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Identifying indicators of illegal behaviour: carnivore killing in human-managed landscapes

Freya A. V. St John[1,*], Aidan M. Keane[1,2,3], Gareth Edwards-Jones[1], Lauren Jones, Richard W. Yarnell[4] and Julia P. G. Jones[1]

[1]*School of Environment, Natural Resources and Geography, Bangor University, Deiniol Road, Bangor LL57 2UW, UK*
[2]*Department of Anthropology, University College London, 14 Taviton Street, London, UK*
[3]*Institute of Zoology, Regent's Park, London NW1 4RY, UK*
[4]*School of Animal Rural and Environmental Sciences, Nottingham Trent University, Brackenhurst Campus, Southwell NG25 0QF, UK*

Managing natural resources often depends on influencing people's behaviour, however effectively targeting interventions to discourage environmentally harmful behaviours is challenging because those involved may be unwilling to identify themselves. Non-sensitive indicators of sensitive behaviours are therefore needed. Previous studies have investigated people's attitudes, assuming attitudes reflect behaviour. There has also been interest in using people's estimates of the proportion of their peers involved in sensitive behaviours to identify those involved, since people tend to assume that others behave like themselves. However, there has been little attempt to test the potential of such indicators. We use the randomized response technique (RRT), designed for investigating sensitive behaviours, to estimate the proportion of farmers in north-eastern South Africa killing carnivores, and use a modified logistic regression model to explore relationships between our best estimates of true behaviour (from RRT) and our proposed non-sensitive indicators (including farmers' attitudes, and estimates of peer-behaviour). Farmers' attitudes towards carnivores, question sensitivity and estimates of peers' behaviour, predict the likelihood of farmers killing carnivores. Attitude and estimates of peer-behaviour are useful indicators of involvement in illicit behaviours and may be used to identify groups of people to engage in interventions aimed at changing behaviour.

Keywords: leopard; randomized response technique; attitude; brown hyaena; illegal; false consensus effect

1. INTRODUCTION

The management of natural resources and conservation of threatened species often rests on the successful management of people's behaviour. For example, reducing over fishing, preventing illegal bushmeat hunting, reducing grazing inside protected areas and encouraging environmentally sensitive farming methods all depend on decisions made by individuals [1–4]. Initiatives intended to encourage changes in behaviour (whether through enforcement of existing laws, creating positive incentives or changing people's attitudes) are most efficient when they target those most likely to be involved in the behaviours of concern. Unfortunately in conservation and natural resource management, many of the behaviours of concern are sensitive because they are illegal or socially taboo, meaning that those involved may not wish to reveal themselves for fear of punishment or social opprobrium [5,6]. As a result, identifying the key groups to target with interventions aimed at changing behaviour can be challenging and there is a need for indicators that can act as reliable proxies for involvement in these various activities.

*Author for correspondence (f.a.v.stjohn@gmail.com).

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A number of studies have looked at people's attitudes towards species, habitats or management interventions, assuming that attitudes are useful indicators of behaviour [7]. However, the evidence for attitude being a reliable and a useful indicator of behaviour is mixed. For example, people involved in a long-term community-conservation programme near Mburo National Park in Uganda, had more positive attitudes towards wildlife and the park than people who had not been part of the programme, but little difference in behaviour was observed and high levels of poaching and illegal grazing continued [4]. Many such studies have been criticized for failing to ensure that the attitudes investigated were consistent with the behaviours of interest [8]. As a result, there is little consensus about whether attitudes can be used as a reliable indicator of behaviour.

A second potential indicator of sensitive behaviour arises from a psychological bias known as the false consensus effect [9]. The term 'false consensus' describes the tendency people have to imagine that others are more like themselves than they really are, causing survey respondents to systematically bias their estimates of population-level prevalence of an activity in accordance with their own behaviour [10]. For example, people who smoke cigarettes have been found to estimate a higher proportion of smokers in the population, compared with

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non-smokers [11]. To date, the potential application of the false consensus effect to natural resource management has not been explored.

Other potential indicators of sensitive behaviours include a person's knowledge of rules. This may include laws enforced by formal institutions, and the perceived sensitivity of actions according to prevailing social norms enforced by informal institutions [12]. While enforced and punished through different mechanisms, both types of rules aim to deter socially unacceptable behaviours and can attract considerable penalties [13,14]. The utility of knowledge of formal rules and the perceived sensitivity of behaviours as indicators of sensitive behaviour have not been investigated in conservation and natural resource management.

In order to properly test the effectiveness of any such indicator, it is necessary to be able to link them to an accurate estimate of sensitive behaviour. Recently, innovative survey methods such as the randomized response technique (RRT) [15] have been used to make improved estimates of the prevalence of illegal natural resource use [16,17]. When the topic of investigation is sensitive, guaranteeing anonymity increases response rate and data validity [18]; however, RRT provides respondents with an additional assurance of privacy beyond that achieved by ensuring respondent anonymity. This is achieved by using a randomizing device (such as dice) to add an element of chance to the question answer process [15,19]. For example, respondents may be instructed to role a die (in privacy) and: if it lands on one, two, three or four to answer the question truthfully, with a 'yes' or 'no'; if the die lands on five to answer 'yes'; and if it lands on six to answer 'no', irrespective of the truth [16]. Because respondents never reveal the result of the die to the interviewer, the interviewer is unaware of which responses are truthful and which are forced by the die, ensuring that sensitive behaviours cannot be linked to individual respondents. RRT has been shown to increase the validity of data on sensitive topics [19,20] in a variety of contexts (e.g. illegal abortion [21] and health insurance fraud [22]) with the extent of gains in data validity increasing with topic sensitivity [19]. Despite their promise, previous applications of RRT to resource management problems have been limited to assessing population-level prevalence of behaviours and have not linked characteristics of individuals or groups to behaviours of interest.

Human–wildlife conflict is a prominent example of a sensitive issue, which is difficult to study directly. Habitat loss and competition for resources in many parts of the world have led many people living in proximity to wildlife to feel that their lives or economic securities are at risk [23]. The problems are particularly acute with respect to carnivores which, owing to their large home ranges and dietary requirements, are pre-disposed to conflict with humans [24]. Many countries have legislation that legally protects carnivores such as wolves (*Canis lupis*) in the United States of America and India [25], but killings continue, making protected carnivore persecution an issue of global conservation concern [23,26]. Illegal carnivore persecution has been measured indirectly in different ways [27,28], but such indirect methods tell us little about the characteristics of the people persecuting carnivores making it difficult to target interventions aimed at reducing carnivore killing.

In this study, we first use RRT to estimate the proportion of South African farmers in the north-eastern provinces killing five carnivore species and performing two illegal behaviours: failing to hold a valid permit to kill a protected carnivore; and using poison to kill carnivores. Secondly, we use logistic regression [29] to investigate individual indicators of carnivore killing focusing on farmers' attitude towards the existence of carnivores on ranches, estimates of their peers' carnivore killing behaviour, perceived sensitivity of RRT questions and beliefs about the existence of sanctions. This approach [29], novel to conservation and natural resource management, allows us to investigate the usefulness of non-sensitive indicators of sensitive behaviours.

2. METHODS

(a) *Case study: carnivore persecution by farmers in north-eastern South Africa*

South African cattle and game farmers have commercial interest in protecting their stock from carnivores, and in this context, some carnivores are killed because they are thought to have predated stock [30]. The South African Biodiversity Act of 2004 aims to protect certain species including the near threatened [31] brown hyaena (*Parahyaena brunnea*) and leopard (*Panthera pardus*), but a permit can be obtained to control species covered by this Act (e.g. by shooting or poisoning) if they are causing damage to stock or pose a threat to human life [32]. Failure to comply with the Act can attract a fine of up to Rs. 100 000 (approx. $15 000) or three times the commercial value of the specimen concerned, up to 5 years in prison, or a combination of fine and imprisonment. Other carnivores, such as snakes (except for the Gaboon adder (*Bitis gabonica*) and African rock python (*Python natalensis*)), black-backed jackal (*Canis mesomelas*) and caracal (*Caracal caracal*) are not protected under the Act, but they are included in this study to introduce variability into the sensitivity of behaviours under investigation. All five species are widely distributed across the study area [33] and are known to be killed on ranches as part of pest control activities [34].

(b) *Data collection*

The survey was piloted on colleagues and improved before a formal pilot of 16 farmers from cattle, game and mixed stock farms at auctions in north-eastern provinces of South Africa. No further improvements were necessary so the pilot data from farmers ($n = 16$) were included in the final analysis. Surveys were administered to a total of 99 farmers at cattle and game auctions in north-eastern provinces between May and September 2010 by F.A.V.St.J. and L.J. The survey was made up of seven short sections: RRT questions, perceived sensitivity of RRT questions, farmers' estimates of the proportion of peers killing carnivores, basic demographics, beliefs about the existence of sanctions and two attitude statement sections. RRT questions referred to the last 12 months to minimize recall inaccuracy while also allowing an adequate time for the behaviour to have occurred (table 1).

(c) *Randomized response technique*

A number of RRT designs are described in the literature, we use one of the more statistically efficient designs: the 'forced response' RRT [20]. Depending on the dice number they roll, respondents are instructed (not forced as the name

Table 1. Randomized response technique questions and information about the sanctions for killing each of the carnivores included in the study.

code	question	sanction
snake	in the last 12 months did you kill any snakes?	none
jackal	in the last 12 months did you kill any jackals?	none
brown hyaena	in the last 12 months did you kill any brown hyaenas?	fine and/or prison[a] in the absence of required permit
caracal	in the last 12 months did you kill any caracals?	none
leopard	in the last 12 months did you kill any leopards?	fine and/or prison[a] in the absence of required permit
poison	in the last 12 months did you use poison to control predators?	fine and/or prison[b]
permit	in the last 12 months did you kill any predators without the required permit from the Local Wildlife Authority	fine and/or prison[a]

[a]Regulation 73 of the South Africa Biodiversity Act 2004 states that: a person is guilty of an offence if they undertake a restricted activity involving a threatened or protected species without a permit. A person convicted of an offence in terms of regulation 73 is liable to (*a*) a fine of Rs. 100 000, or three times the commercial value of the specimen; and/or (*b*) to imprisonment for a period not exceeding 5 years; or (*c*) to both a fine and such imprisonment [32].
[b]Regulation No. R181 published in Government Gazette No. 24 329, of the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act No. 36 of 1947) prohibits the use of an agricultural remedy or stock remedy except as indicated on the label. Any persons failing to comply are liable on conviction to an unspecified fine or imprisonment not exceeding 2 years or to both such fine and imprisonment.

suggests) to either answer a sensitive question truthfully, 'yes' or 'no'; or to give a prescribed response irrespective of the truth (Boruch 1971 in [19]). The result of the dice throw is never revealed to the interviewer, so respondents' privacy is fully protected, but by knowing the probability of respondents being required to answer the sensitive question, and the probability that they were instructed to say 'yes' irrespective of the truth, the aggregate level of the sensitive behaviour can be calculated [16,35].

Respondents were required to answer the sensitive question truthfully, if the sum of the two dice was five through to 10 (probability = 3/4). Respondents were simply asked to give a fixed answer 'yes', if the sum of the two dice was two, three or four (probability = 1/6); and to give a fixed answer 'no' if the sum of the two dice was 11 or 12 (probability = 1/12). The interviewer does not know if the respondent is saying 'yes' because they have undertaken the behaviour, or because the dice summed three or four, (the result of the dice roll is never revealed to the interviewer), so the interviewer does not hold any sensitive information about the respondent. Respondents were given an opaque beaker containing two dice, one example question card and seven question cards each of which displayed the randomizing device instructions. All cards were identical in design, only the questions differed. Respondents first had the method explained to them using the example question. To encourage respondents to follow the RRT instructions, the analogy of following the rules of a game was used, and when the dice summed two, three, four, 11 or 12 respondents were encouraged not to read the question but to give their 'forced' response of 'yes' or 'no' directly. For this section only, the interviewer recorded answers on behalf of the respondent because they needed both hands to hold the RRT cards and shake dice; all other sections were self-completed by respondents.

(d) *Beliefs on the existence of sanctions*

To investigate the relationship between reported behaviour (RRT response) and fear of sanctions, respondents were required to indicate the level of penalty they thought applied for killing each species; no penalty, or a penalty of up to Rs. 100 000 and up to 5 years imprisonment.

(e) *Perceived randomized response technique question sensitivity*

To understand the perceived sensitivity of each behaviour included in the RRT questions, respondents were asked to indicate on a four-point Likert scale [36] (+2 = very uneasy, through to −2 = not at all uneasy. There was no zero in this scale), how they thought most farmers would feel if they were asked to give a direct response to each of the RRT questions.

(f) *Attitude statements*

To ensure that the attitudes investigated were consistent with the behaviours of interest, attitude statements were structured to be target, action, context and time-specific [37]. Using a five-point Likert scale, respondents were asked to indicate their level of agreement with two attitude statements; we used two variants of an 'attitude towards killing' statement as a check on farmers' response consistency. Attitude towards killing statement (i): 'These days (time) I think that jackals (target) should be killed (action) on ranches (context)'; and statement (ii): 'These days I think that killing jackals on ranches is wrong'. Both attitudes statements were completed for each of the five carnivores (10 statements in total). The statements were reverse scored, agreement with 'should be killed on ranches' scored −2 (strongly agree) to +2 (strongly disagree), while agreement with 'killing is wrong' scored +2 (strongly agree) to −2 (strongly disagree); meaning that lower scores corresponded to attitudes that are less favourable to conserving carnivores.

(g) *Farmers' estimates of their peers' behaviour*

To investigate the relationship of farmers' estimates of the proportion of peers killing carnivores with farmers' reported behaviour, respondents were asked to state how many farmers out of 10 (range: 0–10) in the province they thought had undertaken each of the seven behaviours presented in the RRT questions in the last 12 months. Following the principles of the false consensus effect, higher estimates should indicate a person's involvement in the sensitive behaviour [9]; however, farmers' responses were re-coded in the subsequent analyses to be consistent with all other variables, whereby low scores are indicative of involvement in the sensitive behaviour.

(h) *Data analysis*

Data were analysed using R v. 12.2.0 [38]. The proportions of farmers killing each species, using poison, or failing to hold a valid permit (RRT responses) were estimated using the model of Hox & Lensvelt-Mulders [35]:

$$\pi = \frac{\lambda - \theta}{s},$$

where π is the estimated proportion of the sample who have undertaken the behaviour, λ is the proportion of all responses in the sample that are 'yes', θ is the probability of the answer being a 'forced yes', s is the probability of having to answer the sensitive question truthfully. For RRT data, 95% confidence intervals were estimated from 10 000 bootstrap samples. These confidence intervals therefore incorporate both, uncertainty arising from the RRT method and sample uncertainty.

To examine the relationship between respondents' reported behaviour concerning each carnivore (their RRT responses) and their attitudes and perceptions, we fitted a generalized linear mixed model (GLMM) with a binary response and a binomial error distribution. The grouping structure of the data, whereby each respondent answered questions about several species, was reflected in the model by including individual respondent IDs as a random effect. In this situation, GLMMs are able to make more efficient use of the data than a series of single species GLMs would allow [39]. Species, attitude towards killing the species, attitude towards not killing the species, perceived question sensitivity, beliefs about the existence of sanctions, and farmers' estimates of their peers' behaviour were all considered as potential fixed effects within the model.

Prior to modelling, we rescaled the predictor variables so that they were centred on zero and had the same range (from −2 to +2; [39]). The two forms of attitude data were checked for internal consistency using Cronbach's alpha coefficient [36,40], and correlation coefficients were calculated for each pair of variables using Spearman's correlation. Strongly correlated predictor variables were removed to avoid problems of multi-collinearity.

Models with binary responses typically employ a logistic link function. However, simple logistic regression is not appropriate for RRT data because the forced responses introduce bias and additional variability into the data. We, therefore, wrote a customized link function, which incorporated the known probabilities of the forced RRT responses [29]. The resultant model was:

$$\log\left(\frac{\pi - \theta}{\theta + s - \pi}\right) = \alpha_j + \beta_1 x_1 + \cdots + \beta_N x_N,$$

where α_j is the common intercept term for responses given by individual j, $\beta_{N,i}$ is the coefficient for the Nth covariate and x_N is the vector of values for the Nth covariate. This link function behaves similarly to the logit link in logistic regression, constraining the response to lie between lower and upper bounds. With forced responses, the response is bounded at θ and $\theta + s$, but if the probability of forced responses is zero, $\theta = 0$, $\theta + s = 1$ and the link function simplifies to the standard logit link.

The model was fitted by penalized quasi-likelihood (PQL) using the glmmPQL function from the MASS package, which readily accepts user-defined link functions [41]. The PQL is a flexible approach, which allows approximate inference in GLMMs [42], and has been widely applied [43]. However, the use of quasi-likelihood precludes standard likelihood-based approaches to model selection, such as Akaike's Information Criterion (AIC) and likelihood ratio tests, and in some circumstances, it is known to produce biased estimates [44]. To circumvent these limitations, while still benefiting from the power of the GLMM approach, we adopted an *ad hoc* model selection procedure (see the electronic supplementary material, section S1 for a discussion of this approach). First, we fitted a series of generalized linear models (GLM) for all possible combinations of predictors for each carnivore separately. The fit of these models was assessed using AIC [45] (see the electronic supplementary material, table S2), and the structures of the best-fitting models were used as a basis for choosing the fixed effects structure for a GLMM incorporating all species. Finally, the parameter estimates from the GLMM were compared with those derived from the separate species' GLMs as a simple check to rule out the presence of large biases (see the electronic supplementary material, figure S3).

3. RESULTS

For all questions where responses were recorded on a Likert scale, Cronbach's alpha coefficient was above 0.7 showing high internal consistency [40]. Cronbach's alpha was 0.868 ($n = 95$) for perceived RRT question sensitivity, 0.795 ($n = 98$) for the attitude statements in support of killing each species and 0.882 ($n = 97$) for attitude statements suggesting killing each species is wrong.

Ninety-nine farmers completed the survey. The majority of farmers interviewed (90.9%, $n = 90$) were male, the mean age was 49 years (s.e. = 1.0, $n = 98$). Over half of the farmers (55%, $n = 54$) stocked game, or game mixed with cattle or other livestock, while the remainder (45%, $n = 45$) stocked cattle or mixed livestock. Most farmers were aware that there was no penalty for killing most snakes (87%, $n = 83$), jackal (85%, $n = 82$) and caracal (59%, $n = 57$), and most were aware that there was a penalty for killing brown hyaena (60%, $n = 56$) and leopard (88%, $n = 84$).

(a) *Estimated proportion of farmers killing carnivores and breaking rules*

The estimated proportion of farmers that killed each of the species in the last 12 months is shown in figure 1. RRT estimated that a higher proportion of farmers killed non-protected species than protected species. The majority of respondents had killed snakes, and more than 45 per cent had killed the common and widespread jackal, while 22 per cent had killed caracal (the other non-protected species included in the study). Nineteen per cent of farmers had killed leopards on their ranches in the last 12 months while only 6 per cent of respondents had killed brown hyaena in the same period (although as confidence intervals overlap zero, it is possible that no farmers had killed brown hyaena). The proportions of farmers that used poison to kill carnivores, and killed protected carnivores without a valid permit were similar (21% and 22%, respectively).

(b) *Indicators of carnivore killing*

Owing to the low prevalence of farmers killing brown hyaena, we did not carry out modelling for this species. Preliminary examination of the data showed the two attitude statements to be correlated (Spearman's rank coefficient

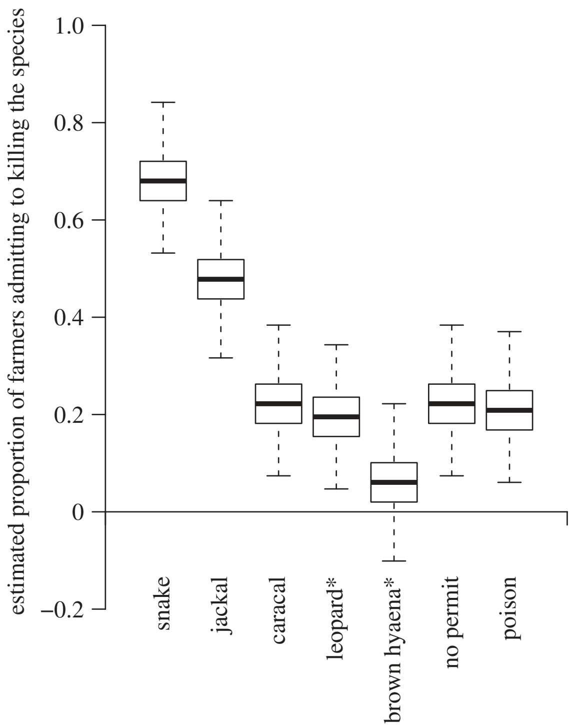

Figure 1. RRT estimates of the proportion of farmers that killed each of the five carnivore species or broke permit and poison-use rules in the 12 months preceding the study. Negative estimates can occur for RRT owing to the stochastic variability of the forced responses. The bold line represents the median, the lower and upper edges of the box are the first and third quartiles and the whiskers the maximum and minimum points. Asterisks denote species protected under the Biodiversity Act of 2004.

$r_s = 0.60$, $p = <0.001$), so to avoid issues of multicollinearity, the variable representing the attitude that 'killing is wrong' was excluded from further analysis; respondents' beliefs about the existence of sanctions correlated with their estimates of peer-behaviour (Spearman's rank coefficient $r_s = 0.47$, $p = <0.001$) and was also discarded. Visualization of the remaining predictors suggested that their effects were approximately linear, so for parsimony, we modelled them as continuous rather than categorical variables.

The likelihood of admitting to killing any given species was negatively and significantly related to farmers' attitude towards killing species on their ranches ($t = -3.326$, d.f. = 247, $p = 0.001$), and question sensitivity ($t = -2.063$, d.f. = 247, $p = 0.04$). Farmers estimates of their peers' behaviour was also negatively, but not significantly related ($t = -1.478$, d.f. = 247, $p = 0.140$) to the likelihood of admitting to killing any given species.

Scenarios simulated from the fitted model illustrate the relative strength of each indicator (attitude, question sensitivity and farmers' estimates of peer-behaviour) at distinguishing differences in whether farmers kill carnivores (figure 2*a–c*). For example, figure 2*a* illustrates that farmers reporting the attitude that carnivores should be killed on their ranches (scenario 1) were more likely to have reported killing any given species, compared with farmers reporting that carnivores should not be killed on ranches (scenario 2). Similarly, farmers estimating that a high proportion of their peers kill carnivores (figure 2*c*; scenario 1) were more likely to have reported killing any given species, compared with farmers reporting low estimates of the proportion of their peers killing carnivores (scenario 2). Results suggest that attitude is the most useful indicator for distinguishing between groups of farmers who are more, or less likely to have killed carnivores; question sensitivity appears only slightly less useful, however in the discussion, we explore our concerns about the causes underlying this effect. Although those who believe that many of their peers have killed carnivores are more likely to have killed carnivores themselves, this indicator provides less information for distinguishing carnivore killers from non-killers. Figure 2*d* illustrates the maximum difference in the behaviour of farmers holding attitudes and perceptions at the two extremes: for example, we predict that farmers who estimated that all their peers kill leopards, reported the attitude that leopards should be killed on ranches, and who thought that the RRT question about killing leopards was not at all sensitive (scenario 1) would have been 69.8 per cent more likely to have admitted to killing leopards, compared with farmers reporting the polar opposite in responses (scenario 2).

4. DISCUSSION

Human behaviours such as illegal hunting [46], fishing [47], wildlife trade [48] or killing owing to human–wildlife conflict [49] can be important threats to biodiversity, making understanding and influencing such behaviours an essential part of the solution [8]. Many studies have reported that carnivores are killed as a result of conflict with human activities, particularly livestock production where farmers may kill carnivores to minimize actual or perceived losses from depredation [50–53]. Such conflicts are particularly controversial when the carnivores concerned are of conservation concern and/or are legally protected [54]. Studies investigating such behaviour have used conventional face-to-face surveys to investigate the prevalence of these activities and the attitudes of people towards carnivores, but some have noted conflicting findings [53], and suspected underreporting [52] because of the sensitive nature of the questions.

In South Africa, where many farmers share land with large carnivores, human–carnivore conflict is of particular conservation concern for the leopard and brown hyaena [34], both considered near-threatened [31]. However, there have been few attempts to estimate the prevalence of killing of these, or other, carnivores. Our estimate that 19 per cent of farmers had killed leopards on their ranches in the last 12 months is worrying given the species' low reproductive rate, cub and sub-adult survival [55]. We found that a similar percentage of farmers reported killing carnivores without the required permit as had killed leopards, suggesting that farmers rarely hold valid permits when killing protected carnivores. Further, many disregard restrictions that apply to the use of poisons (misused agricultural or stock remedies) for controlling carnivores, suggesting that communication and/or enforcement of wildlife laws is inadequate. We found a very small proportion of farmers (possibly none) killed brown hyaena in the last 12 months. Leopards, while less abundant in the study area than brown hyaenas [34], are generalist predators [55], while brown hyaenas are primarily solitary nocturnal scavengers that

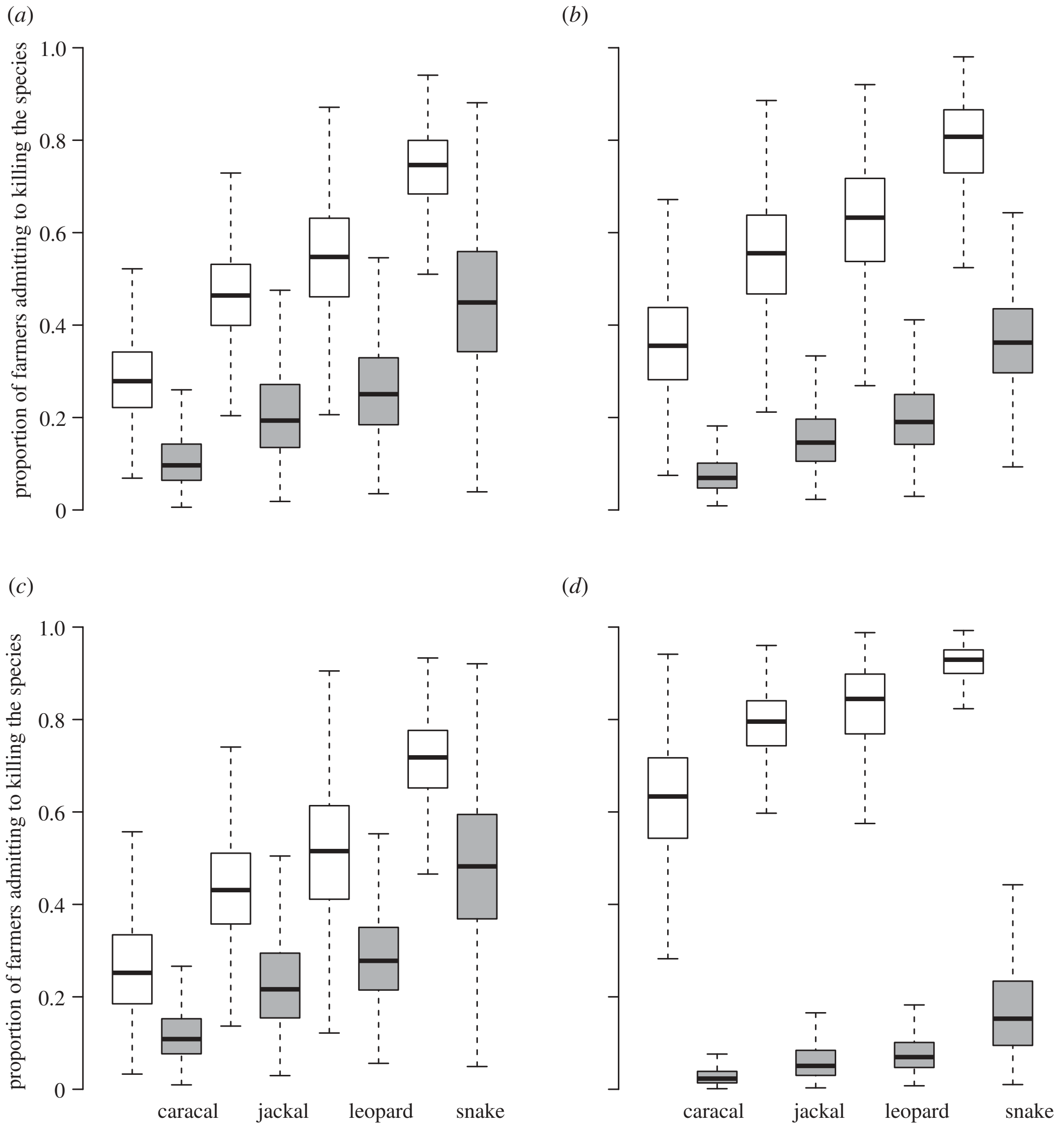

Figure 2. (*a–c*) Simulations from the fitted model illustrating the relative strength of the three variables, separately and (*d*) in combination, as indicators of the aggregate level of carnivore killing. In (*a–c*), the focal indicator is set at its minimum (scenario 1) or maximum (scenario 2) value, while the other indicators are set to their average values. In panel (*d*), all three indicators are set at values that indicate the highest (scenario 1) or lowest (scenario 2) levels of persecution. Scenario 1 in (*d*) represents farmers who hold the attitude that the species should be killed on ranches; think the RRT questions are not sensitive; and estimate that a high proportion of peers kill carnivores; scenario 2 shows the opposite. The bold line represents the median, the lower and upper edges of the box are the first and third quartiles and the whiskers the maximum and minimum points. Open bars, scenario 1; grey bars, scenario 2. (*a*) Attitude towards killing species; (*b*) perceived question sensitivity; (*c*) estimates of behaviour of peers; and (*d*) all three indicators.

supplement their diet with wild fruit, insects and bird eggs [56]. These ecological differences may partly explain the difference in levels of persecution and possibly current densities. Our study confirms suggestions by others that jackals, and to a lesser extent caracals, are commonly killed within farming areas of South Africa, but remain relatively abundant [55,57].

By adapting the logistic regression model to incorporate the known probabilities of forced RRT responses, we were able to investigate individual predictors of carnivore killing in a GLMM framework. In our model, we found a negative relationship between question sensitivity and RRT response; farmers who reported an RRT question about a specific carnivore as being sensitive were less likely to admit to killing that carnivore. There are two possible explanations for this. Reports of perceived question sensitivity may have captured farmers' beliefs about the sensitivity of the action with respect to prevailing social norms, so farmers who reported a question as sensitive were genuinely less likely to kill that carnivore. However, some farmers may not have been willing to admit to killing certain carnivores despite the protection offered by RRT. It is impossible to rule out under-reporting of sensitive behaviour even when using such specifically designed techniques [58,59]. However, evidence from validation studies where the true status of each individual is known, (e.g. through access to police records) suggest that RRT returns more accurate responses compared with conventional survey instruments [19]; and, studies comparing survey methods found that RRT returned significantly higher estimates of sensitive or illegal behaviours compared with conventional surveys, which has been interpreted as evidence of more honest reporting [16,17,21,60,61]. We also used what is known as a symmetrical RRT design (prescribing fixed responses as both yes (when dice sum two, three or four), and no (when dice sum 11 or 12), which has been shown to increase the extent to which respondent follow RRT instructions [62]. Compared with conventional methods, RRT has one principle disadvantage owing to the random noise (added by the forced responses), RRT requires large samples in order to get estimates with acceptable precision [19].

A number of studies have investigated people's attitudes towards carnivores [30,36,50–52,63], but none have formally investigated the relationship of these attitudes with peoples' conservation-related behaviours, e.g. killing of protected species. A farmer's negative attitudes towards a carnivore as a result of stock loses, may be mitigated by offering compensation for losses [25], but if the negative attitudes never resulted in farmers persecuting protected carnivores then such interventions may be considered a poor conservation investment, as such, it is critical to understand in what instances attitudes relate to behaviour. Incorporating attitude as an indicator of behaviour into our GLMM allowed us to investigate directly whether farmers' attitudes towards the existence of carnivores on their ranches reflect their reported behaviour. Results suggest that farmers who hold the attitude that carnivores are pests and should be killed on ranches are indeed more likely to have killed carnivores in the last 12 months (as estimated by RRT). A number of studies have not found a clear relationship between attitudes and behaviour in the context of conservation [4,64]. However, such studies tend to investigate general attitudes (such as a person's attitude towards conservation) and then attempt to link this to a very specific behaviour (such as poaching a particular animal from within a protected area); an approach that has been heavily criticized recently [8,37]. By clearly specifying the timescale, target, action and context of the attitude (these days (time) I think that jackals (target) should be killed (action) on ranches (context)) we found that attitude can be a useful indicator of behaviour.

The relationship between farmers' estimates of the proportion of peers killing carnivores and their own behaviour (as reported through RRT) supports the existence of the false consensus effect [10], whereby people who engage in socially undesirable behaviours provide higher estimates of the prevalence of that behaviour in the population, than do people not engaging in the behaviour [65]. Our data support the suggestion by Petroczi *et al.* [9] that asking respondents to estimate the proportion of people in the population that they think perform sensitive behaviours, and offer some potential in identifying groups of people who perform sensitive behaviours.

Our findings demonstrate the potential value of simple non-sensitive indicators for targeting conservation interventions. However, our finding that attitude and the perceived sensitivity of killing carnivores predict carnivore killing in our models, also supports other evidence that farmers' decisions to kill carnivores on their land is not based purely on economic costs and benefits. For example, Lagendijk & Gusset [66] found that some people living around the greater Kruger area in South Africa do not kill lions even when they suffer economic losses and no compensation is available, and suggest that this is because of 'cultural tolerance'. In fact evidence suggests that cultural tolerance of species, including carnivores, reduces extinction probabilities [67]. Compensation for livestock killed by carnivores may be important to encourage commercial farmers to tolerate carnivores [30]. However, social marketing campaigns that apply commercial marketing concepts and techniques to promote behaviour change have had considerable success in influencing undesirable behaviours such as cigarette smoking and illicit drug use [68]. A social marketing campaign promoting the view already held by many farmers, that killing protected carnivores is generally socially unacceptable, and encouraging national pride and tolerance towards South Africa's protected carnivores may be an effective way of changing farmers' behaviour. Any behaviour-change intervention will take time to affect a change so enforcement of existing laws will continue to be important.

5. CONCLUSIONS

When the subject of a survey is sensitive, as is the case with illegal carnivore persecution, it is naive to expect that respondents will provide honest responses when asked questions directly. The RRT allows researchers to gain more accurate estimates of sensitive behaviours and we have shown that it can be adapted in order to identify indicators of behaviour. Reducing carnivore killing could be critical to the persistence of charismatic and declining carnivores, such as leopard and brown hyena in human-managed landscapes. Our results provide evidence that carefully specified attitude statements and people's estimates of the prevalence of sensitive behaviours among their peers may be useful indicators of an individual's involvement in illicit behaviours. Such information can be used to identify groups of people to involve in interventions aimed at changing behaviour.

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