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Living with Wildlife and Mitigating Conflicts Around Three Indian Protected Areas

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Abstract Crop and livestock losses to wildlife are a concern for people neighboring many protected areas (PAs) and can generate opposition to conservation. Examining patterns of conflict and associated tolerance is important to devise policies to reduce conflict impacts on people and wildlife. We surveyed 398 households from 178 villages within 10 km of Ranthambore, Kanha, and Nagarahole parks in India. We compared different attitudes toward wildlife, and presented hypothetical response scenarios, including killing the problem animal(s). Eighty percent of households reported crop losses to wildlife and 13 % livestock losses. Higher crop loss was associated with more cropping months per year, greater crop variety, and more harvest seasons per year but did not vary with proximity to the PA, suggesting that PAs are not necessarily "sources" for crop raiders. By contrast, complaints of "depredating carnivores" were associated with people-grazing animals and collecting resources from PAs. Many households (83 %) engaged in mitigation efforts. We found that only fencing and guard animals reduce crop losses, and no efforts to lower livestock losses. Contrary to our expectations, carnivores were not viewed with more hostility than crop-raiding wildlife. Households reported greater inclination to kill herbivores destroying crops or carnivores harming people, but not carnivores preying on livestock. Our model estimated crop loss was 82 % across surveyed households (highest in Kanha), while the livestock loss experienced was 27 % (highest in Ranthambore). Our comparative study provides insights into factors associated with conflict loss and tolerance, and aids in improving ongoing conservation and compensation efforts.

Keywords Crop raiding · India · Livestock predation · Mitigation · Park · People · Tolerance · Wildlife

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Introduction

Crop damage and livestock predation by wildlife around protected areas (PAs) are a major conservation problem in many regions, and particularly in India. Crop and livestock losses, and the threat of human injury or death, may increase hostility of the affected people toward wildlife (Treves and Karanth 2003; Sillero-Zuberi et al. 2007). Local resentment is often intensified by conservation regulations that impede local citizens' capacity to cope with losses to wildlife (Dickman 2010). Such resentment may lead to retaliation against species (Gadd 2005; Treves and Naughton-Treves 2005; Linkie et al. 2007; Treves 2009). Due to high densities of people living around PAs in Asia, human–wildlife conflicts can affect many people (Nyhus and Tilson 2004; Fernando et al. 2005; Johnson et al. 2006; Spiteri and Nepal 2008). Ongoing land use change and habitat fragmentation in and around PAs are associated with more conflict incidents as many species (particularly wide-ranging large mammals such as elephants, leopards, wolves, and tigers) move well beyond boundaries of limited PAs (Sekhar 1998; Distefano 2005, Karanth et al. 2012; Athreya et al. 2013; Suryavanshi et al. 2013; Karanth et al. 2013). Developing appropriate strategies first requires assessing conflict levels and patterns, as well as factors associated with tolerance for wildlife (Karanth and Madhusudan 2002).

Despite facing loss and damage to property and lives, cultural and religious practices in India have been associated with high tolerance, meaning low rates of lethal defense strategies (Mishra et al. 2003; Rangarajan 2001; Ogra and Badola 2008; Dickman 2010). Such tolerance for species has played a role in the persistence of some large mammals in some parts of India (Karanth et al. 2010). Evidence of tolerance includes reverence, and consequently protection for monkeys; some ungulates such as *Boselaphus tragocamelus* (Nilgai) and *Gazella bennettii* (Chinkara, Rangarajan 2001); and *Uncia uncia* (snow leopards, Mishra et al. 2003) despite crop and livestock losses. Tolerance is not universal, and in some instances, people kill *Elephas maximus* (elephants) and ungulates (Karanth and Madhusudan 2002; Bagchi et al. 2004), *Canis lupus* (Tibetan wolf, Mishra et al. 2003), *Panthera tigris* (tigers), and *Panthera pardus* (leopards, Treves and Karanth 2003). Nonetheless, compared with other Asian countries, tolerance for wildlife in India is generally high (Athreya et al. Athreya et al. 2010, 2013; Karanth et al. 2012, 2013; Karanth and Nepal 2012). Wildlife survival outside park boundaries may be encouraging to biologists concerned about species isolation, particularly in India where habitat has been greatly reduced. But, even though local communities may tolerate wildlife, they may suffer food insecurity, opportunity costs (e.g., time lost to guarding crops and livestock), and even "diminished psychosocial wellbeing" due to human–wildlife conflict (Barua et al. 2013).

In this article, we examined factors associated with human–wildlife conflict losses and attitudes toward wildlife of households living outside Ranthambore, Kanha, and Nagarahole National Parks, three important PAs in northern, central, and southern India. Indian PAs are surrounded by high densities of people who commonly graze livestock and collect forest resources from inside the PA (Madhusudan 2003; DeFries et al. 2010; Karanth and DeFries 2010; Karanth et al. 2013). Most PAs are not fenced, and people, livestock, and wildlife move across PA boundaries. Attempts by park management to impose restrictions have been met with resistance from local people (Karanth and Nepal 2012). Although in India PAs classified as National Parks do not legally permit any human resource collection, grazing, and other related activities, the laws are difficult to enforce, and illicit resource use within parks is widespread.

Here we define "conflict" as reported incidents of crop raiding and livestock predation, and "loss" as the likelihood an individual household reported crop raiding or livestock predation in the last year (Hill 2004; Sitati et al. 2005; Wang and Macdonald 2006; Spiteri and Nepal 2008). We define "tolerance" as a household opting not to kill wildlife under hypothetical scenarios of crop damage, injury, or killing of livestock or people. By comparing households in three PAs that differ ecologically, socio-economically, and culturally, we identify general and PA-specific factors that influence conflict loss, tolerance for these incidents, and effectiveness of mitigation measures.

Ecologically, the three PAs differ in vegetation characteristics (dry scrub in Ranthambore to moist deciduous forests in Nagarahole), size (Ranthambore is half the size of Nagarahole, and one third the size of Kanha), rainfall (in Ranthambore it is significantly lower than in Kanha and Nagarahole), and the zones of interaction with the surrounding landscape (DeFries et al. 2010). Human population densities range from 67 to 242 people/km^2. Most people cultivate crops and/or raise livestock (>60 %), but they differ in land ownership and caste diversity (Karanth and Nepal 2012). Known cultural and religious practices lead us to expect differences in tolerance across PAs with the lowest tolerance in southernmost Nagarahole due to a tradition of hunting and eating wildlife, and tolerance increasing northward toward Ranthambore where people are largely vegetarian and attach religious–cultural value to protecting some species (Karanth and Madhusudan 2002; Karanth et al. 2010; Chhangani et al. 2010; Velho et al. 2012).

In this study, we first compared reported patterns of conflict with key physical variables and land use practices identified in previous studies. Specifically, we examined variations between the three PAs at varying distances from each PA (proximity to the PA is associated with conflict frequency or intensity related to wildlife densities). We recorded household activities including where livestock are grazed, total number of crops planted per year, size of farms, and use of protection measures (e.g., fencing, night guards). Finally, we explored influence of indirect factors including form of land ownership and years of farming experience. We then examined the variations in people's tolerance and attitudes toward carnivores and herbivores.

We expected the most crop damage to wildlife in households that are close to PAs, have more abundant crops and livestock, and use fewer protection measures to experience more wildlife damage (Treves 2009). Less frequent losses were expected for households having more years of farming experience, and larger landholdings. We expected people to be less tolerant to carnivores than herbivores based on fear and/or the higher cost of losing livestock than crops (Treves and Naughton-Treves 2005). Yet, we also anticipated patterns of tolerance to play out differently across the three PAs due to cultural or religious factors (Kleiven et al. 2004; Treves 2006).

Methods

Study Sites

Ranthambore, Kanha, and Nagarahole National Parks (Fig. 1, RNP, KNP, and NNP from here onward) are located in diverse ecological and socioeconomic settings, and harbor many threatened species such as tigers, leopards, *Cuon alpinus* (wild dogs), elephants, and *Bos gaurus* (gaur), Table 1, 2). All the three were designated National Parks in 1955 and as Project Tiger Reserves in the 1970s, designations intended to spur stricter protection and attract higher levels of funding and public interest (Karanth and DeFries 2010). All three PAs attract tourists and have experienced an explosion of tourism and tourist facilities (DeFries et al. 2010; Karanth and DeFries 2011).

All three PAs are typical of many Indian PAs, surrounded by high-density human settlements and anthropogenic land use particularly cultivation and pastoralism (DeFries et al. 2010; Karanth et al. 2013). These PAs are not fenced, and therefore, people and livestock move freely in and out of the PAs (after the study period, park authorities attempted to fence certain sections of Kanha, Karanth, pers. obs., 2009). Ranthambore is located in an arid landscape within a mosaic of scrub and agriculture fields with little tree cover. Degraded forest patches interspersed among agricultural fields surround Kanha. Nagarahole is surrounded by coffee plantations and irrigated agriculture, with households growing crops up to 9 months a year. All PAs have limited habitat connectivity, with Kanha perhaps the least isolated (DeFries et al. 2010). The majority (81 %) of local residents depend at least partly on the PAs for natural resources (wood, plant parts, and nontimber forest products), and many graze their livestock inside the PAs (Karanth and Nepal 2012). Typically, livestock are herded into the PAs by a few people who may take responsibility for managing livestock belonging to several families. The average herd size was four animals/households comprising mainly not only cattle but also buffalos, sheep, and goats. They are left to graze and herded back to the villages at night (Karanth, pers. obs., 2009, 2011). Herding and grazing occur during the day (Karanth, pers obs., 2009, 2011; Karanth and Nepal 2012).

The compensation mechanisms in place are similar across PAs with individuals reporting losses by providing evidence to forest or revenue officials of the area where their household is located. The compensation is provided once damage (either area, numbers, and type of crops destroyed, or number and breed of livestock killed) is assessed by officials. Essentially, there are no differences in compensation amounts and policies for losses inside the PA versus outside. However, Karanth et al. (2012) found higher compensation in Kanha for households located within the legal buffer versus outside.

Social Surveys and Interviews

Structured and open-ended interviews were conducted with 398 households spread between the three PAs, and opportunistically selected from 178 villages surrounding the three PAs (Karanth et al. 2012). When we approached respondents, we explained that the purpose of the study was to understand conflict loss and compensation experienced by local people living around these PAs. Most respondents were adult men (>85 %) as women were either unavailable or reluctant to be interviewed. We visited villages at various distances around each PA (ranging from 0.01 to 10.50 km), choosing 10 km as an upper estimate within which most conflicts occur (Karnataka, Madhya Pradesh, and Rajasthan Forest Department 2009; Shukla, pers comm., 2009). Survey questions asked respondents about household's demographic characteristics, resource use, attitudes toward wildlife, and mitigation measures (Karanth and Nepal 2012). Respondents were specifically asked to recall conflict incidents experienced by their households during the past year (2008–2009), and provide information on compensation received. Local field assistants conducted surveys during June–August 2009 in the local languages Hindi (RNP and KNP) and Kannada (NNP), and responses were translated to English. Each household's geographic location was mapped and distance to PA was calculated.

Modeling Household Risk to Crop-raiding, Livestock Predation, and Tolerance for Wildlife

To model patterns of reported crop raiding and livestock predation, we fit a priori logit models (as responses were in binary form). We identified factors associated with reported levels of crop raiding and livestock predation using model selection. Here, the focus is on assessing the model fit from an a priori set of candidate models, allowing us to identify the variables significantly associated with conflict

Fig. 1 Location of Ranthambore, Kanha, and Nagarahole National Parks in India (selected parks in black and other parks are gray)

loss based on the best fit using corrected Akaike's information criteria (AICc) as the model selection tool (Burnham and Anderson 2002; Karanth et al. 2012).

Accordingly, we fit separate models for crop loss and livestock loss, representing a different hypothesis about important factors potentially influencing a household's loss. We arrived at a candidate model set based on a priori hypotheses about the influence of individual factors (See Table 8 in Appendix). The models were ranked based on AICc values (Burnham and Anderson 2002). AICc weights (Burnham and Anderson 2002) calculated for each model represent the relative measure of appropriateness of a given model relative to the model set. In such multimodel selection problems, Burnham and Anderson (2002) recommend benchmarking against a "global model" that includes all potentially important variables of interest. The top model (based on AIC) is expected to be a model that includes a subset of these variables, which has the most

Table 1 Details on Ranthambore, Kanha, and Nagarahole National Parks in India

Characteristic	Ranthambore	Kanha	Nagarahole
Size	392 km^2	940 km^2	644 km^2
Location	25°54′–26°12′ N	22°7′–22°27′ N	11°5′–12°15′ N
	76°23′–76°39′ E	80°26′–81°3′ E	76°0′–76°15′ E
State	Rajasthan	Madhya Pradesh	Karnataka
Established	1955	1955	1955
Tourists/year	159,110 (2007–2008)	132,601 (2007–2008)	67,841 (2007–2008)
Vegetation	Dry scrub and deciduous forests	Sal and mixed deciduous forest	Dry and moist deciduous forests, teak plantations
Rainfall	800 mm	1371 mm	1500 mm
	(June–September)	(June–September)	(June–September)
Key species	Tiger, Leopard, Blackbuck, Sambar	Tiger, Leopard, Dhole, Barasingha, Sambar, Chital	Tiger, Leopard, Dhole, Elephant, Gaur, Sambar, Chital
Human population density within 10 km	128/km^2	91/km^2	681/km^2

Information is from DeFries et al. 2010, Karanth and DeFries 2011. KNP area excludes buffer

Table 2 Characteristics of surveyed households around Ranthambore, Kanha, and Nagarahole Parks

Characteristics	Ranthambore	Kanha	Nagarahole
Interviewed	98	117	186
Villages	51	49	78
Male	87 %	93 %	86 %
Age (in years)	38	43	40
Average household size (# members)	9	6	5
Born locally	92 %	91 %	80 %
Hindu	96 %	99 %	98 %
Caste groups	24	13	21
Households owning land	91 %	77 %	84 %
Agricultural crops as primary income	75 %	88 %	61 %
Average land size (acres)	6.1	4.6	4.4
Years of farming	35	40	21
Average distance to field (km) from house	1.1	1.9	1.0
Share crop (yes)	71 %	28 %	11 %
Average number of crops grown	12	13	23
Percentage of households owning livestock	32 %	27 %	27 %
Distance to park (km)	2.9 (0.0–8.1)	3.5 (0.0–9.6)	2.2 (0.0–1.4)
Crop raiding in the last year (yes)	74 %	86 %	79 %
Top crop raiders	Pig, Nilgai, Sambar	Pig, Chital	Elephant, Pig
Livestock predation in the last year (yes)	18 %	8 %	13 %
Animals lost (average)	1–3	1–5	1–5
Top predators blamed for livestock losses	Tiger, Leopard	Tiger, Leopard	Tiger, Leopard

optimal trade-off between model fit and parsimony (Burnham and Anderson 2002).

In developing our candidate model set, we removed obviously correlated variables (number of crops grown versus number of subsistence or commercial crop types) and tested for other correlations among variables by computing Pearsons' correlation coefficients. High correlation (>0.5) resulted in removal of three correlated variables (household practicing cultivation, land ownership, and subsistence versus commercial cultivation). We scaled the regression inputs by dividing by two standard deviations, as suggested by (Gelman 2008), to permit direct comparison of estimated coefficient values. We used the AICc to select the best models to assess model fit (Karanth et al.

2012, 2013). For closely competing models (ΔAIC < 2), we applied model-averaging procedures for parameter estimation, while simultaneously accounting for a large part of multicollinearity (Freckelton 2011). Chi-squared tests of significance were used to test for differences among households across PAs.

We modeled household crop loss as a function of environmental factors (distance to PA edge and PA itself), household resource practices (use of fuel wood, water, and grazing inside the PA), socioeconomic and agricultural factors (number of harvests, number of crops and cropping months, farming experience, land area etc.), and mitigation factors (lighting, fencing, guard animals etc., See Table 8 in Appendix). Similarly, we modeled household risk to livestock predation as a function of multiple factors (See Table 8 in Appendix). For the global "crop loss" model we selected 23 variables and constructed 20 models. For the global "livestock loss" model, we selected 26 variables and constructed 21 models for livestock loss representing our hypotheses. We calculated the weighted average of these individual model estimates to generate overall estimates for probabilities of crop and livestock loss for individual households and around each PA.

To examine and compare tolerance and attitudes toward carnivores and herbivores, we presented households with hypothetical conflict situations and response scenarios, and asked them to select their preferred scenario based on Manfredo et al. (1998). The conflict situations refer to an animal coming outside the PA, damaging crop or property, injuring or killing livestock, and injuring or killing humans. Response scenarios include taking no action, capturing, and relocating animal, frightening or deterring animal, and killing the animal.

Results

Crop Raiding, Compensation, and Modeling Household Loss

About 80 % of households across all PAs reported crop damage in the previous year, ranging from 74 % in RNP to 86 % in KNP ($n = 398$). Wildlife named by respondents included eight herbivores, eight carnivores, monkeys (macaques and langurs), and peacocks (Fig. 2; see Table 2 for details). Wild pigs were reported to be the most frequent raiders across all three PAs. In all PAs, 96 % percent of households reported no injury or death due to confrontations with wildlife and 99 % of households did not report killing problem animals.

In RNP and KNP households experiencing crop damage was reported highest during the months of September to December. In NNP crop damage was experienced year round, but highest from May to August. In terms of intensity, more NNP households reported losing their entire crop to raiding by wildlife (partly attributable to elephants only found in NNP). Average reported per household annual loss of income from crop loss was US $155 in KNP, US $264 in RNP and US $546 in NNP (1 US$ = 52 Indian Rupees, these losses are significant particularly in areas where annual household incomes averaged for households we surveyed $300), but these estimates have to be verified with official records. Most households (89 %) reported that they did not receive any compensation from authorities for crop losses, but reporting efficacy varies by species. In another study, in the Western Ghats, households were more likely to report elephants compared to other species (Karanth et al. 2013). Overall, the majority of respondents

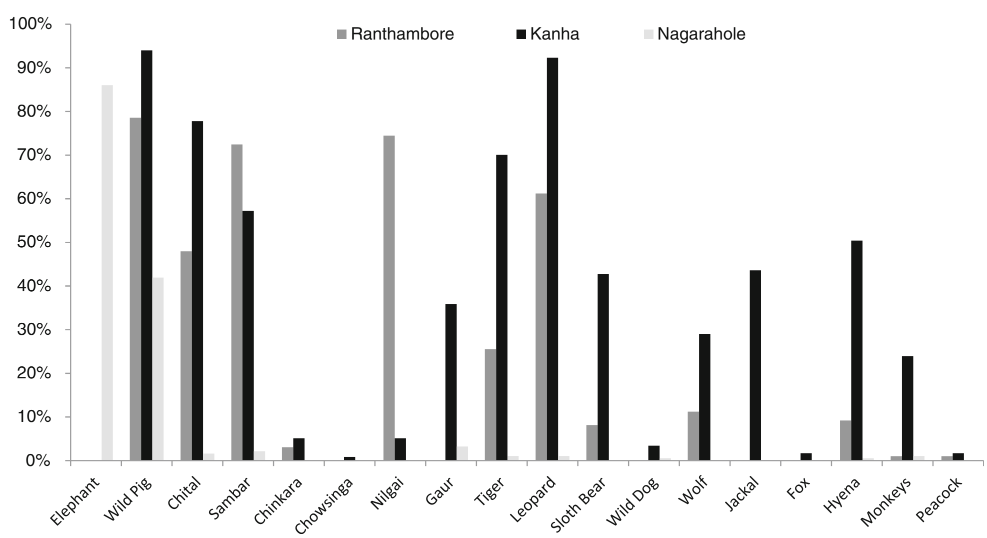

Fig. 2 Reported wildlife species in conflict with households in Ranthambore, Kanha, and Nagarahole National Parks in India

Table 3 Best models and beta coefficients for predicting crop loss around Ranthambore, Kanha, and Nagarahole National Parks

	Crop loss				
Models	8	4	16	6	3
	$w_i = 0.64$	$w_i = 0.18$	$w_i = 0.07$	$w_i = 0.05$	$w_i = 0.03$
Intercept	8.20	6.73	6.69	6.28	6.76
	(1.71)	(1.10)	(1.13)	(1.02)	(1.12)
Distance to park	_	_	_	_	−0.01
					(0.75)
Number of harvests	2.29	1.88	1.91	1.42	1.87
	(1.25)	(1.01)	(1.03)	(0.93)	(1.01)
Land area	_	_	_	_	0.58
					(1.16)
Share crop	2.37	2.36	2.34	_	2.31
	(1.39)	(1.28)	(1.29)		(1.26)
Number of crops per year	4.90	3.27	3.29	3.02	3.21
	(1.53)	(1.07)	(1.07)	(0.99)	(1.10)
Cropping months per year	15.23	13.02	12.90	12.77	13.07
	(3.33)	(2.11)	(2.28)	(2.00)	(2.13)
Fencing	−1.60	_	_	_	_
	(0.97)				
Night watching	0.55	_	_	_	_
	(0.92)				
Guard animals	−1.98	_	_	_	_
	(1.79)				
Lighting	3.26	_	_	_	_
	(1.44)				
Any of the mitigation measure	_	_	0.12	_	_
			(0.84)		
Model AICc	66.64	69.18	71.22	71.68	73.07
ΔAICc	0	2.54	4.59	5.04	6.42

said they had reported crop damage to authorities (80 %), and those receiving compensation were paid US $96 on average (range $45–454).

In modeling factors associated with household risk to crop raiding, we found three top-ranked models with substantial weights (Table 3). As predicted, factors related to forage availability for wildlife- the number of harvests per year, share cropping (growing crops on someone else's land), number of crops per year and cropping months in a year all increased risk (positive β coefficients in Table 3). Although four mitigation factors appeared in the top-ranked model only two (fencing and guard animals) appeared to decrease risk (negative β coefficients in Table 3). We suspect the positive correlation to night watching and lighting is due to these mitigation measures being in place as result of households experiencing past incidents of conflict. For crop loss, the strongest predictor variables were the number of cropping months, number of crops and number of harvests (Table 3). The number of cropping months was five times as influential as variety of crops, and seven times as influential as number of harvests and share cropping (Table 3). Importantly, we found that the individual PA and distance to PA area were not significant in all three PAs. This may suggest crop raiders may not be limited to animals coming out from the PA, and perhaps some raiders may naturally reside outside the PAs.

We estimated probabilities of crop loss for each household and compared across these PAs. We find that average estimated crop loss across all households within 10 km of these reserves was 0.76 in Ranthambore to 0.86 in Kanha, and these estimated probabilities are similar to reported losses (Table 5).

Livestock Predation, Compensation, and Modeling Household Loss

Livestock ownership did not vary across the PAs, with most common animals being cattle, sheep and goats (Table 2). Livestock losses were reported by 13 % of households, ranging from 8 % in RNP to 18 % in KNP. Animals blamed for livestock loss included tiger, leopard, *Hyaena hyaena* (Hyena), dhole (*Cuon alpinus*), *Canis*

Table 4 Best models and beta coefficients for predicting livestock loss around Ranthambore, Kanha, and Nagarahole National Parks

Models	Livestock loss					
	13	9	10	2	4	16
	$w_i = 0.60$	$w_i = 0.23$	$w_i = 0.07$	$w_i = 0.02$	$w_i = 0.02$	$w_i = 0.02$
Intercept	−2.17	−2.16	−2.18	−2.05	−2.06	−2.04
	(0.18)	(0.18)	(0.18)	(0.16)	(0.17)	(0.16)
Distance to park	_	0.12	0.15	0.24	_	_
		(0.33)	(0.33)	(0.31)		
Park-Nagarahole	0.85	0.82	0.71	_	_	_
	(0.96)	(0.97)	(0.97)			
Park-Ranthambore	1.76	1.76	1.82	_	_	_
	(0.90)	(0.90)	(0.92)			
Park-Kanha	0.32	0.35	0.36	_	_	_
	(0.85)	(0.85)	(0.85)			
Wood collected from park	_	_	0.03	_	−0.42	_
			(0.37)		(0.34)	
Water collected from park	_	_	0.81	_	0.68	_
			(0.61)		(0.57)	
Graze livestock in park	1.85	1.84	1.91	1.50	1.64	1.54
	(0.40)	(0.40)	(0.41)	(0.36)	(0.37)	(0.36)
Any mitigation measure	_	_	_	_	_	0.04
						(0.39)
Model AICc	283.04	284.99	287.31	289.70	290.08	290.29
ΔAICc	0	1.94	4.27	6.65	7.04	7.24

aureus (jackal), Mongoose species, *Viverricula indica (civet)*, *Sus scrofa* (wild pig), and *Macaca mulata* and *radiata* (macaques). Leopards were identified as the most damaging species in all PAs. The majority of households (99 %) reported not receiving any compensation from authorities for losses. The compensation mechanisms in place are similar across PAs with individuals reporting losses by providing evidence to forest or revenue officials. Very few of the households reporting losses (less than 1 %) reported about having received any compensation (average $ 87/household for households receiving compensation).

Six top-ranked models of factors associated with reported household livestock loss (Table 4) indicate that as predicted, factors such as grazing, collecting water from the PA, and the individual PA increased household risk (positive β coefficients in Table 4). Although distance to PA and collecting water and wood from the PA appeared in the top models, these factors were insignificant as evidenced by the high standard errors of the β coefficients. Other socioeconomic, demographic, and mitigation factors were not significant. The strongest predictor variable in all models was grazing domestic animals inside the PAs (Table 4). Households in RNP are apparently twice as vulnerable to livestock predation compared with KNP, and five times as vulnerable compared with NNP households (Table 4). This is because RNP households perhaps, have fewer choices of grazing areas outside the PA compared with KNP and NNP. Our results indicate that households' decision to enter the PA to graze and collect forest resources varies across the PAs.

Table 5 Estimated probabilities of crop and livestock losses for 398 households surveyed around three parks in India

Type		RNP	KNP	NNP
Crop loss	Average	0.76	0.86	0.81
	Range	0.0002–1	0.0001–1	0.0002–1
Livestock loss	Average	0.38	0.16	0.27
	Range	0.35–0.79	0.13–0.49	0.19–0.65

We modeled estimated probabilities of livestock loss for each household and compared across PAs. We find average estimated loss across all households within 10 km of these reserves ranged between 0.16 in Kanha to 0.38 in Ranthambore, which are higher than directly reported losses (Table 5).

Resident Tolerance of Crop Raiders and Livestock Predators

Households were presented with hypothetical scenarios about carnivores' and herbivores' behaviors and asked to choose among a range of actions based on Manfredo et al.

Table 6 Comparison of respondents' attitudes toward hypothetical scenarios for carnivores and herbivores, and potential action to be taken (1–4) in Ranthambore, Kanha, and Nagarahole National Parks

Hypothetical Scenario	Carnivore				Herbivore			
	RNP	KNP	NNP	Chi squared Test	RNP	KNP	NNP	Chi Squared Test
Comes outside park	3 (57 %)	1 (71 %)	1 (41 %)	$\chi^2 = 88.92$	3 (70 %)	1 (95 %)	3 (40 %)	$\chi^2 = 174.75$
Damages crops or property	3 (66 %)	2 (34 %)	3 (65 %)	$\chi^2 = 70.57$	3 (71 %)	2 (40 %)	4 (35 %)	$\chi^2 = 75.84$
Injures or kills domestic animals	3 (44 %)	3 (37 %)	3 (57 %)	$\chi^2 = 65.82$	3 (47 %)	3 (35 %)	1 (36 %)	$\chi^2 = 120.51$
Injures or kills humans	3 (55 %)	4 (85 %)	2 (40 %)	$\chi^2 = 40.04$	3 (61 %)	4 (92 %)	3 (34 %)	$\chi^2 = 152.69$

The most preferred option is stated under the park name and differences among parks tested using Chi squared tests ($P < 0.0001$ in all cases)

1 Take no action and monitor situation, *2* Capture and relocate animal, *3* Frighten or deter animal, *4* Kill the animal

(1998). The behaviors include an animal coming outside the PA, damaging crop or property, injuring or killing livestock, and injuring or killing humans. Potential action choices provided include taking no action, capturing and relocating animal, frightening or deterring animal, and killing the animal. Contrary to our expectations, carnivores were not viewed with more hostility than herbivores. Instead, respondents reported greater inclination to kill an herbivore (Table 6). Residents of KNP were also significantly more likely to favor killing wildlife, unexpected—given that KNP has the lowest reported livestock losses to wildlife (8 %, Table 2). Across the three PAs, we found that RNP households preferred to frighten or deter both carnivores and herbivores irrespective of the situation and conflict experience (Table 6) despite the largest number of households (18 %) experiencing livestock predation (Table 2). For KNP households, we found the expected pattern of decreasing tolerance as the severity of the problem increased, with injury or loss of human life being the least acceptable (Table 6). In NNP, households preferred to frighten or deter animals or take no action.

Mitigation Measures

Households were questioned about practices followed to protect their property, domestic animals, and lives. The majority (83 %) of households reported taking measures, most commonly adding or improving night watching (66 %), fencing (61 %), enclosed structures (51 %), and lighting (49 %, Table 7). The only protection mechanism that did not vary across PAs was fencing, which was lower for all three PAs possibly because of high costs of building and maintenance (Table 7). Our analysis suggests that across all PAs, despite the use of many mitigation measures, only fencing and guarding animals appear to be effective in lowering losses.

Discussion

Logistic models indicate unsurprisingly that crop loss is associated with factors related to forage availability (a greater diversity of crops available for longer periods increase the risk of crop raiding). Importantly, the percentage of household reporting crop loss did not vary markedly across PAs (Table 5). We find that regardless of ecological or geographic attributes households universally perceive high losses. Our models suggest that only fencing and guard animals lowered crop loss similar to Sitati et al. (2005) and Linkie et al. (2007), and other mitigation factors had little effect. The fact that distance to PA showed no significant association with reported conflict across a 10-km survey region suggests that crop raiders may not be coming entirely from the PAs alone and may be residing outside park boundaries. Although respondents tended to blame parks as "sources", at least some wildlife might be foraging entirely outside the PAs. Therefore, compensating people for losses becomes particularly challenging in areas where wildlife naturally occurs outside PAs, and losses may not be attributable to wildlife from the PAs (Naughton et al. 2003; Bulte and Rondeau 2005). Other studies from India (Athreya et al. 2013; Banerjee et al. 2013; Karanth et al. 2012, 2013; Suryavanshi et al. 2013) report similar results making it imperative for the government to enact policies that are effective and efficient to ensure wildlife in India are able to persist outside PAs as well.

In contrast, livestock loss was more sensitive to individual practices, such as grazing animals inside the PA, which are often carried out in parallel with collecting fuel wood and water (Karanth and Nepal 2012, Karanth et al. 2012). Respondents reported that livestock losses occurred inside the PAs during the day, and fewer incidents occurred at night when the livestock were corralled near their homes or villages. PA differences also emerged with RNP households reporting

Table 7 Comparison of protection mechanisms and mitigation measures used by households around Ranthambore, Kanha, and Nagarahole National Parks

Protection/mitigation measures	RNP (%)	KNP (%)	NNP (%)	All parks (%)	Chi squared test
Added or improved fencing	69	58	59	61	$\chi^2 = 3.45$, $P = 0.17$
Added or improved night watching	74	87	47	66	$\chi^2 = 55.42$, $P < 0.0001$
Added or improved physical structures	70	86	19	51	$\chi^2 = 150.28$, $P < 0.0001$
Added or improved use of guard animals (e.g., dogs)	36	26	6	19	$\chi^2 = 40.50$, $P < 0.0001$
Added or improved lighting	63	69	28	49	$\chi^2 = 58.25$, $P < 0.0001$
Added or improved scare devices	54	34	40	42	$\chi^2 = 9.19$, $P < 0.01$
Added or improved removal of waste or dead animals	40	66	1	30	$\chi^2 = 153.21$, $P < 0.0001$
Added or improved removal of brush or forest	24	6	2	8	$\chi^2 = 44.12$, $P < 0.0001$
Changed breeds or types of animals owned or managed	15	14	1	8	$\chi^2 = 25.69$, $P < 0.0001$
Started allowing hunters on land	4	5	1	3	$\chi^2 = 6.53$, $P = 0.03$
Started keeping a closer eye on animals	70	87	2	43	$\chi^2 = 252.50$, $P < 0.0001$
Stopped or reduced allowing hunters on land	65	82	1	40	$\chi^2 = 232.63$, $P < 0.0001$
Stopped or reduced feeding other wild animals	67	85	1	41	$\chi^2 = 245.17$, $P < 0.0001$
Stopped or reduced use of public lands with wildlife	26	6	1	8	$\chi^2 = 53.76$, $P < 0.0001$

the highest losses. Livestock losses could be reduced if grazing in PAs were avoided, but this simple finding is realistically hard to manage or enforce around Indian PAs. This is particularly so in RNP and NNP where grazing areas outside are limited compared with KNP, and there is some evidence to suggest that households are increasing stall-feeding (Karanth et al. 2012). In the absence of alternate grazing areas, households in closer proximity to the PAs are likely to graze and collect resources inside (particularly in RNP). We also find that mitigation factors other than fencing and guarding animals did not decrease livestock loss, a finding similar to that in Kolowski and Holekamp (2006). These findings are important particularly when increasing conservation attention and monies are being invested in mitigation practices worldwide, and highlight the need to carefully identify mitigation practices that actually work. These results mirror findings from parallel studies in Central and Southern India (Karanth et al. 2012, 2013), suggesting widespread policy changes might be needed in the system.

The near absence of compensation reported by respondents' accords with other Asian countries, where compensation is low or nonexistent, and losses reported were high relative to annual household income. This potentially presents a challenge to maintaining tolerance for wildlife (Wang and Macdonald 2006; Spiteri and Nepal 2008; Karanth and Nepal 2012). However, there is an urgent need to corroborate losses reported by local residents to official records to identify gaps and improve compensation distribution to households reporting losses. India's current compensation policy is oriented more toward alleviating economic hardship (versus discouraging retaliation against endangered species) (Agarwala et al. 2010; Karanth et al. 2012, 2013). At one level, our study suggests that this policy is on target given that so few respondents reported a wish to kill wildlife raiding crops or hunting livestock. However, given that some respondents may have been reluctant to express this action and in light of the large area and great number of people reporting complaints, any initiative to expand compensation payments will have to be carefully designed and communicated. In developed and developing countries alike, offers of compensation have been associated with higher level of complaint (Naughton et al. 2003; Bulte and Rondeau 2005). Compensation schemes in place in these parks and those elsewhere in India (Karanth et al. 2012, 2013) might have to be revisited and restructured to be made more efficient and targeted toward species of focus.

Four percent of the surveyed households reported that an individual was injured or killed in confrontations with wildlife, and 99 % of households reported they did not kill problem animals. Tolerance for carnivores does not vary significantly across PAs, whereas it does for herbivores, namely KNP households appeared more likely to favor killing problem species of herbivores compared with RNP and NNP. Presented with hypothetical scenarios, households chose to take lethal action against herbivores destroying crops and carnivores harming people. For most scenarios, frightening and deterring animals was the most popular choice, although some respondents might have been reluctant to report their approval for killing animals in light of conservation rules. Our findings are in contrast to other studies that have found respondents more inclined to support lethal control against "problem" carnivores (Knight 2000; Ericsson and Heberlein 2003; Kleiven et al. 2004; Kaltenborn et al. 2006; Holmern et al. 2007).

Our results shed light on the similarities and differences across PAs in India with regard to human–wildlife conflict incidents, and experiences with compensation and mitigation. High densities of people live in close proximity to wildlife, and historically have tolerated some species (Karanth et al. 2010). We find similar crop loss patterns across all PAs attributable to forage availability due to agricultural characteristics, and did not show clear evidence of wildlife coming only from the PAs. In contrast, livestock predation varied markedly by PA, individual household practices and management strategies. Our findings suggest that improving mitigation factors such as fencing and guarding might reduce crop loss, and simply grazing animals outside the PAs might reduce livestock loss. These results are common across all three PAs, although identifying specific mitigation strategies needs to be based on the individual species and practices in each PA. Improving crop protection is perhaps simpler in contrast to enforcing grazing regulations, where the availability of free forage will continue to attract grazing inside PAs despite the high risk of livestock loss.

Potential limitations of our study include possible bias in reported losses, and largely male respondents being accessible to us. Although we have no reason to think there was systematic bias across all three PAs. Our results are corroborated by studies in central India (Karanth et al. 2012) and southern India (Karanth et al. 2013). Our survey radius of 10 km and the number of households exceed those for most field-driven human–wildlife conflict surveys. Yet, our respondents' reports suggest that we could have sampled further from the PAs. These findings have to be corroborated by linking official compensation records to those reported by households, and followed by systematic monitoring of conflict and compensation processes as they occur. We find that despite significant losses and poor compensation, some tolerance for losses to wildlife in India still exists, although it varies by PA and species.

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Appendix

See Table 8.

Table 8 Covariates and a priori predictions about their influence on household risk to crop-raiding and livestock predation in Ranthambore, Kanha, and Nagarahole National Parks

Covariate category	Variable	Crop-raiding	Livestock predation
Park	a. Park (pa)	NNP > KNP > RNP	RNP > KNP > NNP
	b. Distance to park (dpa)	Decreases	Decreases
Park resources	a. Wood from park (wdpa)	Increases	Increases
	b. Water from park (wtrpa)	Increases	Increases
	c. Graze in park (grpa)	Increases	Increases
Agriculture	a. Number of crops (cp)	Increases	NA
	b. Number of harvests (harv)	Increases	NA
	c. Cropping months (crmn)	Increases	Increases
	d. Share crop (scrop)	Increases	Increases
Household	a. Land area (larea)	Increases	NA
	b. Years farming (yrfm)	Decreases	Decreases
	c. Drought experience (dht)	Increases	Increases
	d. Total people in house (hht)	Decreases	Decreases
Mitigation factors	a. Fencing (ma)	Decreases	Decreases
	b. Night watching (mb)	Decreases	Decreases
	c. Birthing structure (mc)	NA	Decreases
	d. Guard animals (md)	Decreases	Decreases
	e. Lighting (me)	Decreases	Decreases
	f. Removal of waste or dead animals (mf)	Decreases	Decreases
	g. Removal of brush (mg)	Decreases	Decreases
	h. Changing breeds (mh)	NA	Decreases
	i. Allowing hunting (mi)	Decreases	Decreases
	j. Closer eye on animals (mj)	Decreases	Decreases
	k. Stopping hunting (mk)	Decreases	Decreases
	l. Stopping feeding wildlife (ml)	Decreases	Decreases
	m. Stopping use of public land (mm)	NA	Decreases

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