4 Species and sites matter

Understanding human–wildlife interactions from 5,000 surveys in India

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Introduction

Understanding and managing human–wildlife interactions remains a global conservation priority. Most often, the interactions that emerge from the literature focus on negative interactions such as crop damage, livestock loss, property damage, human injury and death (Treves and Karanth 2003; Graham *et al.* 2005; Madden 2004; Lagendijk and Gusset 2008; Dickman 2010; Kansky and Knight 2014). Little effort is exerted towards documenting neutral or positive interactions between people and wildlife (Peterson *et al.* 2010). Despite a vast body of literature devoted to understanding human–wildlife interactions – particularly conflict – many fundamental questions remain unanswered. At the core of these interactions is examining how different species influence people's perceptions, attitudes, reporting of conflict and retaliation against species and whether these differences can enable improvements in policy, compensation and mitigation efforts (Bagchi and Mishra 2006; Barlow *et al.* 2010; Dickman 2010; Karanth and Kudalkar 2017).

In our multi-site, multi-species evaluation and comparison of conflict across India, we adopt an approach that focuses on understanding conflict from a species perspective. Specifically, we examine crop and livestock loss reported by households to understand differences at the species and site level. We might expect some herbivore species to exhibit different preferences for specific crops and carnivore species to exhibit different preferences for livestock (such as elephants versus pigs or deer, felids versus canids). We also expect differences in loss experienced to be a function of environmental and landscape-level factors at local site level that influence species differently (Michalski *et al.* 2006; Karanth *et al.* 2013b). Lastly, we are interested in examining if mitigation measures used by people have an effect on conflict. Although conflict is often localised, we are interested in discerning commonalities among groups of species (for example canids or felids) that might help target mitigation efforts (White and Ward 2010). Our large database (over 5,000 surveys) combined with incidents attributed to 12 species (across 11 study sites) in India allows to explore these questions in a systematic and robust manner. Our efforts will help disentangle the multiple dimensions of human–wildlife interactions, especially with respect to developing targeted species programmes. This is much needed in a country where 81,000 conflict incidents were reported and compensated for in one year, and there exist wide variations in how species are covered by states (Karanth and Kudalkar 2017).

Methods

Study sites

We selected 11 sites around wildlife reserves across four states in India – Rajasthan, Madhya Pradesh, Maharashtra and Karnataka. Four sites are situated in the Aravalis of northwest India, two of them in central Indian forests and five sites lie in the Western Ghats of southwest India (Figure 4.1). The four sites in the Aravalis were Jaisamand, Kumbalgarh, Phulwari-ki-nal and Sitamata. In central India, the sites were Tadoba and Kanha. The five sites in the Western Ghats were Anshi-Dandeli, Bhadra, Biligiri Rangaswamy Temple (BRT), Bandipur and Nagarahole. The total surveyed area covered 16,488 km^2, ranging from 622 km^2 around Jaisamand to 3,084 km^2 around Kumbhalgarh (Table 4.1).

The sites cover a range of vegetation types including thorny scrub, dry deciduous, moist deciduous, semi-evergreen and evergreen. These reserves support significant mammalian diversity, including threatened species such as tiger, leopard, wolf, hyena, dhole, sloth bear, elephant, gaur, sambar, chital, chinkara and nilgai. Annual rainfall ranges from 425 mm in Kumbhalgarh to 4,000 mm in Anshi-Dandeli and elevation varies from 3 m in Dandeli-Anshi to 1,587 m in Bhadra (30 m DEM; Table 4.1). Human population density varies from 94 people/km^2 around Tadoba-Andhari to 443 people/km^2 around Nagarahole and

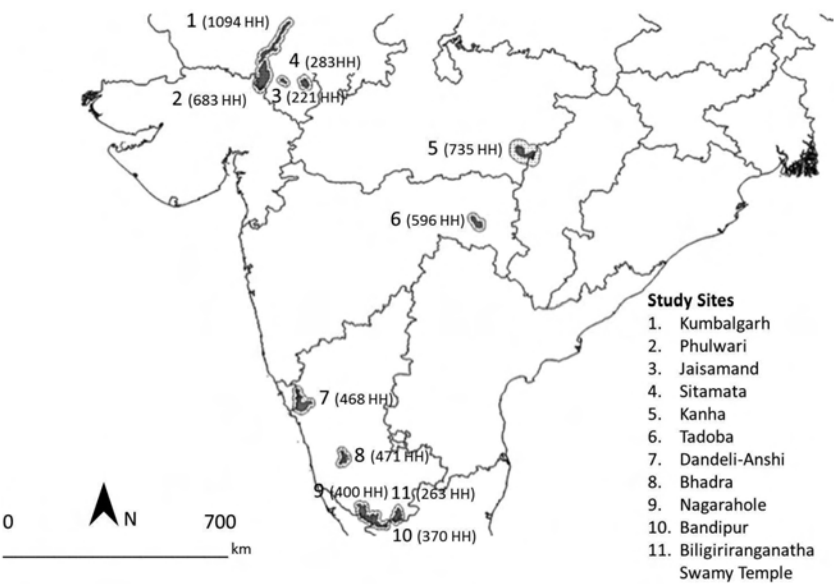

Figure 4.1 Location of study sites in India

Bandipur (Census of India 2011; Table 4.1). Livestock population densities range between 69 heads/km^2 around Tadoba-Andhari to 445 heads/km^2 around Dandeli-Anshi (Livestock Census of India 2007; Table 4.1). Other site characteristics are in Table 4.1.

Survey design and field data collection

We surveyed 5,154 households across 11 sites between 2011 and 2014 (Table 4.1). Human research ethics protocols approved by Columbia University, USA, Duke University, USA and the Centre for Wildlife Studies, India were followed in all questionnaire surveys. Across all sites a total of 3,074 villages were selected within a 10 km buffer of each reserve. A total of 1,286 grids of size 13 km^2 were surveyed, and about 60 per cent of the villages within each cell were randomly selected (Karanth *et al.* 2012, 2013b, Table 4.1). In each grid cell, between one to ten households were opportunistically surveyed. In villages where we conducted more than one survey, we ensured that households surveyed were located as far away from each other as possible. Teams of trained volunteers and research assistants conducted the surveys in Hindi, Kannada and Marathi, and all surveys were later transcribed into English.

In each household we interviewed both adult female and male respondents, and in our sample about 60 per cent of surveyed individuals were men. Common to all sites were questions on demographic and socio-economic characteristics, nature and type of conflict, species involved, agricultural and livestock characteristics, and mitigation measures employed by households. Additionally, spatial variables such as distance to protected area, distance to water body, distance to forest cover, percentage forest cover within a 3 km buffer and percentage of grassland/scrub within a 3 km buffer were extracted for each surveyed household (Karanth *et al.* 2012, 2013a, 2013b).

Variable and model selection

Each interviewed household reported experiencing crop loss and/or livestock loss in the most recent year, and we recorded all species reported by people. If a species was reported by at least 30 households of a particular site, that site was selected as a subset for that particular species (to ensure minimum sample sizes were met). Reports of incidents with bonnet macaque, rhesus macaque and hanuman langur were grouped together as 'primate conflict', as many surveyed households were unable to distinguish the three species, and reported them as 'monkey' incidents. Canids (desert fox *Vulpes vulpes pusilla*, Indian fox *Vulpes bengalensis*, jackal *Canis aureus* and wolf *Canis lupus*) were often misidentified, and for our analysis we grouped these species together as canids. Canids were reported by people for causing both crop damage and livestock predation. We have separately looked at canids (CR) – jackal or fox reported against crop loss – and canids (LP) – jackal, fox or wolf reported against livestock loss. For damage, the 12 responses that we modelled were incidents attributed to chinkara *Gazella bennetti*, chital *Axis axis*, elephant *Elephas maximus*, gaur *Bos gaurus*, nilgai, canid (CR), primates, pig *Sus*

Table 4.1 Site characteristics

Characteristics	*Kumbalgarh*	*Phulwari*	*Jaisalmand*	*Sitamata*	*Kanha*	*Tadoba*	*Dandeli-Anshi*	*Bhadra*	*Nagarahole*	*Bandipur*	*BRT*
Park area (km^2)	610	511	52	423	940	625	1,303	492	644	880	540
Dominant vegetation	Thorny scrub, dry deciduous forest	Thorny scrub, dry deciduous forest	Thorny scrub, dry deciduous forest	Thorny scrub, dry deciduous forest	Sal, moist deciduous, dry deciduous forest	Tropical dry deciduous forest	Tropical evergreen, semi-evergreen forests	Tropical moist deciduous, evergreen forests	Tropical moist, dry deciduous forests	Tropical moist, dry deciduous forests	Tropical dry, moist deciduous, evergreen forests
Rainfall (mm)	425–775[(b)]	600–875[(b)]	600–875[(b)]	625–900[(b)]	1,000–1,500[(c)]	975–1,375[(a)]	1,250–4,000[(d)]	2,000–2,540[(d)]	900–1,500[(d)]	625–1,250[(d)]	600–3,000[(d)]
Elevation (m)	11–1134	225–998	244–488	218–882	371–858	190–266	3–804	583–1,587	698–967	678–993	572–979
Total area surveyed in km^2	3,084	2,022	622	778	1,159	1,374	1,859	1,807	1,391	1,313	1,079
Total grids cells	290	196	50	84	218	173	245	174	119	122	119
Grid cells surveyed	238	156	48	60	97	107	143	139	107	101	83
Villages surveyed	494	350	109	143	347	187	304	316	274	262	215
Total HH surveyed	1,047	683	221	283	735	596	468	471	400	370	263
Average HH members (range)	8 (0–32)	8 (1–29)	7 (1–26)	7 (0–26)	6 (0–26)	5 (0–16)	7 (0–55)	5 (0–30)	5 (0–50)	5 (0–60)	6 (0–16)
Education <8th Grade	76%	80%	74%	82%	39%	54%	50%	63%	58%	47%	64%
Average livestock (range)	2 (0–150)	3 (0–18)	2 (0–16)	2 (0–23)	7 (0–131)	4 (0–78)	5 (0–38)	4 (0–153)	3 (0–40)	4 (0–35)	3 (0–85)
Human population density in adjoining districts (persons per km^2) ¥	Udaipur 262 Rajsamand 255 Pali 164	Udaipur 262	Udaipur 262	Udaipur 262 Chittorgarh 197	Mandla 121 Balaghat 184 Kabirdham 194	Chandrapur 94	Belgaum 356 Uttar Kannada 140	Chikmagalur 158 Devanagere 326 Shimoga 207	Kodagu 135 Mysore 443	Chamaraja-nagar 180 Mysore 443	Chamaraja-nagar 180
Livestock density in adjoining districts (total livestock per km^2)¶	Udaipur 197 Rajsamand 243 Pali 187	Udaipur 197	Udaipur 197	Udaipur 197 Chittorgarh 184	Mandla 154 Balaghat 203 Kabirdham 174	Chandrapur 69	Belgaum 445 Uttar Kannada 97	Chikmagalur 182 Devanagere 371 Shimoga 203	Kodagu 84 Mysore 337	Chamaraja-nagar 194 Mysore 337	Chamaraja-nagar 194

Sources:

¥ – Census of India 2011; ¶ – Livestock Census of India 2007
(a) – Nagendra *et al*. 2010 (Vegetation); IMD website, last five years' data (Rainfall)
(b) – Robbins *et al*. 2007 (Vegetation); IMD website, last five years' data (Rainfall)
(c) – DeFries *et al*. 2010 (Vegetation); IMD website, last five years' data (Rainfall)
(d) – Karanth *et al*. 2013b (Vegetation); IMD website, last five years' data (Rainfall)

scrofa, sambar *Boselaphus tragocamelus*, canid (LP), leopard *Panthera pardus* and tiger *Panthera tigris*.

Top mitigation measures utilised by people to protect crops, livestock and property were recorded in all sites, and also used as predictors. These included four measures common to all sites for crop loss (added or improved fencing, added or improved scare devices, added or improved lighting and use of guard animals) and one for livestock loss (closer eye on animals).

Multiple spatial attributes of each study site were extracted and used as predictors. Land use land cover maps were used (250k BHUVAN, ISRO) to extract forest and grassland/scrub habitat, and QGIS version 2.2.0 – Valmiera (Quantum GIS Development Team 2014, qgis.osgeo.org) was used to extract distances and areas. The five selected landscape-level predictors were distance to forest cover, distance to water body, distance to reserve, percentage forest cover in a 3 km radius and/or percentage scrub and/or grassland within a 3 km radius (see Karanth *et al.* 2012, 2013a, 2013b).

We also assessed number of crops grown by households reporting crop loss and number of livestock owned for those reporting livestock loss. We documented 40 major crop types across 11 sites. We grouped these into eight broad categories – cereals, millets, vegetables, legumes and pulses, large palatable crops (sugarcane and banana), cash crops with canopy cover and small cash crops. All categories except small cash crops were used as predictors.

The study site itself used a covariate. We modelled the site as a factor variable, where one of the sites is taken as a reference and the other sites are modelled relative to this reference site. This allows us to account for potential local site-based influences across such a heterogeneity of sites not accounted for by other variables.

For each species, data were subset based on previous ecological knowledge and reporting by households. For example, leopard incidents were reported in all 11 sites, and therefore the full dataset was used. In contrast, elephant conflict incidents were reported in five sites, and for our analysis we only used these sites. Each dataset was tested for multicollinearity, and predictors with a Pearson's correlation coefficient > 0.5 were discarded (Karanth *et al.* 2010; Karanth *et al.* 2012; Karanth *et al.* 2013a, 2013b). The predictors were standardised by subtracting the mean and dividing by two standard deviations to enable direct comparison of beta coefficients within models (Gelman 2008).

For each species, an *a priori* set of models were defined, ranging from five models for primate, wolf and livestock-predation related to jackal/fox to six models for all other species. These were then fit into a logistic regression (Generalised Linear Model) framework due to binary response variables. A Corrected Akaike Information Criterion (AICc) was obtained for every model (Burnham and Anderson 2002). Each set of models were ranked based on AICc weights, and the top models in each set that together explained >95 per cent of the variability were selected (Supplementary Information). The AICc framework is an information theory approach that prioritises better fit models, but penalises over-specified models, and therefore serves as an indicator of optimal trade-off between parsimony and fit. Probability estimates for each reported species causing crop loss or livestock death was obtained by model averaging.

Results

Our analysis focused on understanding conflict incidents attributed to 12 species reported by 5,154 households across 11 study sites in India. We modelled species-specific reported loss and damage as a function of the varieties of crop grown or number of livestock owned, the study site, landscape characteristics and mitigation measures employed. We obtained one to three top ranked models for each species.

Crop cultivation and loss

Surveyed households reporting crop loss were relatively high in all sites, ranging from 58 per cent in Bhadra to 80 per cent in Jaisamand (Table 4.2). The number of crop raiding incidents experienced varied between 0 to 8 annually across sites. The highest number of incidents were attributed to wild pig in five sites (Kanha, Tadoba, Dandeli-Anshi, Bhadra and BRT, Table 4.2). Elephant incidents were reported most in Nagarahole and Bandipur. Nilgai was the main crop raider in Kumbhalgarh, Jaisamand, and Sitamata while canids ranked highest in Phulwari. Average reported loss across all sites was Rs 3,269 (average ranging from Rs 6,763 in Sitamata to Rs 38,692 in Bhadra, Table 4.2).

Cultivation of cereal (rice, maize, wheat, barley) was positively associated with chital, chinkara, gaur, nilgai, pig, sambar and canid (CR) raiding incidents. There were no significant trends for elephant and primate incidents (Table 4.3). Millet cultivation did not figure in the top models for chital conflict, and there was no significant trend for primate incidents. Chinkara and gaur conflict was negatively related to millet cultivation, while elephant, nilgai, pig and sambar conflict was positively associated with millet (Table 4.3).

Cultivation of legumes and pulses (includes nine crops) was associated positively with chital, chinkara, nilgai, pig and sambar conflict, and negatively with gaur raiding incidents (Table 4.3). Legumes were raided by chital, pig, sambar, nilgai and to a lesser extent chinkara, did not figure in the top models for primate incidents, and showed no trend with respect to elephant and gaur incidents.

Vegetables showed no strong associations for most species except for households reporting canid (CR), nilgai and sambar incidents. Cultivation of areca, rubber and coffee (plantation cash crops with canopy) were positively associated with primate incidents and no significant relationship with elephant incidents. Sugarcane and/or banana (large palatable crops) showed a positive association with canid (CR) and a negative association with gaur incidents while there was no significant association with elephant and sambar incidents.

The size of agricultural landholding was positively associated with chital, elephant, gaur and sambar incidents as predicted, and negatively associated with chinkara and canid (CR) incidents. There was no significant trend observed for other species (Table 4.3).

Table 4.2 Loss and mitigation across sites

Characteristics	*Kumbalgarh*	*Phulwari*	*Jaisalmand*	*Sitamata*	*Kanha*	*Tadoba*	*Dandeli-Anshi*	*Bhadra*	*Nagarahole*	*Bandipur*	*BRT*
HH reporting crop loss	78%	64%	80%	74%	79%	72%	66%	58%	59%	74%	67%
Average crop loss in Rs	10,768 (0–1,000,000)	4,625 (0–500,000)	7,110 (0–100,000)	6,763 (0–100,000)	4,324 (0–175,000)	14,159 (0–250,000)	9,934 (0–60,000)	38,692 (0–800,000)	21,521 (0–700,000)	22,015 (0–450,000)	22,888 (0–700,000)
Number of crop raiding incidents	0–6	0–7	0–4	0–6	0–6	0–8	0–5	0–7	0–6	0–5	0–6
Top ranked crop raiders (% of HH reporting)	Nilgai 97% Pig 40% Primate 11%	Canids 59% Chinkara 55% Nilgai 28%	Nilgai 99% Jackal 22% Pig 12%	Nilgai 91% Pig 33% Chinkara 17% Canids (CR) 17%	Pig 94% Chital 32% Primate 32%	Pig 99% Chital 45% Nilgai 42%	Pig 43% Elephant 19% Gaur 12%	Pig 87% Elephant 31% Primate 25%	Elephant 45% Pig 44% Chital 4%	Elephant 80% Pig 77% Chital 6%	Pig 98% Elephant 49% Primate 10%
Top crop loss mitigation measure (% of HH reporting)	Night watching 70% Fencing 59% Lighting 55%	Scare Devices 35% Night watching 31% Fencing 21%	Night watching 72% Scare Devices 57% Lighting 40%	Night watching 66% Scare Devices 59% Lighting 48%	Night watching 62% Scare Devices 46% Fencing 21%	Night watching 51% Scare Devices 33% Fencing 33%	Night watching 55% Scare Devices 44% Fencing 44%	Scare devices 37% Night watching 35% Fencing 36%	Night watching 31% Scare devices 27% Fencing 25%	Night watching 58% Scare devices 25% Fencing 35%	Night watching 57% Scare devices 36% Fencing 27%
HH reporting livestock loss	20%	11%	9%	7%	36%	17%	13%	16%	18%	15%	9%
Average livestock loss in Rs.	2,031 (0–100,000)	1,009 (0–100,000)	1,357 (0–100,000)	663 (0–25,000)	1,078 (0–75,000)	2703 (0–200,000)	2,954 (0–75,000)	7,370 (0–500,000)	12,352 (0–1,000,000)	2,190 (0–50,000)	2,249 (0–70,000)
No. of livestock raiding incidents	0–3	0–3	0–3	0–2	0–5	0–2	0–3	0–2	0–2	0–2	0–3
Top predators (% of HH reporting)	Leopard 66% Canid 21% Wolf 20%	Canid 43% Wolf 33% Leopard 26%	Leopard 84% Canid 21%	Leopard 71% Canid 19% Wolf 10%	Canid 48% Wolf 47% Tiger 38% Leopard 31%	Tiger 67% Leopard 32% Canid 7%	Tiger 82% Leopard 28% Canid 10%	Tiger 74% Leopard 24% Canid 9%	Leopard 73% Tiger 36%	Leopard 70% Tiger 41% Canid 4%	Leopard 87% Canid 22% Tiger 13%
Top livestock loss mitigation measure (% of HH reporting)	Closer eye 23% Fencing 14% Lighting 5%	Closer eye 9% Guard animals 7% Fencing 6% Night watching 6%	Closer eye 9% Night watching 5% Lighting 2%	Closer eye 13% Fencing 5% Lighting 3%	Birthing structures 45% Closer eye 44% Night watching 19%	Closer eye 5%, Fencing 3% Night watching 2%	Closer eye 9% Removal of dead and waste animals 4% Guard animals 1%	Closer eye 9% Guard animals 5% Reduced use of public land 2%	Closer eye 9% Guard animals 4% Scare devices 3%	Closer eye 3%	Closer eye 2%

Table 4.3 Model-averaged beta estimates with standard error for wild species

Covariates	*Chital conflict*		*Chinkara conflict*			*Elephant conflict*			*Gaur conflict*		*Canid (CR) conflict*	*Nilgai conflict*	
	5 *wi* = 0.8	6 *wi* = 0.15	6 *wi* = 0.48	5 *wi* = 0.41	4 *wi* = 0.11	3 *wi* = 0.44	5 *wi* = 0.33	4 *wi* = 0.23	4 *wi* = 0.94	5 *wi* = 0.04	4 *wi* = 1	4 *wi* = 0.69	5 *wi* = 0.31
(Intercept)	–2.51 (0.18)	–2.56 (0.18)	–2.87 (0.15)	–2.88 (0.15)	–2.86 (0.15)	–1.98 (0.17)	–1.93 (0.17)	–1.91 (0.17)	–2.31 (0.27)	–2.08 (0.20)	–1.71 (0.19)	1.24 (0.19)	1.24 (0.19)
Kumbalgarh											–1.82 (0.25)	0.05 (0.21)	0.04 (0.21)
Phulwari			2.05 (0.19)	2.03 (0.20)	1.98 (0.20)						1.34 (0.22)	–2.57 (0.23)	–2.56 (0.23)
Sitamata			0.19 (0.24)	0.23 (0.24)	0.12 (0.25)						–0.74 (0.27)	–0.60 (0.25)	–0.59 (0.25)
Kanha	1.31 (0.22)	1.39 (0.22)											
Tadoba	1.72 (0.23)	1.76 (0.23)										–1.96 (0.22)	–1.98 (0.22)
Bhadra	0.54 (0.24)	0.62 (0.23)				0.18 (0.21)	0.22 (0.21)	0.14 (0.21)	–0.55 (0.30)	–0.75 (0.29)			
Nagarahole						2.42 (0.25)	2.33 (0.25)	2.30 (0.26)					
Bandipur						2.52 (0.23)	2.39 (0.24)	2.39 (0.25)	–0.43 (0.34)	–0.48 (0.33)			
BRT						1.26 (0.25)	1.13 (0.26)	1.15 (0.26)					
Scrub within 3 km			0.70 (0.13)	0.68 (0.13)	0.69 (0.13)						0.31 (0.13)	–0.59 (0.11)	–0.60 (0.11)
Forest within 3 km	0.58 (0.16)	0.65 (0.16)				0.97 (0.18)	0.94 (0.18)	0.95 (0.18)	0.64 (0.29)	0.58 (0.29)			
Distance to water			–0.29 (0.14)	–0.29 (0.14)	–0.33 (0.15)	0.50 (0.12)	0.51 (0.12)	0.48 (0.12)	0.24 (0.20)		–0.30 (0.14)	–0.25 (0.11)	–0.24 (0.11)
Distance to Protected Area	–0.29 (0.13)				–0.11 (0.14)	–0.71 (0.12)	–0.73 (0.12)	–0.72 (0.12)	–0.83 (0.21)	–0.79 (0.20)			

Agricultural landholding size	0.32 (0.11)	0.32 (0.10)		−0.26 (0.22)	−0.32 (0.23)	0.25 (0.11)		0.26 (0.11)	0.94 (0.22)	0.92 (0.21)	−0.49 (0.22)	0.12 (0.13)	0.14 (0.13)
Scare devices	0.58 (0.13)	0.63 (0.13)	0.82 (0.15)	0.88 (0.16)	0.89 (0.16)	0.91 (0.12)	0.88 (0.13)	0.87 (0.13)	1.05 (0.22)	1.00 (0.22)	0.78 (0.14)	1.18 (0.11)	1.19 (0.11)
Guard animal	0.39 (0.15)	0.41 (0.15)			0.06 (0.18)						0.58 (0.16)	0.11 (0.14)	0.13 (0.14)
Lighting	0.19 (0.15)		0.36 (0.19)	0.42 (0.19)	0.39 (0.20)	0.76 (0.17)	0.74 (0.17)	0.73 (0.17)	0.94 (0.23)	0.89 (0.22)			
Fencing				−0.17 (0.17)	−0.17 (0.17)	0.78 (0.12)	0.82 (0.12)	0.79 (0.12)	−0.24 (0.21)	−0.26 (0.21)	0.59 (0.16)	1.23 (0.11)	1.24 (0.11)
Legumes and pulses	0.65 (0.15)	0.67 (0.15)			0.23 (0.15)			−0.11 (0.21)	−0.60 (0.39)	−0.55 (0.39)		0.56 (0.12)	0.58 (0.12)
Vegetables	0.18 (0.31)			−0.35 (0.22)	−0.38 (0.22)			0.26 (0.21)	−6.72 (7.15)		0.30 (0.18)	0.34 (0.18)	
Millets			−1.04 (0.27)	−0.95 (0.27)	−0.98 (0.27)		0.30 (0.14)	0.29 (0.15)	−0.87 (0.45)	−0.86 (0.44)		0.74 (0.17)	0.77 (0.16)
Cereals	1.12 (0.18)	1.14 (0.18)	1.63 (0.59)	1.70 (0.59)	1.62 (0.59)		0.12 (0.12)	0.14 (0.12)	0.84 (0.29)	0.82 (0.29)	1.40 (0.59)	1.31 (0.18)	1.32 (0.18)
Large palatable crops							−0.18 (0.15)	−0.22 (0.15)	−0.41 (0.29)		0.99 (0.33)		
Large cash crops								0.07 (0.12)					
Closer eye on livestock													
Number of sheep or goat													
Number of cattle or buffalo													
Sheep or goat grazed on community land													
Cattle or buffalo grazed in forest													

(continued)

Table 4.3 (continued)

	Pig conflict		*Primate conflict*		*Sambar conflict*			*Canid conflict*			*Leopard conflict*		*Tiger conflict*	
	5 wi = 0.73	*4 wi = 0.27*	*6 wi = 0.62*	*5 wi = 0.34*	*5 wi = 0.5*	*6 wi = 0.41*	*4 wi = 0.09*	*1 wi = 0.44*	*5 wi = 0.43*	*4 wi = 0.1*	*5 wi = 0.87*	*4 wi = 0.11*	*5 wi = 0.85*	*4 wi = 0.15*
(Intercept)	0.25	0.25	−2.18	−2.19	−2.75	−2.64	−2.75	−1.22	−1.21	−1.22	−2.11	−2.09	−2.66	−2.70
	(0.16)	(0.16)	(0.20)	(0.21)	(0.22)	(0.21)	(0.23)	(0.15)	(0.15)	(0.15)	(0.18)	(0.20)	(0.19)	(0.20)
Bhadra	0.24	0.22	0.50	0.42									0.69	0.72
	(0.18)	(0.18)	(0.24)	(0.24)									(0.24)	(0.25)
Bandipur	1.26	1.27												
	(0.21)	(0.21)												
BRT	0.83	0.83												
	(0.23)	(0.23)												
Kanha	1.16	1.16	1.30	1.34							−1.10	−1.08	0.88	0.92
	(0.21)	(0.21)	(0.24)	(0.24)							(0.27)	(0.29)	(0.25)	(0.26)
Kumbalgarh	−1.84	−1.83	−0.37	−0.31				−1.67	−1.74	−1.72	−0.07	−0.12		
	(0.21)	(0.21)	(0.28)	(0.29)				(0.20)	(0.21)	(0.21)	(0.23)	(0.25)		
Nagarahole	0.28	0.27									0.42	0.46		
	(0.21)	(0.21)									(0.24)	(0.25)		
Phulwari	−2.96	−2.96	0.42	0.42				−1.01	−0.98	−0.98				
	(0.23)	(0.23)	(0.25)	(0.25)				(0.22)	(0.22)	(0.22)				
Sitamata	−2.19	−2.18												
	(0.26)	(0.26)												
Tadoba	1.32	1.32			1.23	1.06	1.20				−0.76	−0.85	0.83	0.90
	(0.21)	(0.21)			(0.29)	(0.28)	(0.30)				(0.27)	(0.30)	(0.25)	(0.28)
Scrub 3km	−0.48	−0.48	0.59	0.55					−0.16	−0.15		0.06		
	(0.11)	(0.11)	(0.14)	(0.14)					(0.17)	(0.17)		(0.15)		
Forest 3km	0.33	0.33	0.19	0.20			0.10				0.70	0.62	0.75	0.74
	(0.11)	(0.11)	(0.16)	(0.16)			(0.20)				(0.14)	(0.15)	(0.19)	(0.19)
Distance water	0.20	0.19		−0.14	0.62	0.61	0.64		−0.28	−0.28	0.13	0.15		0.11
	(0.09)	(0.09)		(0.12)	(0.22)	(0.21)	(0.22)		(0.17)	(0.17)	(0.14)	(0.14)		(0.17)
Distance pa					−0.50		−0.48					−0.15	−0.32	−0.33
					(0.18)		(0.19)					(0.15)	(0.14)	(0.15)

Agricultural landholding size		0.10			0.23		0.25			0.00		−0.03		0.03
		(0.07)			(0.15)		(0.16)			(0.12)		(0.13)		(0.14)
Scare devices	1.07	1.07	0.46	0.45	0.64	0.70	0.68							
	(0.09)	(0.09)	(0.12)	(0.12)	(0.20)	(0.19)	(0.20)							
Guard animal	0.41	0.41		0.19	0.26		0.28							
	(0.10)	(0.10)		(0.13)	(0.22)		(0.23)							
Lighting							−0.27							
							(0.24)							
Fencing	0.90	0.90	0.62	0.58	0.66	0.73	0.68							
	(0.09)	(0.09)	(0.12)	(0.13)	(0.19)	(0.19)	(0.20)							
Legumes and pulses	0.64	0.63			0.68	−0.49	0.69							
	(0.10)	(0.10)			(0.22)	(0.18)	(0.23)							
Vegetables		−0.03					0.49							
		(0.13)					(0.35)							
Millets	0.60	0.60		−0.22	0.58	0.80	0.54							
	(0.10)	(0.10)		(0.17)	(0.33)	(0.21)	(0.33)							
Cereals	1.22	1.22	0.22	0.21	0.72	0.71	0.72							
	(0.10)	(0.10)	(0.18)	(0.18)	(0.23)	(0.22)	(0.23)							
Large palatable crops							−0.54							
							(0.46)							
Large cash crops			0.48	0.52										
			(0.15)	(0.15)										
Closer eye on livestock								1.30	1.30	1.28	1.85	1.84	1.17	1.16
								(0.16)	(0.16)	(0.16)	(0.15)	(0.15)	(0.18)	(0.18)
Number of sheep or goat								0.33	0.34	0.32	0.37	0.36		
								(0.12)	(0.12)	(0.12)	(0.10)	(0.10)		
Number of cattle or buffalo								0.14		0.13	0.36	0.35	0.36	0.35
								(0.13)		(0.14)	(0.10)	(0.11)	(0.12)	(0.12)
Sheep or goat grazed on community land								0.88	0.90	0.89				
								(0.20)	(0.20)	(0.20)				
Cattle or buffalo grazed in forest												0.34	0.50	0.51
												(0.21)	(0.16)	(0.16)

Figure 4.2 Example of crop loss in India
Source: Krithi Karanth

Livestock ownership and loss

Livestock ownership ranged from 0 to 153 animals per household (Table 4.2). Most (51 per cent) livestock owned across all sites was cattle, 29 per cent was goat, 15 per cent was buffalo and 4 per cent was sheep. Less than 1 per cent of households reared other livestock like pigs, camels and horses. Cattle and buffalo were largely grazed in fields (54 per cent) and forests (29 per cent). Sheep and goats were grazed on community land and scrub hills (42 per cent), followed by forests (31 per cent of HH) and fields (27 per cent of HH).

Livestock loss was reported by fewer households across all sites, ranging from 7 per cent of surveyed households in Sitamata to 36 per cent in Kanha (Table 4.2). Households reported experiencing 0 to 5 incidents of livestock predation per year. Livestock loss was mainly attributed to leopard in six sites (Kumbalgarh, Jaisaimand, Sitamata, Nagarahole, Bandipur and BRT, Table 4.2). Tiger related incidents were highest in Tadoba, Dandeli-Anshi and Bhadra, while canids were reported most in Phulwari and Kanha (Table 4.2).

All reported conflict incidents were attributed to three species types – tiger, leopard and canids (LP). The number of sheep and/or goat owned by each household was positively associated with leopard and canid (LP) conflict, agreeing with our predictions (Table 4.3). Grazing of goats and/or sheep on community land

(HH reports of 'hills', 'open scrub' and 'grassland' combined) was tested against canid (LP) conflict, and the resulting association was significant and positive (Table 4.3). The number of cow and/or buffalo owned by each household was positively associated with leopard and tiger conflict as predicted, but showed no significant association with canid (LP) conflict (Table 4.3). Grazing of cow and/or buffalo was tested and tiger conflict was positively associated, while leopard conflict showed no significant association.

Sites, reserves and landscape characteristics

We found that for all 13 species, the study site was strongly associated with conflict (Table 4.3). We identified site level variations. Kanha, Tadoba and Bhadra were associated with higher chital related incidents while sambar was highest in Tadoba. Nagarahole, Bandipur and BRT with elephant, and Bandipur and Tadoba with pig incidents. Phulwari with chinkara and Kanha with primate related incidents. Tiger incidents were identified in Kanha and Tadoba. No significant trends emerged for other species.

We used distance to the reserve as a covariate for seven out of the twelve species, which are known to occur predominantly in forested areas (Karanth *et al.* 2012). We found that distance to reserve was negatively associated with sambar, elephant, gaur and tiger related incidents, as expected. There was no significant association

Figure 4.3 Example of livestock loss in India
Source: Krithi Karanth

for other species (Table 4.3). We predicted incidents reported for chinkara, nilgai and canid (LP) to be negatively associated with distance to water within the 10 km buffer outside the park. Proximity to water was positively associated with occurrence of elephant, gaur, pig and sambar related incidents (Table 4.3), as predicted. Distance to water negatively influenced conflict with chinkara, nilgai and canid (LP) as expected. There was no significant association of distance to water for other species (Table 4.3).

Among habitat characteristics, we predicted a positive association of deciduous and/or evergreen forest cover within 3 km of the household with higher conflict. For pig, chital, elephant, gaur, tiger and leopard conflict we found positive associations conforming to our predictions (Table 4.3). The percentage of scrub forest and grassland (including degraded scrub, scrub land, fallow land and grassland) within a 3 km buffer of the household was used as a predictor for seven species. Chinkara, canid (CR) and primate conflict incidents were positively associated, while unexpectedly pig and nilgai showed negative association (Table 4.3).

Mitigation measures

Six major mitigation measures were employed by surveyed households to protect their crops and livestock. For crop protection, night watching was the top-ranked mitigation measure in nine sites, with the exception of Phulwari and Bhadra, where scare devices were ranked higher (Table 4.2). Other top measures included fencing used in nine sites, and lighting used in four sites. Use of scare devices as a mitigation measure was significant and positive for all crop-raiding species. Fencing was positively associated with all crop-raiding species, except gaur, chinkara (both species with negative but insignificant betas) and chital (did not figure in its top models). Use of guard animals as a mitigation measure was tested against all crop-raiding species except elephant and gaur. It was positively associated with chital, canid (CR) and pig conflict, and there was no significant association with primate, sambar, chinkara and nilgai conflict. Use of lighting was examined for chinkara, chital, elephant, gaur and sambar conflict – it was positive and significant for elephant, gaur and chinkara conflict, and insignificant when tested against chital and sambar conflict. All mitigation measures used as predictors for a particular species, whenever significant, were positively associated with conflict.

To address livestock loss, households reported keeping a closer eye on animals as the top measure in ten sites except Kanha and it was positively associated with incidents attributed to felids and canids (Tables 4.2 and 4.3).

Estimating crop and livestock loss by species

A comparison of betas within the model-averaged estimates for each species showed that study site had the largest influence in all cases (Table 4.3). The relative importance of the other predictor categories – mitigation measures, crop category or livestock count and landscape variables – was species dependent.

The mean estimated probabilities for crop loss were much higher than livestock loss across all sites, as expected (Table 4.4). The mean estimated crop loss across all sites was highest for nilgai at >0.90 (in Jaisamand, Kumbalgarh and Sitamata) and for pig >0.90 (in Kanha, Bandipur, Tadoba and BRT). Least damage-causing species included gaur and sambar in Bhadra and canids in Kumbalgarh and Phulwari. The mean estimated probabilities for livestock loss were lower than crop loss. The highest estimated losses (>0.30) were for canids in Kanha and tigers in Tadoba. Additional site-specific details are in Table 4.4.

Discussion

We found characteristic patterns in occurrence of human–wildlife conflict incidents with differences emerging across species and sites. Overall, reported crop loss and estimated crop loss incidents were much higher than livestock loss incidents (similar to other studies including Naughton-Treves *et al.* 2005; Agarwala *et al.* 2010; Karanth *et al.* 2012, 2013a, 2013b; Karanth and Kudalkar, 2017). Most commonly reported incidents for crop loss related to pig, elephant and nilgai. Livestock loss incidents were most frequently reported for leopard, tiger and canids.

We find distinct patterns of raiding depending on the crop grown – with cereals raided by most species except elephants and primates. In contrast, millets were raided by four species, legumes by five species and vegetables by three species. These findings across 11 sites reinstates the importance of re-orienting cropping patterns or identifying new crop varieties as potential solutions to mitigating crop loss. Although some minimal levels of raiding will continue to occur, the scale and intensity of damage can be significantly assuaged by shifting from cereals to millets in areas of high conflict. This shift in crop cultivation will perhaps be more agreeable to policy makers who often highlight the regrettable loss of food security associated with the push to convert to cash crops in areas of high wildlife conflict (Godfray *et al.* 2010).

At a species level, it is very clear that different species are associated with crop loss at different locations, making it very difficult to institute broad-scale policies and highlighting the importance of identifying local-scale patterns (Barlow *et al.* 2010). Two interesting patterns emerged – the association of omnivorous canids (CR) with sugarcane damage, and the mild influence of crops on elephant conflict. The former is in line with the folk perception that jackals eat sugarcane and other crops (K. Karanth, personal observation in Madhya Pradesh and Karnataka; Shashank Dalvi, personal communication in Maharashtra), although the more likely reason could be the high density of mice in these fields (Arjun Srivathsa, personal communication in Karnataka). There is a need to investigate perception, as a false claims propagated by superstition could do much harm when in fact they are more likely helping farmers. If, for example, jackals do in fact feed on sugar cane, more targeted mitigation measures can be envisaged. Literature does show significant vegetative matter in jackal faeces, but not enough to associate with crop raiding or sugarcane.

Table 4.4 Mean probability estimates (with error) for study sites

Conflict species	*Kumbalgarh*	*Phulwari*	*Jaisamand*	*Sitamata*	*Kanha*	*Tadoba*	*Anshi-Dandeli*	*Bhadra*	*Nagarahole*	*Bandipur*	*BRT*	*Mean*	*Range*
Chinkara	0.29 (0.16)	0.77 (0.12)		0.47 (0.18)								0.48	0.01–0.96
Chital					0.61 (0.15)	0.58 (0.19)	0.32 (0.15)	0.31 (0.19)				0.46	0.08–0.97
Elephant							0.46 (0.20)	0.31 (0.22)	0.63 (0.18)	0.72 (0.17)	0.49 (0.26)	0.52	0.04–0.99
Gaur					0.20 (0.14)		0.32 (0.20)	0.16 (0.19)				0.23	0.01–0.99
Canid CR	0.12 (0.11)	0.12 (0.07)			0.37 (0.14)							0.50	0.02–0.99
Nilgai	0.95 (0.06)	0.63 (0.18)	0.97 (0.03)	0.94 (0.08)		0.70 (0.24)						0.83	0.08–0.99
Pig	0.66 (0.25)	0.35 (0.18)		0.62 (0.22)	0.95 (0.05)	0.92 (0.07)	0.87 (0.12)	0.83 (0.13)	0.81 (0.12)	0.93 (0.05)	0.90 (0.09)	0.76	0.03–0.99
Primate	0.17 (0.07)	0.31 (0.10)			0.45 (0.09)		0.20 (0.09)	0.26 (0.11)				0.26	0.06–0.73
Sambar						0.33 (0.16)		0.17 (0.12)				0.27	0.04–0.81
Canid LP	0.12 (0.11)	0.12 (0.07)			0.37 (0.14)							0.17	0.04–0.77
Leopard	0.16 (0.14)				0.15 (0.11)	0.06 (0.06)			0.15 (0.10)	0.12 (0.08)		0.13	0.03–0.98
Tiger	0.17 (0.10)		0.17 (0.12)			0.30 (0.15)					0.16 (0.09)	0.20	0.05–0.90

We also find decreased influence of crops in elephant conflict, which points to the possibility of other reasons. The narrative around elephant conflict has received much focus (Jathanna *et al.* 2015a, 2015b), and around the five major protected areas of Karnataka where elephants occur (Karanth *et al.* 2013a), there has been a steady shift to unpalatable cash crops. The absence of crops as a strong driver of crop conflict despite high levels of conflict, point to either increased effectiveness of mitigation measures, cultivation of unpalatable crops or both. In the Karnataka sites we find that a shift in cropping patterns has not translated to decreased levels of conflict. The estimated losses suggest that elephant conflict is proportional to elephant numbers in each of the five reserves. Elephants are large-bodied mammals – they are wide-ranging and cannot be restricted to wildlife reserves (Hoare 1999; Fernando *et al.* 2005; Jathanna *et al.* 2015a, 2015b; Lakshminarayanan *et al.* 2016). This is especially true at the boundaries of parks, and parks in Karnataka have hard edges, that exacerbate this conflict due to high visibility of elephants when they move across the landscape.

The association of a number of livestock with higher vulnerability to conflict incidents, although unsurprising, highlights the importance of the need for effective livestock protection measures (Michalski *et al.* 2006; Kissui 2008). Studies have shown that better corrals (bomas in East Africa) significantly reduce predation of livestock by wild carnivores (Breitenmoser *et al.* 2005; Ogada *et al.* 2003). Reduced grazing pressure in protected areas is also an important factor in reduced livestock conflict, and conflict will continue to occur with many people still choosing to graze their livestock in the forest and scrub areas where forage is freely available. This is also known to increase disease transmission between wild and domestic animals, as well as deplete food availability for wild animals (Bagchi *et al.* 2004; Baker *et al.* 2008; Dar *et al.* 2009).

The nature of influence of landscape predictors reiterates the importance of wildlife reserves as source populations for some conflict-prone species, especially forest-dwelling species. The legal sanctity of a protected reserve is often associated with more intact vegetation and less anthropogenic activity (Fernando *et al.* 2005). While leopard, canids, nilgai and pig are known to occur in disturbed areas, other species actively select less disturbed habitats (Karanth *et al.* 2012, 2013a). The combined influence of less conflict further away from protected areas, more conflict with greater forest cover, little or no influence of scrub habitat (except for leopard) and more conflict associated with greater natural cover (used specifically for species of the scrub), all point to proximal effects playing a major role in conflict. This has been supported by other studies such as Hoare (1999), Naughton-Treves *et al.* (2005), Sitati *et al.* (2005) and Azevedo and Murray (2007) who documented similar patterns in Africa and South America.

A uniformly strong positive association of all (except one, brush forest removal) mitigation measures with conflict points to a long history of conflict in most locations, complemented by (a) the lack of species-specific mitigation measures being employed, (b) the general ineffectiveness of these mitigation measures in protecting losses for households experiencing conflict and (c) the likely situation of post-conflict mitigation measures being employed instead of preventive measures of proven efficacy. A parallel study by Karanth and Kudalkar (2017) found that although up to 12 different mitigation measures were deployed by households around protected reserves in India, use varied by state. They found that mitigation use was driven by households' conflict history (more than 20 years for livestock and 10–20 years for crops), proximity to reserves, and crops or livestock owned. Overall, mitigation use was more likely for crops (88 per cent) compared to livestock (32 per cent) (Karanth and Kudalkar 2017).

Mitigation measures are usually unscientific, rarely tested prior to implementation, general in nature and insensitive to temporal shifts, calling for greater focus on improving them (Webber *et al.* 2007). Households incur a heavy cost for investment of time and resources in mitigation measures, and many of these costs are hidden and particularly worrisome if they are ineffective (Graham and Ochieng 2008; Barua *et al.* 2013).

Some limitations of our study perhaps include uneven (and sometimes small) sample sizes in some locations, non-accounting of the possibility that the household is located at a large distance from the farmland /grazing land, among others. Despite these limitations, the current study is one of the few that look at disaggregated multi-species conflict as opposed to lumping all species together to examine crop or livestock loss. Preliminary insights show both site-specific factors and species-specific characteristics have a significant role to play in conflict patterns that emerge.

We do find some similarities, with particular species such as pig and leopard which are universally reported across different sites, and also between closely-related species. These similarities underline the possibility of an effective country-wide framework to manage conflict for the most common species based on sound ecological knowledge while allowing enough flexibility for site-specific modifications (Barlow *et al.* 2010). Increasingly confrontational sociocultural values, heightening land matrix contrast around protected reserves (Tadoba), and spillover of conflict species due to successful protection (as in the case of Bandipur and Nagarahole) and variability in success between different states of the country in managing conflict, all point at the need for a central policy to deal with human–wildlife conflict (Treves and Karanth 2003). At present, there are individual state-based policies that vary greatly in their application (from species listed, compensation rendered etc.).

Attributing causal relationships between mitigation measures and the persistence of conflict is particularly difficult, especially without time series data showing changes in conflict with changes in intensity of mitigation measure usage. The positive association to conflict in most cases hints at *post hoc* usage rather than a pre-emptive application, with locations that have a long history of conflict. The persistence of conflict, despite these mitigation measures, points to their diminished effectiveness. Few studies evaluate the effectiveness of mitigation measures (Jackson and Wangchuk 2004; Woodroffe *et al.* 2005; Graham and Ochieng 2008; Gehring *et al.* 2010) and we find this to be of critical importance given the time and effort being invested in mitigation strategies.

Our study is perhaps the first of its kind to examine in detail the role that species and sites play in shaping the occurrence of crop and livestock related losses in diverse ecological and socio-economic settings across India. We find that understanding the role that different species play along with the history of conflict at a location, and the differences in economic/cultural/social perceptions of losses need to be integrated into conflict management practices. Karanth and Gupta (in review) in their analysis of state-wide compensation policies found huge variations across India. Among states 22/29 compensated for crop loss, 18/29 for property damage, 26/29 compensated for livestock depredation, and 28/29 compensated for human injury/death, with significant variations in compensation policies and procedures. Similarly, their study found that across India in 2012–2013, 81,100 total incidents were reported and compensated nationwide (73 per cent crop loss and property damage, 21 per cent livestock predation, 6 per cent human injury and <0.4 per cent human death). The average expenditures per incident were US$46 for crop and property damage, $68 for livestock, $103 for human injury and $3,188 for human death (Karanth and Kudalkar, 2017). It is important to note that the total number of incidents are higher than most countries in the world, and the associated compensation rates are among the lowest in the world. Therefore, we believe that such multi-species and multi-site comparisons are critical to developing locally relevant policies and management actions with respect to improving ongoing prevention, mitigation and compensation efforts (Jackson and Wangchuk 2004; Madden 2004; Lagendijk and Gusset 2008; Dickamn 2010; White and Ward 2010; Kansky and Knight 2014) and our study provides the necessary building blocks to do so.

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