Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Behavioral Sciences

Understanding sensory mechanisms to develop effective conservation and management tools

Daniel T Blumstein[1] and Oded Berger-Tal[1,2]

Applying mechanistic insights from animal behavior to wildlife management and conservation biology problems has had documented successes as well as much promise. For wildlife managers seeking to control problem animals, or conservation biologists seeking to increase the number of threatened or endangered species, a fundamental understanding of sensory mechanisms provides the levers that can modify behavior and influence higher-level population processes. We review recent insights and describe future challenges in using and evaluating sensory mechanisms within a conservation behavior framework.

Addresses
[1] Department of Ecology and Evolutionary Biology, University of California, 621 Young Drive South, Los Angeles, CA 90095-1606, USA
[2] Applied Animal Ecology Division, Institute for Conservation Research, San Diego Zoo Global, CA, USA

Corresponding author: Blumstein, Daniel T (marmots@ucla.edu)

Current Opinion in Behavioral Sciences 2015, **6**:13–18

This review comes from a themed issue on **Integrated study of animal behavior**

Edited by **Dustin Rubenstein** and **Hans Hofmann**

http://dx.doi.org/10.1016/j.cobeha.2015.06.008

Introduction

Conservation behavior is an applied discipline that requires both an understanding of biological phenomena and then the effective application of those phenomena to solve conservation and management problems [1••]. The challenges of conservation are to stabilize or increase the size of declining populations while the challenges of wildlife management are to control animal movement and to reduce overabundant populations. Much recent work has focused on identifying sensory mechanisms underlying behavior, particularly those that may have demographic consequences and, in recent years, those that act at the interface of anthropogenically-driven rapid environmental change.

Why a mechanistic view?

From an applied perspective, mechanisms can be viewed as levers that can be used to modify behavioral or demographic outcomes. Historically, wildlife managers have aimed to respond to wildlife population trends. Declining populations were protected and their population sizes augmented, and efforts have been made to control or eradicate out-breaking or invasive populations. However, the sheer magnitude and rate of the biodiversity crisis our world faces is making most of these efforts futile and there is a growing realization that in order to have a chance at stopping the next massive species extinction, we cannot just respond to populations' trends, but instead seek to understand them, predict them, and in some cases manipulate them. To do so, we need to link the decision-making process of individual organisms with population and community dynamics. In other words, a mechanistic approach to conservation is required [2].

However, finding the mechanistic underpinning of wildlife behavior is often challenging, and is still frequently left as a vague black box. Conservation behavior [1••,3,4••], conservation genetics [5] and more recently conservation physiology [6,7] have all been developed to provide wildlife managers with specific mechanistic tools, which allow for better planning and decision making and aim to improve the success of conservation and management programs. Investigations of sensory mechanisms and their application to wildlife conservation and management have been rapidly increasing in the past few years, and are becoming a vital tool in the conservationist's toolbox. Below we review selected recent highlights and emerging trends from this growing literature on the relationships between sensory mechanisms, behavior, and conservation or wildlife management (see Table 1 for summary and additional examples).

A few examples of how identifying sensory mechanisms is being used to understand conservation behavior problems

Reducing vehicular collisions

Animals are routinely struck by cars, aircrafts and other vehicles and these impacts are detrimental to both wildlife and humans [8•]. Vulnerability to vehicular collisions has been studied by looking for life history and natural history correlates of mortality as well as by identifying sensory mechanisms involved in detecting and fleeing from rapidly approaching objects. For instance, Cook and Blumstein [9] found that omnivorous mammals and herbivorous birds were more likely to be killed by cars. But mechanistic approaches that focus on animals' sensory physiology are particularly promising because they, somewhat uniquely, offer the promise of developing effective mitigation strategies.

Table 1

Some recent examples, published between 2013 and 2015, of wildlife sensory mechanisms studies that either inform us of a conservation concern or provide a management and mitigation tool

Conservation or management problem	Sensory mechanisms involved	Suggested solution	References
Collisions of birds with vehicles (cars and trucks)	Visual	Reducing speed of vehicles and making them more conspicuous (e.g., through the use of flashing lights)	[14,48]
Collisions of birds with airplanes	Visual	Adjusting frequency and brightness of plane's lights to the birds' visual field	[15,49]
Advancements in street light technology and shifts to whiter light sources such as LED is changing the balance among nocturnal predators and prey	Visual	Designing street lamps with eco-friendly spectral light composition	[50–52]
Artificial night lighting alters the phenology of dawn and dusk singing in European song birds	Visual	Reduce the use and intensity of artificial night lighting	[53]
Artificial lights near the coast alters the composition of marine epifaunal communities	Visual	Reduce the use and intensity of artificial night lighting	[54]
Artificially-lit bridge attracts mayflies, while the polarized light properties of its surface promote oviposition on its asphalt surface, reducing fitness to zero.	Visual	Locating the bridge's lights lower and closer to the surface of the road and shading them	[55]
Birds causing crops loss and colliding with planes	Auditory	Broadcasting directional sound to interfere with communications and alarm calls of the birds in order to deter them	[56]
Urban noise undermines female mate preferences in birds	Auditory	Reduce noise levels	[57]
Anthropogenic noise reduced the efficiency of anti-predatory behavior and increases stress in European eels	Auditory	Reduce noise levels	[24]
Anthropogenic noise from ships reduce foraging efficiency in fish and other marine species	Auditory	Reduce noise levels	[19,23]
Anthropogenic noise disturbs communication and increases stress in a variety of species	Auditory	Reduce noise level and when possible adjust auditory output to minimize disturbance	[17–21,58]
Noise from gas wells alters activity levels and echolocation calls in bat species	Auditory	Built sound-damping walls around compressor stations	[59]
Communal roosting site act as an ecological trap by attracting conspecific to their scent regardless of the colony's fate	Olfactory	None suggested	[60]
Higher temperatures due to global warming reduced the efficacy of sexual scent signals in rock lizards	Olfactory	None suggested	[61]

Tyrrell and Fernández-Juricic [10] reviewed — from a visual sensory physiology perspective — how variation in the degree of visual coverage around a prey species' head, its visual acuity, its temporal visual resolution, the number and characteristics of fovea (areas in the eye with particularly acute visual discrimination), the ability to detect motion, and the ability to resolve stimuli against their background, may affect predator detection abilities and escape behavior. Because detecting an approaching vehicle requires the same visual processes, and because animals respond similarly toward approaching vehicles (e.g. [11]), the sensory approach is vital toward developing more predictive models and developing strategies to reduce collisions.

Animals could flee approaching threats in at least two ways. They could maintain a spatial margin of safety by focusing on the distance the threat is from them and thus flee at some threshold distance, or they could maintain a temporal margin of safety by estimating the time to impact of the approaching threat and fleeing at some expected time to impact (e.g. [12,13]). By employing video playbacks of approaching vehicles to brown-headed cowbirds, DeVault *et al.* [14] found that cowbirds used a distance-based rather than a temporal-based escape strategy: they appeared to flee when objects were a certain distance away. However, this assessment mechanism was overwhelmed by rapidly approaching vehicles (>120 km/hour) which cowbirds did not flee. The authors concluded that the evolved sensory abilities were mismatched to these novel rapidly moving objects and this made cowbirds vulnerable to being struck by quickly moving planes and cars driving at highway speeds. Suggested management strategies to mitigate such responses include reducing speed limits and making objects (like planes which cannot be slowed) more obvious by using flashing lights [15].

Mitigating anthropogenic noise and light pollution

Humans, and the machines they invented, have had a profound effect on background noise levels. Increased acoustic noise levels may reduce the distance and area over which acoustic signals can be perceived by animals [16]) and this has been demonstrated to interfere with signaling behavior and communication (e.g. [17,18]), and reduce foraging efficiency (e.g. [19]). Anthropogenic noise can increase acute or chronic physiological stress (e.g. [20,21]), and noise has also been shown to distract prey and reduce their ability to respond to approaching threats [22–24]. To reduce these potentially extremely deleterious impacts, as well as to use noise strategically to repel animals from certain locations, a mechanistic understanding is essential. Indeed, recent reviews have specifically sought to gain a mechanistic insight into the effects of noise pollution on animals [25,26•]. Researchers identify the acoustic stimuli that individuals react to, and how these stimuli elicit behavioral and physiological responses. For example, is the behavioral change the result of the sound being perceived as a threat, or is it due to interference with cue detection? Such a sensory mechanistic approach allows the creation of conceptual frameworks that may enable wildlife managers to correctly identify and understand deleterious effects of noise pollution on various organisms and choose an appropriate method to mitigate these effects [26•].

The need for a mechanistic point of view is perhaps even more evident in the case of light pollution. Artificial light is increasingly changing all aspects of natural light regimes [27•]. The impacts are wide-spread and include extensive changes to species reproduction, orientation, predator–prey interactions and communication in both terrestrial and marine environments [28,29]. Gaston *et al.* [27•] have recently proposed a mechanistic framework which examines the ways in which artificial light alters natural light regimes (spatially, temporally, and across wavelengths) as well as the ways in which light influences biological systems, in particular the distinction between light (or lack of light) as resource and light as a source of information. Species react differently to artificial light because they differ in the wavelength to which their visual systems are most sensitive and responsive [30]. By integrating knowledge of how species' detect and respond to artificial light, we can develop novel mitigation tools to reduce the deleterious effects of light pollution.

Mechanisms underlying species' ability to respond to human-induced rapid environmental change

A large and growing recent body of literature is looking at behavioral responses to human-induced rapid environmental change (HIREC). These anthropogenic changes include habitat loss, the spread of invasive species, pollution and climate change, and are all characterized by being rapid enough to put organisms in evolutionary novel conditions which natural selection has not prepared them for [31]. Given that 'the first line of defense' against a changing environment is usually behavioral, research on behavioral responses to HIREC is rapidly gaining popularity (e.g. [32–34,35••]). Studies on behavioral responses to HIREC focus on two main mechanistic questions.

The first is how animals adjust their behavior as a result of HIREC and what the impacts of these behavioral adjustments are [35••]. In order to answer this question, researchers strive to understand the mechanisms of behavioral plasticity, its influence on population persistence and the subsequent evolutionary response of populations [34,36,37]. While behavioral plasticity may buffer the effects of HIREC in some species, in others, maladaptive behaviors can lead into 'evolutionary traps' by increasing the mismatch between environmental cues and conditions that have historically been associated with these cues [33]. Thus, knowledge on how animals perceive and respond to environmental cues is paramount for any attempt to mitigate evolutionary traps [38].

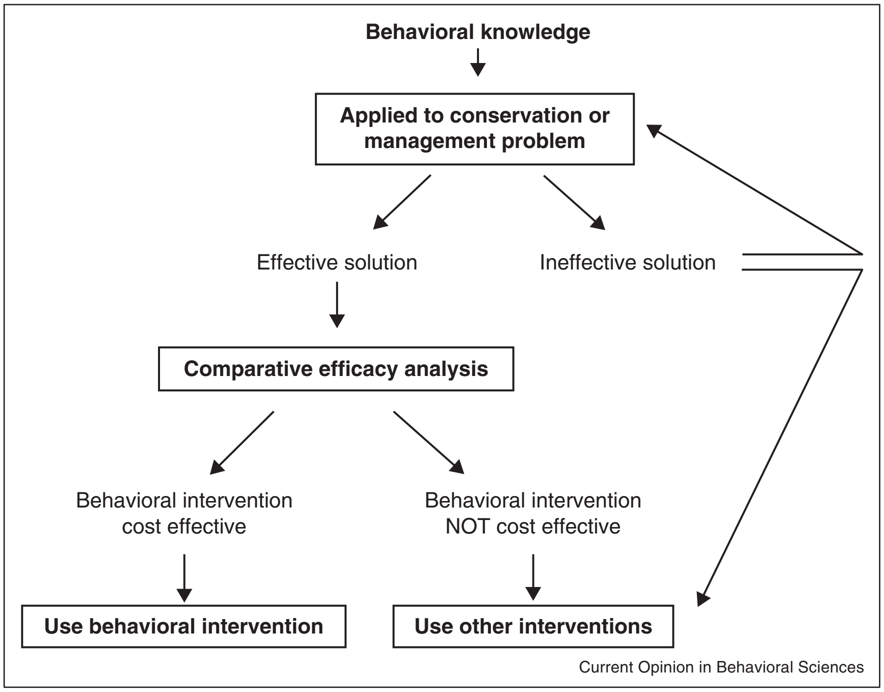
The second question logically follows: why do some species (and individuals) respond well to HIREC, whereas others do not? [39••,40]. Here researchers strive to understand variation in behavioral responses using a variety of established theories such as signal detection theory or adaptive plasticity theory with the goal of generating predictions on which species are more vulnerable to the negative effects of HIREC, as well as creating tools to effectively eliminate or mitigate evolutionary traps [33,38,40].

Evaluation: does applying behavioral principles increase conservation efficacy?

We need more than an academic understanding of sensory mechanisms if we are to effectively apply this knowledge to solve critical management issues. Many conservation behavior papers only describe the *potential* importance of behavioral knowledge to conservation issues, but stopping there has been challenged [41,42]. Excitingly, some studies have begun to apply mechanistic knowledge to try to solve specific management problems (see examples in the previous sections), and this is an essential step. But we must go even beyond applying it; we must evaluate it. Proper evaluation is a fundamental aspect of effective conservation behavior [1••].

Following a larger trend (www.conservationevidence.com, www.environmentalevidence.org), recent conservation behavior work has highlighted the importance of building in evaluation into management actions and estimating the efficacy of these actions. This can work several ways. First, there can be formal experiments conducted in an adaptive management framework [43] to identify those interventions that work and those that do not. Second, there can be systematic reviews and formal meta-analyses [44,45•] of published literature to estimate effect sizes and efficacy.

Figure 1



A schema through which a mechanistic knowledge of animal behavior (sensory or otherwise) can be applied to solve wildlife conservation or management problems. If the intervention is effective it must be evaluated against other possible interventions in a formal comparative efficiency analysis. The most cost-effective intervention should be the one used.

Both evaluation approaches are essential to properly translate the many *potential* mechanistic *insights* for wildlife conservation and management into *effective* conservation and management *interventions*. However, one should not stop there; formal comparative effectiveness analyses [46,47] are also needed (Figure 1). If it is much more costly to use a conservation behavior intervention than some other option, all else being equal, the other option should be preferred.

Conclusions

We suggest that by adopting a mechanistic approach, in particular, one that focuses on sensory mechanisms, behavioral biologists can develop potential tools to solve wildlife conservation and management problems. We have reviewed some exciting recent discoveries that have adopted a mechanistic approach and we have outlined a schema through which behavioral biologists aiming to translate behavioral insights into management tools should adopt. The field of conservation behavior does not have the solutions for all conservation problems, but it may offer extremely useful tools to solve certain problems. The coming years will help identify where these tools can be most profitably applied.

Conflict of interest statement

Nothing declared.

Acknowledgements

We thank Dustin Rubenstein and Hans Hofmann for encouraging us to write this perspective, and Esteban Fernández-Juricic and two anonymous reviewers for comments on previous versions. DTB is supported by the National Science Foundation (DEB-1119660), OB-T is supported by a Fulbright fellowship and a San Diego Zoo post-doctoral fellowship.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. •• Blumstein DT, Fernández-Juricic E: *A Primer on Conservation Behavior*. Sinauer Associates, Inc.; 2010.
This primer provides a practical guide for the integration of behavioral ecology into conservation biology. It includes conceptual and methodological tools aimed to aid in solving biological conservation and wildlife management problems.

2. Blumstein DT, Fernández-Juricic E: **Emergence of conservation behavior**. *Conserv Biol* 2004, **8**:1175-1177.

3. Sutherland WJ: **The importance of behavioural studies in conservation biology**. *Anim Behav* 1998, **56**:801-809.

4. •• Berger-Tal O, Polak T, Oron A, Lubin Y, Kotler BP, Saltz D: **Integrating animal behavior and conservation biology: a conceptual framework**. *Behav Ecol* 2011, **22**:236-239.
Newly developing interdisciplinary scientific fields require a well-structured underlying framework to be able to evolve. Here, a conceptual framework is proposed, indentifying the key linkages between animal behavior and conservation biology. The framework is simply structured, hierarchical and parsimonious, and it set the stage for generating hypotheses and developing subfields within the discipline.

5. Frankham R, Ballou JD, Briscoe DH: *Introduction to Conservation Genetics*. 2nd ed.. Cambridge University Press; 2010.

6. Cooke SJ, Sack L, Franklin CE, Farrell AP, Beardall J, Wikelski M, Chown SL: **What is conservation physiology? Perspectives on an increasingly integrated and essential science**. *Conserv Physiol* 2013, **1** http://dx.doi.org/10.1093/conphys/cot001.

7. Cooke SJ, Blumstein DT, Buchholz R, Caro T, Fernández-Juricic E, Franklin CE, Metcalfe J, O'Connor CM, Cassidy St, Clair C, Sutherland WJ, Wikelski M: **Physiology, behaviour and conservation**. *Physiol Biochem Zool* 2014, **87**:1-14.

8. • Lima SL, Blackwell BF, DeWault TL, Fernández-Juricic E: **Animal reactions to oncoming vehicles: a conceptual review**. *Biol Rev* 2015 http://dx.doi.org/10.1111/brv.12093.
This review focuses of the behavioral reactions of various animals to oncoming vehicles in an effort to shed light on animal–vehicle collisions. Animals often fail to avoid an oncoming vehicle, and these failures may occur in detection, threat assessment or in choosing and performing an appropriate evasive behavior. The response of animals is in many cases taxa-specific and the review calls for novel behavioral research and experimental work across taxa to create generalizations and help find solutions to this acute problem.

9. Cook TC, Blumstein DT: **The omnivores dilemma: diet explains variation in roadkill mortality**. *Biol Conserv* 2013, **167**:310-315.

10. Tyrrell LP, Fernández-Juricic E: **Sensory systems and escape behavior**. In *Escaping from Predators: An Integrative View of Escape Decisions.* Edited by Cooper Jr WE, Blumstein DT. Cambridge University Press; 2015.

11. Bernhardt GE, Blackwell BF, DeVault TL, Kutchbach-Brohl L: **Fatal injuries to birds from collisions with aircraft reveal antipredator behaviours**. *Ibis* 2010, **152**:830-834.

12. Dill LM: **Distance-to-cover and the escape decisions of an African cichlid fish, *Melanochromis chipokae***. *Environ Biol Fishes* 1990, **27**:147-152.

13. Cárdenas Y, Shen B, Zung L, Blumstein DT: **Evaluating temporal and spatial margins of safety in galahs**. *Anim Behav* 2005, **70**:1395-1399.

14. DeVault TL, Blackwell BF, Seamans TW, Lima SL, Fernández-Juricic E: **Speed kills: ineffective avian escape responses to oncoming vehicles**. *Proc R Soc Biol* 2015, **282**:20142188.

15. Blackwell BF, DeVault DL, Seamans TW, Lima SL, Baumhardt P, Fernández-Juricic E: **Exploiting avian vision with aircraft lighting to reduce bird strikes**. *J Appl Ecol* 2012, **49**:758-766.

16. Barber JR, Crooks KR, Fristrup KM: **The costs of chronic noise exposure for terrestrial organisms**. *Trends Ecol Evol* 2010, **25**:180-189.

17. McLaughlin KE, Kunc HP: **Experimentally increased noise levels change spatial and singing behavior**. *Biol Lett* 2013, **9**:20120771.

18. Naguib M: **Living in a noisy world: indirect effects of noise on animal communication**. *Behaviour* 2013, **150**:1069-1084.

19. Voellmy IK, Purser J, Simpson SD, Radford AN: **Increased noise levels have different impacts on the anti-predator behavior of two sympatric fish species**. *PLoS ONE* 2014, **9**:e102946.

20. Blickley JL, Word KR, Krakhauer AH, Phillips JL, Sells SN, Taff CC, Wingfield JC, Patricelli GL: **Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*)**. *PLoS ONE* 2012, **7**:e50462.

21. Tennessen JB, Parks SE, Langkilde T: **Traffic noise causes physiological stress and impairs breeding migration behaviour in frogs**. *Conserv Physiol* 2014, **2**:cou032 http://dx.doi.org/10.1093/conphys/cou032.

22. Chan AAY-H, Blumstein DT: **Attention, noise, and implications for wildlife conservation and management**. *Appl Anim Behav Sci* 2011, **131**:1-7.

23. Wale MA, Simpson SD, Radford AN: **Noise negatively affects foraging and antipredator behaviour in shore crabs**. *Anim Behav* 2013, **86**:111-118.

24. Simpson SD, Purser J, Radford AN: **Anthropogenic noise compromises antipredator behaviour in European eels**. *Glob Change Biol* 2014 http://dx.doi.org/10.1111/gcb.12685.

25. Kight CR, Swaddle JP: **How and why environmental noise impacts animals: an integrative mechanistic review**. *Ecol Lett* 2011, **14**:1052-1061.

26. • Francis CD, Barber JR: **A framework for understanding noise impacts on wildlife: an urgent conservation priority**. *Front Ecol Environ* 2013, **11**:305-313.
Noise is an intense, widespread pollutant, which affect countless species worldwide. Anthropogenic noise can be perceived as a threat, or it may interfere with cue detection. Both pathways lead to behavioral and physiological responses that have direct consequences on animals' fitness. In order to correctly mitigate the effects of noise on animals, wildlife managers must correctly identify and understand the ways in which anthropogenic noise is reducing fitness.

27. • Gaston KJ, Bennie J, Davies T, Hopkins J: **The ecological impacts of nighttime light pollution: a mechanistic appraisal**. *Biol Rev* 2013, **88**:912-927.
Artificial light is increasingly modifying natural light regimes by encroaching on dark refuges in space, in time, and across wavelengths. The conservation impacts of light pollution are wide-spread and include extensive changes to species reproduction, orientation, predator–prey interactions and communication. This mechanistic review highlights the potential influence of nighttime lighting at all levels of biological organization, and the current research gaps, in particular with relation to identifying intensity thresholds and the spatial extent of impacts in the vicinity of artificial lights.

28. Lyytimaki J: **Nature's nocturnal services: light pollution as a non-recognized challenge for ecosystem services research and management**. *Ecosyst Serv* 2013, **3**:e44-e48.

29. Davis TW, Duffy JP, Bennie J, Gaston KJ: **The nature, extent, and ecological implications of marine light pollution**. *Front Ecol Environ* 2014, **12**:347-355.

30. Gaston KJ, Davies TW, Bennie J, Hopkins J: **Reducing the ecological consequences of night-time light pollution: options and developments**. *J Appl Ecol* 2012, **49**:1256-1266.

31. Sih A, Ferrari MCO, Harris DJ: **Evolution and behavioural responses to human-induced rapid environmental change**. *Evol Appl* 2011, **4**:367-387.

32. Candolin U, Wong BBM (Eds): *Behavioural Responses to a Changing World: Mechanisms and Consequences*. Oxford University Press; 2012.

33. Robertson BA, Rehage JS, Sih A: **Ecological novelty and the emergence of evolutionary traps**. *Trends Ecol Evol* 2013, **28**:552-560.

34. Foster SA, Sih A: **Behavioural plasticity and evolution**. *Anim Behv* 2013, **85**:1003.

35. •• Wong BBM, Candolin U: **Behavioral responses to changing environments**. *Behav Ecol* 2014 http://dx.doi.org/10.1093/beheco/aru183.
Anthropogenic environmental changes currently represent the single greatest threat to global biodiversity. Behavior plays a pivotal role in determining the fate of species. Adaptive plastic responses can allow some species to track the changing environment. These changes in behavior can have long lasting effects on ecosystems' function and stability. Altered behaviors may also have important evolutionary consequences.

36. Foster SA: **Evolution of behavioural phenotypes: influences of ancestry and expression**. *Anim Behav* 2013, **85**:1061-1075.

37. Snell-Rood EC: **Evolutionary causes and consequences of behavioural plasticity**. *Anim Behav* 2013, **85**:1004-1011.

38. Greggor AL, Clayton NS, Phalan B, Thornton A: **Comparative cognition for conservationists**. *Trends Ecol Evol* 2014, **29**:489-495.

39. •• Sih A: **Understanding variation in behavioural responses to human-induced rapid environmental change: a conceptual overview**. *Anim Behav* 2013, **85**:1077-1088.
Why do some animal readily adapt to human-induced rapid environmental changes (HIREC), while others do not? This paper offers a conceptual framework to explain variation in behavioral response to HIREC, and suggests that the degree of match/mismatch between past

environments and the novel environment produced by HIREC is key to explaining this behavioral variation.

40. Sih A, Ehlman S, Halpin R: **On connecting behavioral responses to HIREC to ecological outcomes: a comment on Wong and Candolin**. *Behav Ecol* 2014 http://dx.doi.org/10.1093/beheco/aru229.

41. Blumstein DT: **Prioritizing conservation behavior research: a comment on Wong & Candolin**. *Behav Ecol* 2014 http://dx.doi.org/10.1093/beheco/aru208.

42. Schakner ZA, Petelle MB, Berger-Tal O, Owen M, Blumstein DT: **Developing effective tools for conservation behaviourists: reply to Greggor et al**. *Trends Ecol Evol* 2014, **29**:651-652.

43. Walters CJ, Holling CS: **Large-scale management experiments and learning by doing**. *Ecology* 1990, **71**:2060-2068.

44. Collaboration for Environmental Evidence: Guidelines for Systematic Review and Evidence Synthesis in Environmental Management. Version 4.2. 2013, Environmental Evidence: www.environmentalevidence.org/Documents/Guidelines/Guidelines4.2.pdf.

45. • Dicks LV, Walsh JC, Sutherland WJ: **Organising evidence for environmental management decisions: a '4S' hierarchy**. *Trends Ecol Evol* 2014, **29**:607-613.

The limited use of scientific information in environmental decisions has been attributed partly to decision-makers' lack of access to relevant scientific literature and to a lack of effort to incorporate the growing evidence base into decision frameworks. This paper builds on the highly successful evidence-based clinical practice that is now routine in the medical disciplines, and describes a '4S' hierarchy for organizing relevant science to inform decision makers and improve environmental decision-making process.

46. American College of Physicians: **Information on cost-effectiveness: an essential product of a national comparative effectiveness program**. *Ann Inter Med* 2008, **148**:956-961.

47. Smith RK, Dicks LV, Mitchell R, Sutherland WJ: **Comparative effectiveness research: the missing link in conservation**. *Cons Evid* 2014, **11**:2-6.

48. DeVault TL, Blackwell BF, Seamans TW, Lima SL, Fernández-Juricic E: **Effects of vehicle speed on flight initiation by Turkey vultures: implications for bird-vehicle collisions**. *PLoS ONE* 2015, **9**:e87944.

49. Blackwell BF, Fernández-Juricic E: **Behavior and physiology in the development and application of visual deterrents at airports**. In *Wildlife in Airport Environments: Preventing Animal–aircraft Collisions through Science-based Management.* Edited by DeVault TL, Balckwell BF, Belant JL. The John Hopkins University Press; 2013.

50. Davies TW, Bennie J, Inger R, de Ibarra NH, Gaston KJ: **Artificial light pollution: are shifting spectral signatures changing the balance of species interactions?** *Glob Change Biol* 2013, **19**:1417-1423.

51. Pawson SM, Bader MKF: **LED lighting increases the ecological impact of light pollution irrespective of color temperature**. *Ecol Appl* 2014, **24**:1561-1568.

52. Stone EL, Wakefield A, Harris S, Jones G: **The impacts of new street light technologies: experimentally testing the effects on bats of changing from low-pressure sodium to white metal halide**. *Phil Trans R Soc B* 2015, **370**:20140127.

53. Da Silva A, Valcu M, Kempenaers B: **Light pollution alters the phenology of dawn and dusk singing in common European songbirds**. *Phil Trans R Soc B* 2015, **370**:20140126.

54. Davies TW, Coleman M, Griffith KM, Jenkins SR: **Night-time lighting alters the composition of marine epifaunal communities**. *Biol Lett* 2015, **11**:20150080.

55. Szaz D, Horvath G, Barta A, Robertson BA, Farkas A, Egri A, Tarjanyi N, Racz G, Krista G: **Lamp-lit bridges as dual-traps for the night-swarming Mayfly, *Ephoron virgo*: interactions of polarized and unpolarized light pollution**. *PLoS ONE* 2015, **10**:e0121194.

56. Mahjoub G, Hinders MK, Swaddle JP: **Using a "sonic net" to deter pest bird species: excluding European starling from food sources by disrupting their acoustic communication**. *Wildlife Soc B* 2015 http://dx.doi.org/10.1002/wsb.529.

57. Des Aunay GH, Slabbekoorn H, Nagle L, Passas F, Nicolas P, Draganoiu TI: **Urban noises undermines female sexual preferences for low-frequency songs in domestic canaries**. *Anim Behav* 2014, **87**:67-75.

58. Schmidt R, Morrison A, Kunc HP: **Sexy voices – no choices: male song in noise fails to attract females**. *Anim Behv* 2014, **94**:55-59.

59. Bunkley JP, McClure CJW, Kleist NJ, Francis CD, Barber JR: **Anthropogenic noise alters bat activity levels and echolocation calls**. *Glob Ecol Conserv* 2015, **3**:62-71.

60. Grether GF, Levi A, Antaky C, Shier DM: **Communal roosting sites are potential ecological traps: experimental evidence in a Neotropical harvestman**. *Behav Ecol Sociobiol* 2014, **68**:1629-1638.

61. Martin J, Lopez P: **Effects of global warming on sensory ecology of rock lizards: increased temperatures alter the efficacy of sexual chemical signals**. *Funct Ecol* 2013, **27**:1332-1340.