Tools and Technology Article

Spatiotemporal Distribution of Black Bear–Human Conflicts in Colorado, USA

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ABSTRACT Management and conservation of large carnivores increasingly includes conflicts with humans. Consequently, a greater understanding of spatiotemporal trends of conflicts is needed to efficiently allocate resources and apply targeted management. Therefore, we examined spatial and temporal distribution of American black bear (*Ursus americanus*; hereafter, bear)–human conflicts in Colorado, USA, related to 3 conflict types (agriculture operations, human development, and road kills). We used the Getis–Ord G_i^* spatial clustering statistic to describe location and assess magnitude of bear–human conflicts in Colorado during 1986–2003 and investigated temporal trends of bear–human conflicts by type. Bear–human conflicts showed distinct spatial clustering by type, and areas of high clustering overlapped conflict types. Clustering for agriculture operations conflicts had the largest overall G_i^* value and overlapped counties with high sheep production. Both human development and road-kill conflict clusters were high in areas of high-quality oak (*Quercus* spp.)–shrub habitat in the central and southern portions of Colorado's Front Range region and near the city of Durango in southwestern Colorado. Bear–human conflicts varied by year and type but overall increased during the 18 years. Summed across years, most conflicts were related to agriculture (32%), followed by road kills (27%) and human development (24%). The greatest proportion of agriculture operations–related conflicts (76%), human development–related conflicts (36%), and road kills (47%) occurred in 1988, 1999, and 2003, respectively. Considering that bear–human conflicts in Colorado increased over time and will likely continue to increase, we suggest wildlife managers improve data collection by obtaining detailed location data, categorizing conflict types uniformly, and applying conflict regulations consistently to strengthen inference of similar analyses. We also suggest that managers target efforts to mitigate damage by focusing on areas with high clustering of conflicts. (JOURNAL OF WILDLIFE MANAGEMENT 72(8):1853–1862; 2008)

DOI: 10.2193/2007-442

KEY WORDS American black bear, bear–human conflicts, clustering, Colorado, Getis–Ord statistic, spatiotemporal analysis, *Ursus americanus*, wildlife damage management.

Conflicts between wildlife and humans are a global problem as humans encroach into wildlife habitats and wildlife increasingly uses human-developed landscapes (Woodroffe et al. 2005*a*). Wildlife–human conflicts emerge due to diverse causes and span various taxa and continents (e.g., Warne and Jones 2003, Michalski et al. 2006, Sitati and Walpole 2006, Van Belle et al. 2007). Although wildlife–human conflicts can pose danger to human safety and cause damage to property, management of these conflicts can also have deleterious effects on wildlife populations, such as extirpation and range collapse (Woodroffe et al. 2005*b*). Therefore, wildlife–human conflicts will continue to be a global management priority for many wildlife species.

In North America, conflicts between American black bears (*Ursus americanus*; hereafter, black bear or bear) and humans have increased dramatically in the last few decades (e.g., Beck 1991, Beckmann and Berger 2003, Zack et al. 2003, Gore et al. 2005) and, in recent surveys, 20 states reported growing trends in bear–human conflicts (Hristienko and McDonald 2007). In Colorado, USA, black bear–human conflicts increased during the 1970s and by the 2000s, conflicts were related to a third of all bear mortalities in the state (Beck 1991, Apker 2003). During the same time period, Colorado's human population almost doubled to approximately 4.3 million and current projections suggest a >60% growth by 2030 (Hobbs and Stoops 2002). As development increases in the urban–wildlands interface and people continue to live, develop, and recreate in wildlife habitats, bear–human conflicts will require greater attention from resource managers.

Wildlife–human conflicts are often clustered in space and time and can cause major economic losses to a few stakeholders in addition to localized wildlife population declines (Thirgood et al. 2005). However, for most species, little is known about how conflicts vary spatiotemporally by conflict type. Thus, a greater understanding will help to develop strategies to minimize and mitigate conflicts and allow more efficient allocation of resources through targeted management activities. Therefore, our objectives were to describe characteristics of bear–human conflicts in Colorado as they related to 3 distinct types of bear–human conflict (agriculture operations, human development, and road kills), to describe temporal trends in conflicts in Colorado, and to apply a spatial clustering statistic to examine distribution of bear–human conflict clusters related to each conflict type.

STUDY AREA

We restricted our analyses to the western two-thirds of Colorado, where bears primarily occur (Colorado Division of Wildlife [CDOW] 2005; Fig. 1). Because bears are

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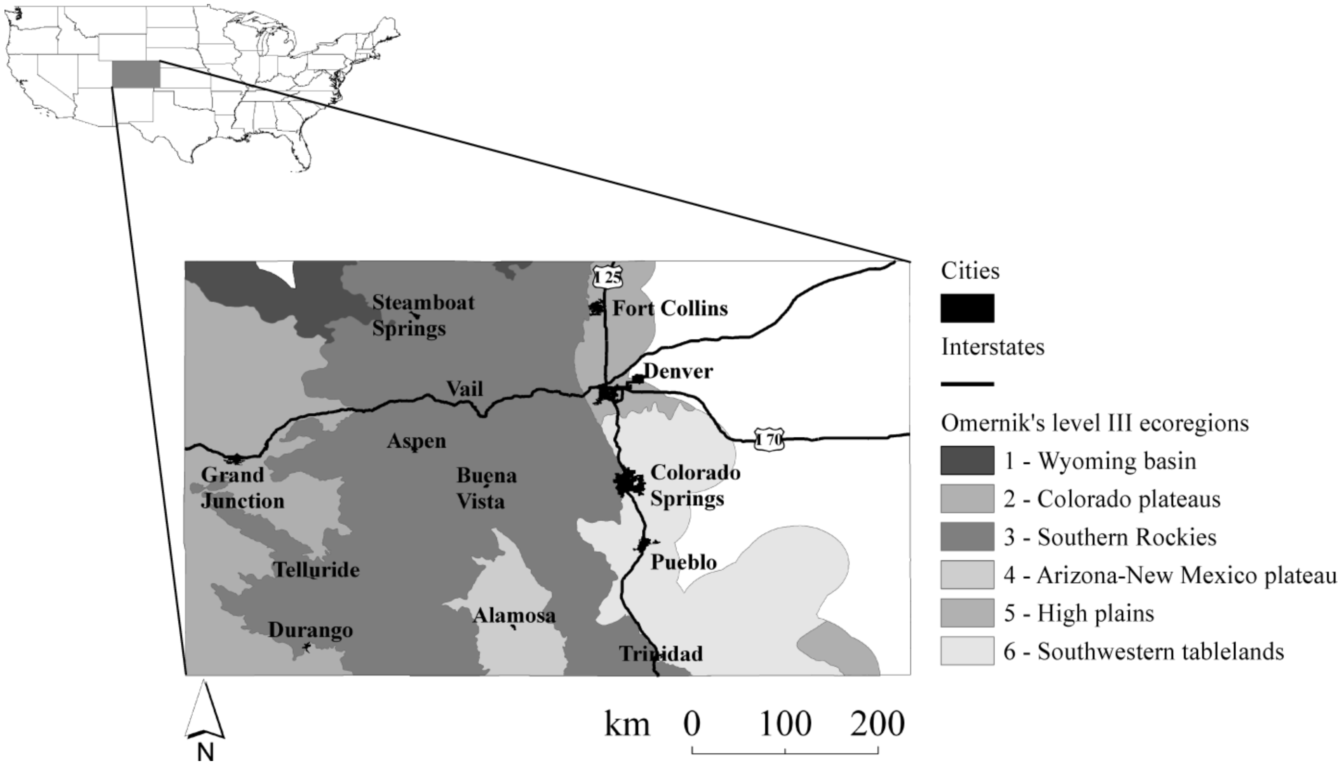

Figure 1. Selected cities, interstates, and Omernik's Level III ecoregions (shaded areas) in the area used to study black bear–human conflicts in Colorado, USA, from 1986 to 2003. The Colorado Division of Wildlife's bear range map (2005) defined the core area, which we buffered by 40 km to account for bear dispersal and fall feeding movements.

highly mobile animals and can move great distances (≤40 km on average while migrating to fall feeding areas [Beck 1991] or as dispersing subadults [C. Costello, Wildlife Conservation Society, unpublished data]), we buffered the range map by 40 km and used this expanded range for analyses. The resulting study area included 2 major interstate highways, metropolitan areas just east of the Rocky Mountains from Fort Collins to Denver to Trinidad that we refer to as the Front Range, and several mountain resort towns (Fig. 1). Land ownership was 45% private and 55% public (Wilcox et al. 2006).

The study area ranged in elevation from 1,100 m to 4,397 m and consisted of 6 Omernik's Level III ecoregion classifications (Omernik 1987), with the southern Rockies ecoregion being the dominant classification (57%), followed by southwestern tablelands (18%; Fig. 1). Vegetation associations at lower elevations in the eastern portion of bear range and along the Front Range contained grasslands that transitioned into ponderosa pine (*Pinus ponderosa*) and piñon (*P. edulis*)–juniper (*Juniperus* spp.) woodlands in the Rocky Mountain foothills. Woodlands along the foothills of the Rockies changed with increasing elevation into lodgepole pine (*P. contorta*), Douglas-fir (*Pseudotsuga menziesii*), and spruce (*Picea* spp.)–subalpine fir (*Abies lasiocarpa*) coniferous forests at higher elevations of the central Rockies. These communities composed most of the southern Rockies ecoregion with high-quality bear habitat, consisting of aspen (*Populus tremuloides*) forests and mountain shrublands, distributed throughout (Beck 1991). With decreasing elevations west of the Continental Divide, vegetation communities transitioned into drier piñon–juniper forests and semidesert shrublands. Gambel oak (*Quercus gambelii*) communities that are considered high-quality bear habitat (Beck 1991, Vaughn 2002) were distributed along the southwestern portions of the Front Range, portions of Southern Rockies ecoregion, and areas near Durango in southwestern Colorado.

METHODS

Bear–Human Conflicts Database

Black bear management in Colorado changed considerably during the 1990s. Bears were hunted in spring and fall until the spring hunt was banned through a citizen ballot initiative in 1992 (Decker et al. 1993, CDOW 2002, Apker 2003). In 1994, CDOW implemented a new bear management policy with a 2-strikes rule for problem bears. This policy mandates that any nuisance bear that is captured, tagged, and relocated after the first offense be destroyed upon engaging in a second offense (CDOW 2002). Depredating and dangerous bears that kill livestock or pose an immediate threat to human safety may be destroyed upon first offense. Accordingly, we defined conflicts as any bear–human encounter that prompted action of CDOW, affiliated entities such as United States Department of Agriculture-Wildlife Services (USDA-WS), or landowners, to either trap or kill bears. We also included records of bears killed by vehicles or trains (i.e., road kills) as conflicts.

Colorado requires that all harvest and non-harvest bear carcasses be uniquely tagged and recorded. Every bear trapping and handling event where sedative drugs were administered, which therefore includes all first-strike bear trapping events, was also recorded. We acquired an electronic database from CDOW that included non-harvest bear mortalities (i.e., second strikes, road kills, and unknown mortalities) since 1979 and augmented the database with all first-strike incidents based on available hard copy records from CDOW for 1986 to 2003. Although different forms were used over the years and data recorded varied for each incident, data generally included first- or second-strike classification; date; location (county, Game Management Unit [GMU], township, range, section, or Universal Transverse Mercator [UTM] coordinates); bear's gender and age (cub, yearling, subadult, and adult categories estimated by managers based on teeth characteristics, body size, and evidence of breeding); whether it was previously tagged; reason for trapping or killing; and comments, including a short description of the incident. We reviewed all hard copies and, based on description of each incident, categorized first- and second-strike records as related to 4 conflict types: agriculture operations, human development, road kills, or unknown. We omitted non-harvest bear mortalities from 1979 to 1985 (4.2% of all records) because these records did not have a hard copy and could not be categorized by type.

Agriculture-related records included all conflicts involving agricultural products, such as livestock (e.g., sheep, cattle, and poultry) and crops (e.g., orchards, apiaries), and records in which USDA-WS resolved the conflict. We classified conflict as human development–related (hereafter human-related) if a conflict was associated with human food sources (e.g., bird feeders, garbage), property damage (e.g., break-in of residences or vehicles), or aggressive behavior or attack towards humans or pets. We controlled for conflict-type misclassifications between agriculture-related and human-related categories by considering conflict narrative and location. However, if any doubt existed regarding conflict type, we classified it as unknown. Lastly, road-kill conflicts included bear–vehicle collisions on interstates, United States highways, state highways, local roads, and collisions with trains.

We plotted conflict records with the best location information available using data projected in UTM, North American Datum (NAD) 1927. We used UTM coordinates if available but, alternatively, we plotted records with township, range, and section data based on UTM coordinates of their centroid, which was provided by CDOW. We first projected data using either zone 12N or 13N, and then displayed it in a Geographic Coordinate System (GCS), NAD 1983, and unified all UTM zones. We then extracted county name by location and checked for plotting errors by comparing plotted and reported county names. Incorrect records were usually related to errors in data entry, the original UTM zone reported, or a location near the border of adjacent counties. Whenever possible, we corrected location errors using additional data from the conflict forms such as address of the report or watershed drainage. We removed records with uncorrectable location data from the analysis (approx. 1% of plotted records).

Spatiotemporal Patterns

The first law of geography states that things that are near are more similar, that is, autocorrelated, than things that are farther apart (Tobler 1970, Fortin and Dale 2005). Often, exploratory data analysis employs simply visualizing patterns to identify potential clusters of autocorrelated data, but autocorrelation statistics provide methods to statistically and quantitatively analyze patterns. Global spatial association statistics average values across a study area to determine degree of association between locations, thus providing an overall autocorrelation value but not locations where autocorrelation exists. In the presence of global spatial autocorrelation across study extent, several statistics are used to depict significant local clustering patterns and assess local spatial autocorrelations and non-stationarity (i.e., lack of homogeneity of mean and variance throughout the analysis extent; Anselin 1995, Getis and Ord 1996, Sokal et al. 1998). Local indicators of spatial association (a term coined by Anselin 1995) include local Moran's I, local Geary's C, and the local Getis–Ord G and G^* statistics.

The local Moran's I statistic measures covariance between a focal point i and its neighbor j for the quantity of interest x, whereas the local Geary's C statistic compares squared differences between the focal point and its neighbors (Getis and Ord 1996). Both statistics produce similar results that characterize whether local neighbors have similar, dissimilar, or no association in values of x (Getis and Ord 1996, Fortin and Dale 2005). Whereas the results of Moran's I and Geary's C statistics shed light on local spatial structure, they do not provide information about local high or low clusters (i.e., hot and cold spots) across study extent (Fortin and Dale 2005). The Getis–Ord local G and G^* statistics achieve the latter by comparing the sum in variable x within a local neighborhood relative to the global sum of study extent (G statistic excludes and G^* includes focal point i). Therefore, we used the Getis–Ord G^* clustering statistic to identify hot-spot locations of bear–human conflicts.

Using ArcMap 9.0 Spatial Statistics toolbox, we mapped bear–human conflict clusters using the Getis–Ord G_i^* statistic, defined as

$$G_i^* = \frac{\sum_j w_{ij}(d)x_j}{\sum_j x_j} j \text{ may equal } i,$$

where G_i^* measures degree of association in variable x (conflict count as described below) for j points located within distance d of the focal point i, including i, as compared to total value of all j points across study extent (Getis and Ord 1992). The binary weight matrix $w_{ij} = 1$ if j is within distance d of i and $w_{ij} = 0$ otherwise. Once G_i^* is calculated for each point, it is redefined as a standard deviate value for each point by subtracting the mean, or expected G_i^*, and dividing it by the standard deviation (Getis and

Ord 1996). When clustering is higher or lower than expected, the resulting G_i^* statistic will have large positive or negative values, respectively, the former identifying the existence of a concentration of high values of conflicts (Mitchell 2005). Because the Getis–Ord G_i^*statistic is redefined as a standard deviate, it allows further identification of significant hot spots.

To tabulate conflicts, we superimposed a grid on the analysis extent, counted number of conflicts within each grid cell per year, and summed number of conflicts over the 18-year data span (x_j). Different analysis scales can produce different results (Turner et al. 2001, Dungan et al. 2002), and choosing the appropriate grid cell size (grain) and analysis neighborhood (distance d) for the Getis–Ord statistic depends in part on the analysis goal which, in our study, was management oriented. Therefore, we based selection of both grid cell size and values of d on the area of GMUs, which are used by CDOW in statewide management of wildlife. The smallest, largest, and mean GMU areas in Colorado in our study extent were 7,132 ha, 391,000 ha, and 140,846 ha, respectively. Accordingly, we calculated cell size as the hypothetical radius of the area of the smallest GMU, or 4.76 km, and calculated the analysis neighborhood size as the hypothetical radius for the mean and largest GMU, or $d = 21.17$ km and 35.28 km, respectively (hereafter, 21-km and 35-km analyses). To assess sensitivity of results to different grain sizes, we conducted additional analyses where cell size equaled 0.5 (2.38 km) and 2 times (9.53 km) the 4.76-km scale. We therefore conducted analyses for agriculture-related records, human-related records, and road kills with 6 combinations each for the 3 grain sizes (2.38 km, 4.76 km, and 9.53 km) and 2 distance band values ($d = 21$ km and 35 km). To compare between neighborhood analysis for each conflict type and grain size combination, we examined correlation between neighborhood analyses results using coefficient of determination (Ott and Longnecker 2001; PROC REG, SAS Institute, Cary, NC). Lastly, the GCS projection resulted in minor distortion of the ratio of latitude and longitude coordinates and influenced measurement of distance with a 4.5% distortion in Colorado (Snyder 1982). This resulted in a minimal distortion of 90 m and 150 m for the 21-km and 35-km distance bands, respectively.

Based on locations of conflict clusters, we then examined spatial relationship of clusters for each conflict type with relevant landscape features. We identified areas of high clustering of human-related conflicts and road kills in relations to cities and roads using Geographic Information System (GIS) coverages available from the Colorado Department of Transportation (2003). We further examined correlation of the Getis–Ord G_i^* results with road traffic volume data using the coefficient of determination (PROC REG; SAS Institute). Distribution of agriculture operations was available only as county summary statistics from the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture. We identified sheep as the major category of agriculture-related bear–human conflicts in Colorado. Therefore, to examine distribution of conflict clusters relative to agriculture operations, we linked sheep-farming county statistics data for the 2002 agriculture census with the GIS county coverage for Colorado and displayed each county's relative sheep production rank measured by sheep and sheep farm densities (Colorado Department of Transportation 2003, NASS 2005). We then examined whether areas of high sheep production and areas of high clustering of agriculture-related bear–human conflicts overlapped. Lastly, to evaluate the temporal trend of bear–human conflicts in Colorado, we modeled counts for each conflict type as a function of time (yr) and examined direction and strength of trends using linear regression (PROC REG; SAS Institute).

RESULTS

The non-harvest database had 2,405 bear–human conflict records from 1986 to 2003, including first-strike trapping events. Approximately 24% ($n = 585$) of records could not be plotted and, after removing and correcting for inconsistencies ($n = 20$), we used 1,800 plotted records (35% from UTM coordinates and 65% from township, range, section centroids) for analyses. Conflicts were most commonly related to agriculture operations ($n = 565$, 23.5% of conflicts), followed by road kills ($n = 509$, 21.2%), human development ($n = 432$, 18.0%), and unknown ($n = 294$, 12.2%). Most agriculture-related conflicts involved sheep (46.7%), unspecified (25.4%), and poultry (7.1%; Table 1). Property damage, including residence break-in or damage to vehicles and campers, accounted for 42.6% of human-related conflicts, and proximity to humans (bears were sighted in close proximity to people, thus facilitating an action by officer or landowner) accounted for 24.5%. Road kills occurred on interstates, highways, local roads, and railroads, with greatest number (40.7%) attributed to highways.

Clustering, as indicated by the Getis–Ord G_i^* statistic, varied by conflict type, analysis grain, and neighborhood size (Table 2). Clustering for agriculture-related conflicts had the highest G_i^* value for any given cell size and analysis neighborhood, with the largest overall value (53.3) occurring at cell size of 2.38 km and distance band of 21 km. The mean G_i^* and standard deviation decreased as cell size increased with analysis neighborhood held constant, but it increased as neighborhood size increased with cell size held constant (Table 2). Correlations between G_i^* values of the 21-km and 35-km neighborhood analyses were >0.82 for all analyses combinations (i.e., by cell size and conflict type, $P \leq 0.001$). In addition, relative spatial location and distribution for clusters in Colorado did not change with cell size or distance band. Therefore, we plotted results at the 4.76-km cell resolution and the 21-km distance band based on the smallest and mean GMU size as described in our methodology.

Clusters of agriculture-related conflicts had higher concentration in the northwestern portion of the state and

Table 1. Records of black bear–human conflicts by subcategories of conflict types in Colorado, USA, from 1986 to 2003. Subcategories are listed from most to least frequent.

Conflict type	Subcategory	No. of records	% of total
Agriculture operations–related	Sheep	360	46.7
	Unspecified	196	25.4
	Poultry	55	7.1
	Apiary	37	4.8
	Miscellaneous[a]	27	3.5
	Goat	26	3.4
	Cattle	22	2.9
	Pig	17	2.2
	Alpaca and llama	16	2.1
	Orchard	15	1.9
	Total	771	100.0
Human development–related	Property damage[b]	245	42.6
	Proximity to humans[c]	141	24.5
	Attack–aggressive behavior[d]	81	14.1
	Garbage	61	10.6
	Miscellaneous[e]	33	5.7
	Unspecified	7	1.2
	Bird feeders	7	1.2
	Total	575	100.0
Road kills	Highways	260	40.7
	Interstates	170	26.6
	Unspecified	168	26.3
	Local roads	33	5.2
	Railroads	8	1.3
	Total	639	100.0
Unknown		420	100.0

[a] Includes conflicts related to horses, burros, and domestic game.
[b] Includes conflicts related to actual and attempted break-ins into residences, vehicles, and campers.
[c] Includes events where bears were sighted in close proximity to people, which facilitated an action by an officer or landowner.
[d] Includes events with a real or perceived attack or aggressive behavior by the bear on humans or pets.
[e] Miscellaneous records include events caused by food stored outside, noncommercial orchards, and issues related to gardens.

overlapped several key sheep-producing counties including Delta, La Plata, Montrose, and Rio Blanco (Fig. 2). Human-related conflict clusters included areas in the southern portions of the Front Range, in central Colorado near the city of Buena Vista, in the west near Grand Junction, and in the vicinity of Telluride and Durango in southwestern Colorado (Fig. 2). Clusters of road kills included the Interstate 70 corridor west of Denver, roads along the Front Range, especially near Colorado Springs and Trinidad, and roads in southwestern Colorado near Durango (Fig. 2). Further comparison of G_i^* results to traffic volume indicated a weak relationship between high road-kill cluster values and traffic volume ($r^2 = 0.03$, $P \leq 0.001$). In general, the Trinidad and Durango areas had high cluster overlap for all conflict types (Fig. 2), and human-development conflicts overlapped with road kills mainly on the Front Range and southwestern areas of Colorado near Durango.

Numbers of bear–human conflicts varied annually, but in general showed a significant increasing trend from 1986 to 2003 for all conflict types (agriculture: $\beta = 4.9$, SE $= 1.3$, $P < 0.001$; human: $\beta = 5.0$, SE $= 1.2$, $P < 0.001$; road kills: $\beta = 5.9$, SE $= 1.3$, $P < 0.001$; Fig. 3). Greatest numbers of conflicts per year were (in decreasing order) 440 in 2002, 371 in 2001, 326 in 2000, and 289 in 1995 (Fig. 3). General patterns over time showed that proportion of human-related

Table 2. Getis–Ord G_i^* statistic results by cell size and distance bands (d) for black bear–human conflict types in Colorado, USA, from 1986 to 2003. We calculated the G_i^* statistic as the sum of conflict counts within a local neighborhood relative to study extent, including the focal point. The G_i^* statistic is then redefined as a normal standard deviate that assumes positive or negative values when clustering is higher or lower than expected, respectively.

	Human development–related			Road kills							
Agriculture operations–related	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range		
2.38	45,431	21	0.03	3.5	−1.4, 53.3	0.03	2.4	−1.3, 24.1	0.02	2.9	−1.3, 27.7
		35	0.07	4.2	−2.4, 35.7	0.05	3.1	−2.2, 24.3	0.06	3.6	−2.2, 22.0
4.76	11,417	21	0.02	2.7	−1.1, 42.2	0.03	2.1	−1.2, 21.7	0.02	2.4	−1.0, 22.1
		35	0.06	3.3	−1.9, 27.9	0.05	2.8	−2.0, 22.2	0.04	3.0	−1.8, 17.5
9.53	2,882	21	0.01	1.9	−0.7, 30.1	0.02	1.7	−0.9, 16.7	0.01	1.7	−0.7, 18.0
		35	0.03	2.4	−1.4, 20.0	0.04	2.4	−1.8, 17.7	0.03	2.3	−1.3, 13.5

[a] n is no. of grid cells that intersected with the 40-km buffered bear range in Colorado and that we used to attribute no. of conflicts to calculate the G_i^* statistic.

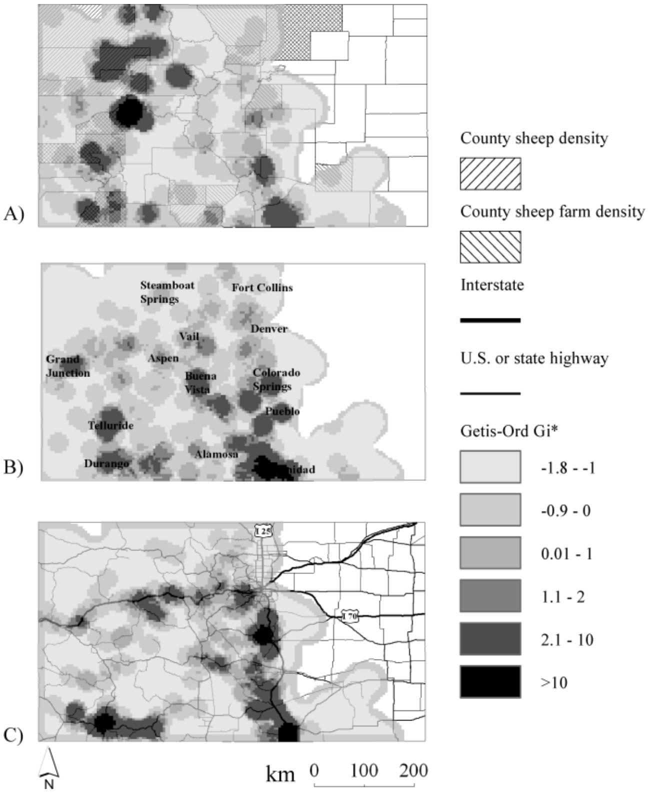

Figure 2. Cluster distribution of black bear–human conflicts in Colorado, USA, from 1986 to 2003, calculated as the Getis–Ord G_i^* statistic mapped by conflict type related to (A) agriculture (overlaid with counties that rank as the top 10 sheep producers by the sheep density or sheep farm density; National Agricultural Statistics Service 2005), (B) human development (shown with selected cities), and (C) bear road kills (shown with interstates and United States or state highways). We conducted all analyses at cell resolution of 4.76 km and distance band (d) of 21 km and higher cluster values are indicated in darker shade of gray ($2.1 < G_i^* < 10$) and black ($G_i^* > 10$).

conflicts and road kills increased and agriculture-related conflicts decreased (Fig. 3). Highest proportion of agriculture-related conflicts (76%), human-related conflicts (36%), and road kills (47%) occurred in 1988, 1999, and 2003, respectively.

DISCUSSION

Black bear–human conflicts in Colorado increased from 1986 to 2003, and based on the Getis–Ord G_i^* spatial clustering statistic, high spatial clustering was evident for the combined data and by conflict type. In general, proportion of conflicts related to agriculture operations decreased over time but accounted for most bear–human conflicts across all years. Excluding the unspecified subcategory, sheep-related conflicts dominated agriculture-related bear–human conflicts. Similar patterns were observed in Idaho, USA, with black bears (Johnson and Griffel 1982) and in agriculture lands in Montana, USA (Wilson et al. 2005), Norway (Knarrum et al. 2006), and in the French Pyrenees of Austria and Spain (Kaczensky 1999) with brown bears (*U. arctos*). Additionally, data from Europe suggested domestic sheep were the most common livestock species depredated by brown bears (Kaczensky 1999). Whether the observed patterns reflect variation in tolerance by individual sheep producers towards bears is unclear. If sheep herding grounds overlap high-quality bear habitat, problems with bears are likely to persist. For example, in Norway, killing of depredating brown bears did not reduce number of depredations as more bears immigrated into the area (Sager et al. 1997).

Clustering patterns of conflicts related to human development were not restricted to rural mountain communities and had high occurrence in areas with substantial human population growth such as the Colorado Front Range

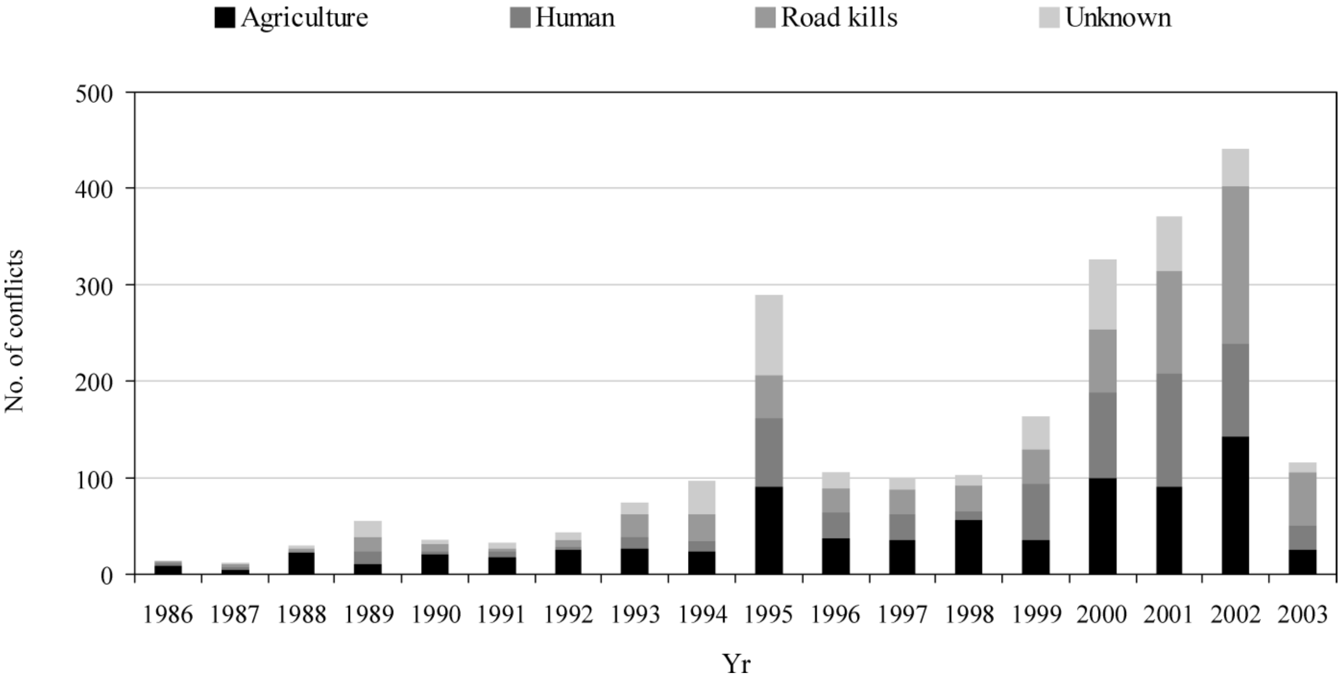

Figure 3. Temporal trends of black bear–human conflicts in Colorado, USA, from 1986 to 2003, presented by conflict type.

(Colorado Department of Local Affairs 2005). In addition, they occurred in urban centers (e.g., Colorado Springs, Trinidad, and Durango) near high-quality bear habitat such as oak–shrub vegetation, suggesting that cities with greater urban and oak–shrub habitat edge will have more conflicts. Effects of urban development in the urban–wildland interface are not restricted to bear–human conflicts in Colorado and urbanization will become an increasing priority in management of many wildlife species (DeStefano and DeGraaf 2003, Shochat et al. 2006). That wildlife–human conflicts are not unique to rural areas and that development near urban areas continues to grow suggests that future management strategies will need to account for both types of communities.

Property damage was the leading cause of human-related conflicts in Colorado. Claims were paid for damage to personal property (e.g., grills, vehicles, and structures) by the state of Colorado until 2000 when liability was limited to only agriculture-related property and products (Apker 2003). Thus, complaints and damage claims related to human development may decline in future years as compensation for personal property is limited. The subcategories "proximity to humans" and "attack–aggressive behavior" had the second- and third-most conflicts, respectively, suggesting that fear of an attack often promotes action by managers or the public. From the early 1900s through the 1980s, 23 human fatalities resulted from black bear attacks in North America (Thirgood et al. 2005), and estimates of fatal attack rates by black bears in the United States are 0.3 human fatalities per year (Conover et al. 1995). Still, risk perception from black bears can especially increase following media coverage of a black bear attack (Gore et al. 2005). Therefore, real or perceived fear of carnivores will continue to be a key factor driving management of wildlife–human conflicts.

Large carnivores are vulnerable to road-related mortality due to their large area requirements and high mobility (Forman et al. 2003). Road kills by definition result in bear mortality and were the largest source of mortality for an unhunted black bear population in Florida, USA (Forman et al. 2003). In our study, road kills accounted for approximately 25% of all bear–human conflicts and may pose a substantial mortality risk for bears. Our results showed no relationship between traffic volume and high road-kill cluster values, with bear road kills 1.5 times more likely to occur on highways compared to interstates. Bears may avoid high-traffic-volume roads such as interstates and thus are more likely to cross and be killed on smaller roadways. Results for other studies in this regard are equivocal. In Arkansas, USA, translocated bears crossed Interstate 40 (Shull 1994), yet in North Carolina, USA, bears avoided the same interstate and exhibited a negative relationship between road crossings and traffic volume (Brody and Pelton 1989). Because wildlife often avoids human activity and will cross roads at night (e.g., Dussault et al. 2006, Klocker et al. 2006, Reynolds-Hogland and Mitchell 2007) and because temporal traffic volume patterns will vary, a more temporal-specific traffic volume measure could better reflect road-kill risks for wildlife.

Similar to human-related conflicts, road-kill clusters occurred near high-quality bear habitat near Durango, Colorado Springs, and Trinidad. Local conditions, such as roads that affect driver response to wildlife or movement corridors that are bisected by roads, may contribute to these patterns. For example, high numbers of road kills occurred on Interstate 25 in the Trinidad area where road sinuosity was high and driving visibility was poor and near No Name Creek in the Glenwood Springs Canyon where the riparian corridor crossing Interstate 70 was surrounded by otherwise less passable terrain. Similar patterns have been found for ungulates and where riparian zones bisect highways (Finder et al. 1999, Barnum 2003, Clevenger and Wierzchowski 2006), which highlights the importance of creating safe movement corridors for bears, especially in areas where road kills are highly clustered. Ultimately, approaches that identify habitat linkages in black bear habitat (e.g., Kindall and Van Manen 2007) may offer improvements in understanding and predicting locations of road-kill clusters.

Agricultural production of sheep, cattle, and apiaries in Colorado has declined since the 1980s, and the conversion rate of land from agriculture to other land uses has accelerated (Colorado Agricultural Statistics Service 2003). Concurrently, the human population in Colorado almost doubled since the 1970s, with a corresponding increase in human development (Hobbs and Stoops 2002). These temporal trends in human development and activity and agriculture production corresponded with the observed general increase in proportion of human-related conflicts and road kills and the general decrease in proportion of agriculture-related conflicts. In addition, the overall temporal increase in bear–human conflicts observed might result from 1) bear population trends, 2) changes in conflict management in the state, and 3) climatic events affecting natural food production. First, after passage of the 1992 ballot initiative that banned spring hunting and hunting with hounds and bait, the bear population in the state possibly increased and consequently more conflicts were reported. Baruch-Mordo (2007) found significant positive relationships between normalized harvest records for black bears and bear–human conflicts in Colorado, suggesting both harvest and conflicts were increasing. Still, inference on whether such a relationship is the result of an increase in bear numbers is limited by the lack of reliable estimates of bear populations through time, which are not available for Colorado and are difficult to attain (Gese 2001, Waits 2004). Second, with implementation of a 2-strikes policy for bears in 1994, more conflicts were potentially handled by CDOW. In fact, high conflict numbers observed in 1995 (Fig. 3) may have been the result of implementation of this new management policy. Third, weather events, for example drought events that occurred in the early 2000s in western Colorado (National Oceanic and Atmospheric Administration 2006), likely resulted in severe natural food shortages for bears that caused bears to seek alternative food sources and engage in more conflicts with humans, as reflected by the observed temporal trends in the early 2000s (Fig. 3). Baruch-Mordo (2007) examined the relationship between bear–human conflict occurrence in Colorado and variables such as the amount of bear habitat, human housing density, and weather-related variables; the latter considered surrogates for natural food production. Baruch-Mordo (2007) found that weather-related variables were the most important predictors of conflict occurrence but argued that direct monitoring of natural food production is needed to better understand influence of food shortages on temporal trends in bear–human conflicts.

The conflict database and observed patterns may show bias from a number of factors. First, number of black bear conflicts reported was probably influenced by localized management efforts of CDOW and their respective approaches to data collection and bear management policy. Some managers have been more vigilant in recording conflict information or more prone to strictly interpret the state's 2-strikes bear policy towards enforcement. These factors may have resulted in increased conflict numbers for a given location and clustering of conflicts that were not process based (i.e., related to bear–human conflict behavior) but instead biased toward action by managers. Due to changes in personnel and management approaches, localized bear management probably changed over time, and, although it may be difficult to quantify, future analyses should attempt to account for this bias by incorporating a management factor. Second, despite checking for errors in assigning conflict type as described in our methods, we may have misclassified conflict incidents (other than road kills) and the unknown type may be biased towards certain conflict types. However, clusters of combined conflicts were similar with and without inclusion of unknown conflicts (Baruch-Mordo 2007), suggesting that spatial clustering patterns were not influenced by misclassification. Further, we have no reason to believe that misclassification rates varied by conflict type. Finally, false absences due to unreported conflicts possibly occurred. We assumed that mandatory reporting by CDOW of handled bears and the requirement that all bear carcasses be tagged and reported in Colorado resulted in accurate reporting for management-related conflict types (i.e., agriculture- and human-related). In addition, unreported road kills are less likely to occur because bear–vehicle collisions will result in substantial vehicle damage and thus the incident is likely to be reported. Therefore, unreported incidents may primarily comprise illegal kills, which would result in underestimation and could affect cluster locations.

A number of factors are important to keep in mind when using the Getis–Ord G_i^* clustering statistic and interpreting results. First, we summed conflict count across the 18 years of data; thus, we were not able to differentiate temporal trends in cluster location and how such variation affected management actions. Future research could examine spatial clustering of bear–human conflicts as a function of time. Second, we included multiple records for an individual bear ($<1.5\%$ of plotted records), which can result from repeat offenders prior to the 2-strikes rule, 2-strikes bears, or a tagged bear later killed in a vehicle collision. In these cases, implications to managers were similar in that when a conflict occurred resources were expended. Third, high prevalence of zeros can result in a skewed distribution of the G_i^* statistic and requires a larger number of neighbors or points, that is, increasing d, for the statistic to reach normality (Ord and Getis 1995). We likely observed high values of G_i^* because the overall expected statistic was very small due to the large number of zeros. Sokal et al. (1998) suggested that, in cases of nonnormality, the Getis–Ord G_i^* results should be considered exploratory and the focus should be on identifying areas of non-stationarity and outliers rather than on evaluating cluster significance. Therefore, we focused on reporting the relative intensity of clustering patterns. Fourth, as previously mentioned, the scale chosen for grid cell size and distance band can influence results. Results for this analysis showed high correlation between the different scales with similar spatial patterns but researchers should continue to examine performance of the statistic at different scales. Lastly, because the Getis–Ord is a neighborhood statistic, it smoothes point data and areas near high conflict areas so that a location may receive a high clustering value even though it had no reported conflicts. Therefore, this statistic should be used with caution to identify regional clustering patterns.

MANAGEMENT IMPLICATIONS

Increases in spatially clustered bear–human conflicts can result in local impacts to a few stakeholders and the wildlife population. Considering that solutions for managing conflicts between bears and humans will vary depending upon the conflict type, our results suggest that more effective management may result from allocation of limited resources in targeted areas. Further, mitigation efforts can be directed towards prevention of common conflict subcategories we reported, which included domestic sheep, property damage such as break-ins, and highway-related mortality. Lastly, based on our review of bear–human conflict data, wildlife agencies should review data collection protocols to strengthen inference of future analyses of conflict data. In particular, database improvements should include collection of detailed location data (e.g., UTM coordinates), uniform categorizations of conflict types to reduce potential for reporting and classification biases, and consistency in implementing regulations, which will reduce bias due to different interpretations of bear conflict policy by local managers.

ACKNOWLEDGMENTS

We greatly appreciate funding and support provided by the USDA-WS-National Wildlife Research Center, Fort Collins, Colorado; in particular, we thank M. Yeary and D. Moreno. We also thank the CDOW for providing access to the conflict records used to develop the database, in particular J. Apker and M. Lloyd. We appreciate help in gathering and understanding data that was provided by numerous personnel with the CDOW and USDA-WS. Finally, we would like to thank K. Crooks of the Department of Fish, Wildlife, and Conservation Biology at Colorado State University for his thorough comments on this manuscript.

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Associate Editor: Miller.