results given potential biases toward more likely reporting of perceived aggressive encounters by park users. However, it might be prudent to adopt more liberal standards and err on the side of caution given the potential for human injury when encountering bears in certain conditions. Hence, we also present the 90% and 80% credible intervals. We believe these intervals represent an adequate density of the probable posterior values of the odds while still preventing unreasonable acceptance of null effects in the context of known behavioral tendencies of grizzlies and black bears and details of attacks that have occurred within YNP and beyond. Under these intervals, we find a couple of additional noteworthy trends. First, in backcountry off-trail travel, model estimates show that the odds of an attack response are significantly higher, at 3.7× the odds of a neutral response during a grizzly interaction in this setting. Thus, extra caution should be taken when traveling off-trail in grizzly habitat. Next, when interactions with black bears occur in occupied backcountry campsites, the odds of an attack response are 7.2× the odds of a neutral reaction, while

grizzlies are 98% less likely to respond with attack behavior than neutral behavior in backcountry campsite interactions.

These models do not directly account for human responses to an interaction and how those might affect the behavioral response of the bear, but rather, trends should be considered estimates of the differences in location and species of bear encountered. Our aim is to help managers and outdoor recreationists understand that interaction outcomes will differ by the location of the interaction in addition to the type of bear that is encountered.

The direction of significant effects is accurately represented in logistic regression model coefficients, but the magnitude of the effect may not be absolute across all models or groups owing to arbitrary scaling factors related to the unexplained variance implemented by these models (Mood 2010, Norton et al. 2018). Where additional variables improve model fit, as in our combined model with species as an explanatory variable, coefficients and resulting odds ratios might be somewhat overestimated in some cases as a result of lower standard deviation of the error (Norton et al. 2018). However, given that the values of significant terms estimated by the models generally coincide with our preliminary estimates of behavior likelihoods from the raw data, we believe our results are adequate approximations of noteworthy behavioral outcomes in bear–human interactions for this population. They are therefore useful for providing managers with insights into the effects of encounter location and species that should be considered when crafting safety messaging for those who work and/or recreate in bear habitats.

Management considerations

In our study, bears' interactions with people were generally predictable. Grizzly bears and black bears exhibited neutral behaviors or fled during most interactions. Curious approaches, agitation and/or warning behaviors, physical contact, and attacks were uncommon. Bear attacks are very uncommon, so bear safety messages designed to encourage calm, confident responses during bear–human interactions are warranted, and may have better efficacy than those that generate fear and apprehension, such as the common warning "bears are unpredictable." Confidence can be an important factor when responding to curious or predatory bears. Confidence can also be an important factor when standing ground against charging bears reacting with defensive aggression to surprise encounters. Bear spray carry and knowledge of its efficacy (Herrero and Higgins 1998; Herrero 2002; Smith et al. 2008, 2020) can also promote confidence in recreationists, giving them the courage to stand their ground rather than run when charged by bears during surprise encounters. In contrast, statements like "bears are unpredictable" may instill in recreationists a sense of hopelessness in response to bear encounters (Smith 2006).

Most of the bear-inflicted human injuries that did occur in YNP involved unintentional surprise encounters with grizzly bears in backcountry areas. Therefore, emphasizing human behaviors that can reduce the chances of surprise encounters, as well as emphasizing behaviors that can diffuse backcountry confrontations when they occur, may be the most effective safety messages for reducing the frequency of grizzly bear attacks in YNP. To reduce the chances of surprise encounters with bears, the International Union for the Conservation of Nature, North American Bears Expert Team (NABET) recommends hiking in groups of $\geq$3 people, being vigilant when in bear habitat, and making noise in areas with poor visibility (Gunther et al. 2023). During interactions, backing away slowly from nervous bears to give them space, standing one's ground and using bear spray when charged by bears, and playing dead once defensive bears make contact are considered NABET's best practices for diffusing confrontations during surprise encounters.

Most black bear attacks during our study occurred in campsites and/or involved people who were sleeping or resting in a prone position when bitten. Therefore, safety messages that emphasize how to react when bitten by curious bears may be the most effective messages for preventing curious black bear bites from escalating into full predatory attacks. North American Bears Expert Team recommends being aggressive and fighting back when interacting with curious or predatory bears. Predatory attacks on people generally persist until the bear is scared away, overpowered, injured, or killed by the person being attacked or their companions (Herrero 2002).

Most of the reported bear–human interactions in YNP, as well as most of the reported neutral responses by bears, occurred along park roads where habituation to human activities is common (Haroldson and Gunther 2013, Gunther et al. 2018). However, most bear safety messages distributed in YNP are designed to address hiking and camping in bear country, proper food storage, and not feeding bears. Roadside bear–human interactions are the most common interaction reported, so additional safety messaging on appropriate human behaviors around habituated roadside bears and roadside bear-viewing etiquette may be warranted. Best practices for visitors viewing habituated bears along roads include (1) not throwing food to roadside bears because

human food-conditioned bears are more likely to cause conflicts and be removed by managers; (2) not approaching, encircling, or following bears foraging in roadside meadows to reduce the chances of defensive reactions by bears; (3) not running in proximity to roadside bears because running can trigger a chase response (Herrero 2002); and 4) always maintaining ≥100 m from bears because bears rarely react with defensive aggression to encounters that occur at distances >100 m.

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Supplemental material

Table S1. Model outputs for Bayesian Multinomial Logistic Regression of all Yellowstone National Park bear–human interaction data combined, 1991–2022, examining reaction behavior (k) by location and species (n = 17,171). SD is standard deviation.

Table S2. Model outputs for Bayesian Multinomial Logistic Regression of Yellowstone National Park grizzly bear–human interaction data combined, 1991–2022, examining grizzly reaction behavior (k) by location (n = 7,090). SD is standard deviation.

Table S3. Model outputs for Bayesian Multinomial Logistic Regression of Yellowstone National Park black bear–human interaction data combined, 1991–2022, examining black bear reaction behavior (k) by location (n = 10,081). SD is standard deviation.