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No single solution: application of behavioural principles in mitigating human–wildlife conflict

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There is no proverbial silver bullet for mitigating human–wildlife conflict, but the study of animal behaviour is foundational to solving issues of coexistence between people and wild animals. Our purpose is to examine the theoretical and applied role that behavioural principles play in understanding and mitigating human–wildlife conflict, and delineate gaps in behavioural theory relative to mitigating these conflicts. Specifically, we consider two different, yet contemporary, examples of human–wildlife conflict: animal–vehicle collisions and carnivore depredation of livestock. Although ostensibly unrelated, both conflict areas share common themes relative to animal behavioural responses to disturbance and perception of risk. We first place the effects on wildlife due to these conflicts in the scope of population sustainability, and then examine current research relative to the following three questions. How is behavioural ecology relevant to these particular areas of conflict? Are advances toward understanding the mechanisms by which animals process information and make decisions being translated into management methods? How might management efforts be affected over time by individual behaviours, method integration and habituation/sensitization? Regarding animal–vehicle collisions, only in the last decade have researchers applied an antipredator theoretical framework with sensory ecology to understand aspects of marine mammal, terrestrial mammal and bird responses to vehicle approach, speed and associated stimuli. However, the size and speeds of modern vehicles demand that we improve economic models and possibly develop novel theoretical frameworks to better predict animal responses to vehicle approach. Within the context of carnivore–livestock depredation, our understanding of individual predator behaviour relative to perceived risk and factors contributing to the development of problem individuals will influence the efficacy of the most promising, nonlethal management approaches (e.g. distractive techniques, reproductive inhibition and olfactory barriers). In both cases, successful management is contingent upon a mechanistic understanding of how animals respond to disturbance and the information utilized to assess risk.

Human history is rife with poorly planned responses to problems occurring between people and wildlife. These responses have all too often resulted in a limited, short-term resolution, alienated some stakeholders, failed completely or exacerbated problems (see Conover, 2002; Murton, 1971; Wright, 1980). Human needs for space, shelter and food will continue to ensure some degree of perceived 'trespass' when it comes to wildlife, a situation that paves the way for human–wildlife conflicts (i.e. situations occurring 'whenever an action by either humans or wildlife has an adverse effect on the other'; Conover, 2002, page 4).

Nonlethal management approaches are critical to mitigating human–wildlife conflicts (Shivik, 2006) and more sustainable from ecological and social perspectives (e.g. these methods avoid negatively affecting nontarget species, polarizing stakeholder groups; Treves & Naughton-Treves, 2005; Woodroffe, Thirgood, & Rabinowitz, 2005). Understanding the behaviour of the target species is

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central to the efficiency and efficacy of nonlethal methods (e.g. development of repellents and methods to provoke animal fear; Conover, 2002; animal response to human disturbances; Blumstein, 2006; Bejder, Samuels, Whitehead, Finn, & Allen, 2009), although the role of behaviour is sometimes not explicitly acknowledged in management policies or practices.

Our goals for this review are to (1) examine the theoretical and applied role that behaviour plays in understanding and mitigating human–wildlife conflicts, particularly as related to larger and long-term conservation efforts, and (2) delineate gaps in behavioural theory relative to mitigating current human–wildlife conflicts. Ultimately, we seek to find opportunities for animal behaviour-related research to develop new knowledge of critical value for conservation practitioners, information which could lead to a stronger application of conservation behaviour principles. We focus on two very different, yet contemporary, examples of human–wildlife conflict: animal–vehicle collisions and carnivore depredation of livestock. The development of nonlethal management for both conflict areas finds its conceptual grounding in understanding how animals initially respond to human disturbances or perceived risk (e.g. Frid & Dill, 2002), but also how animals adapt to levels and periodicity of human-related risk (e.g. Lima & Bednekoff, 1999).

We will first consider the effects on wildlife due to these conflicts in the scope of population sustainability. Specifically, what are the conservation implications, if any, in reducing mortality associated with these conflicts via integration of behaviourally based, nonlethal methods (e.g. see Caro, 2007)? We will then examine current research in these areas relative to the following questions. (1) How is behavioural ecology (including social and sensory aspects that affect resource use and antipredator strategies; Caro, 2005) relevant to the particular area of conflict? (2) How are advances toward understanding the mechanisms by which animals process information and make decisions (e.g. Blumstein & Fernández-Juricic, 2010) being translated into management methods? (c) How might management efforts be affected over time by individual behaviours, method integration and habituation/sensitization (e.g. Bejder et al., 2009)? Importantly, we will not delve into the complex aspects of human behaviour as related to mitigating these two areas of human–wildlife conflict, as others have addressed these dimensions (see Baruch-Mordo, Breck, Wilson, & Broderick, 2009; Huijser et al., 2008; Madden & McQuinn, 2014).

ANIMAL–VEHICLE COLLISIONS

Scope of the Problem

Animal–vehicle collisions (AVCs), whether on roads or railways, or in shipping lanes or the air, represent an evolutionarily novel threat to wildlife (DeVault, Blackwell, Seamans, Lima, & Fernández-Juricic, 2015; Lima, Blackwell, DeVault, & Fernández-Juricic, 2015). AVCs are generally viewed, at least initially, from the perspective of property damage and threats to human safety (e.g. DeVault, Blackwell, & Belant, 2013; Huijser et al., 2008). However, myriad species are affected by AVCs without subsequent damage to a vehicle or human injury (e.g. Fahrig & Rytwinski, 2009; Glista, DeVault, & DeWoody, 2008; Mckenna, Mckenna, Malcom, & Berenbaum, 2001; Soluk, Zercher, & Worthington, 2011). This lack of records for nondamaging AVCs can veil real threats to population sustainability (Lima et al., 2015), and hamper our ability to quantify suspected, severe population effects and to understand and manage this problem.

Estimates of the magnitude of collision-related mortality across taxa are variable, yet the ecological losses when viewed as additive to other anthropogenic sources of mortality (including indirect effects of roads, railways and shipping lanes, as well as animal collisions with anthropogenic structures; Dorsey, Olsson, & Rew, 2015; Hovick, Elmore, Dahlgren, Fuhlendorf, & Engle, 2014; Loss, Will, & Marra, 2014) are staggeringly high and affect a wide range of taxa worldwide. For large and medium-sized mammals in North America, collisions with automobiles account for about 9% of all known mortality (Collins & Kays, 2011). In Europe, automobiles are generally responsible for 5–10% of the mortality of ungulates (Seiler & Helldin, 2006). Vehicle collisions also pose severe threats to some terrestrial mammal species of conservation concern such as Florida panthers, *Puma concolor coryi* (Schwab & Zandbergen, 2011), eastern quolls, *Dasyurus viverrinus,* and Tasmanian devils, *Sarcophilus laniarius* (Jones, 2000).

Smaller vertebrates often compose the majority of casualties when comprehensive surveys are conducted (González-Gallina, Benítez-Badillo, Rojas-Soto, & Hidalgo-Mihart, 2013), despite being greatly underestimated in road-mortality surveys (Santos, Carvalho, & Mira, 2011; Teixeira, Coelho, Esperandio, & Kindel, 2013). For example, along some roads, reptiles and amphibians (especially frogs and toads) can account for >90% of all vertebrates killed by automobiles (Ashley & Robinson, 1996; Glista et al., 2008; Smith & Dodd, 2003), and road mortality can have severe adverse effects on some herpetofauna populations (Beebee, 2013; Mazerolle, Huot, & Gravel, 2005).

Birds also experience substantial losses from vehicle collisions, with annual estimates of 200 million individuals in the U.S.A. (Loss et al., 2014), 13.8 million in Canada (Bishop & Brogan, 2013), and 350 000 to 27 million individuals across several European countries (Erritzøe, Mazgajski, & Rejt, 2003), considering mortality by automobiles only. More birds are killed in the U.S.A. and Canada by vehicles than by collisions with communication towers, wind turbines and hunting (Calvert et al., 2013; Conover, Dinkins, & Haney, 2013; DeVault, 2015). Mortality from vehicles probably contributes to significant population declines for some bird species (Kociolek, Clevenger, St Clair, & Proppe, 2011; Mumme, Schoech, Woolfenden, & Fitzpatrick, 2000; Summers, Cunnington, & Fahrig, 2011; see also Bujoczek, Ciach, & Yosef, 2011), including species of conservation concern (e.g. southern cassowary, *Casuarius casuarius johnsonii*; Goosem, Moore, Byrnes, & Gibson, 2011). In addition to collisions with automobiles, birds are often struck by aircraft (DeVault et al., 2013). In the U.S.A., the Federal Aviation Administration maintains a database of wildlife–aircraft collisions or 'strikes', with >13 000 bird strikes reported annually under a voluntary reporting system (Dolbeer, Wright, Weller, & Begier, 2014).

Unfortunately, data for road mortality of insects are limited and vary widely by taxa (Mckenna et al., 2001; Soluk et al., 2011), although the number of insects killed by automobiles is undoubtedly extremely high (Lima et al., 2015, and citations therein). Data are similarly limited on the population-level effects of animal–train collisions (Dorsey et al., 2015) and vessel collisions involving marine mammals (Knowlton & Kraus, 2001; Neilson, Gabriele, Jensen, Jackson, & Straley, 2012; see also Lima et al., 2015).

Conceptual and Empirical Approaches to Understanding AVCs

One of the most important assumptions to test from a conceptual perspective as related to AVC is that an animal's response to vehicle approach is similar to its response to predator approach. This assumption has been indirectly corroborated in some studies. An examination of injuries to birds struck by aircraft revealed that fatal injury locations were predominantly ventral, suggesting that birds had taken evasive action in response to the aircraft, albeit too late (Bernhardt, Blackwell, DeVault, & Kutchbach-Brohl, 2010). Additionally, escape response by free-ranging turkey vultures,

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