Price *et al. Environ Evid* 2019, **8**(Suppl 1):12
https://doi.org/10.1186/s13750-019-0156-4

Environmental Evidence

SYSTEMATIC MAP PROTOCOL

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What evidence exists on the effectiveness of different types of olfactory lures as attractants for invasive mammalian predators? A systematic map protocol

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Abstract

Background: Alien mammalian predators are a major cause of species extinction and decline globally. Baits and lures, usually human-food based (for example meat, nuts or oils), are widely deployed in trapping programs to attract target species, but their effectiveness compared to other types of olfactory lures, for example social odours or prey odours, has never been systematically examined. Depending on the context, there can be high proportions of non-target captures, for example when targeting feral cats using cage traps, or low capture success, for example, when targeting introduced rats on tropical islands. Here we use a systematic process to map evidence on the effectiveness of different categories of olfactory attractants for invasive mammalian predators within different ecological contexts. We aim to look for where evidence clusters and knowledge gaps occur, for example, across different lure types or across different habitat-types, and highlight opportunities for future research into behaviourally-relevant olfactory lures.

Methods: We will compile evidence from bibliographic databases, online search engines, government websites, specialist sites and expert contacts, and include 'grey' literature. Where possible, a Boolean-style full search string will be used, including Population, Intervention and Outcome search terms. Searches will be conducted in English, but a public request to the IUCN SSC Invasive Species Specialist Group (ISSG) will be made for literature including in languages other than English. Search comprehensiveness will be evaluated against 25 benchmark articles known to the authors. We will base inclusion of articles on presence of quantitative data, subject identity (invasive mammalian predator species), comparator (more than one type of olfactory lure assessed or lure compared to a control) and outcome (quantified attraction to lures or controls). Inclusion consistency checks will be performed with 10% of the titles and abstracts and 10% of the full texts. We will critically appraise the literature only on the basis of study design (e.g. appropriate controls) and sample size, rather than interpret the results. Finally, we will develop a searchable literature database accompanied by systematic 'heat' maps to visually represent knowledge clusters and gaps within different subsets of evidence, and a narrative synthesis of the evidence.

Keywords: Predator control, Invasive species, Pest control, Alien species, Introduced predators, Baits, Trapping programs, Olfaction, Mammal

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Background

Alien mammalian predators are a major cause of species extinction and decline globally. An extensive literature documents the impacts of alien predators on native species, with decline or extinction inextricably linked to predator introduction [1]. Introduced rodents occur on every continent and island system permanently inhabited by people (with the exception of Antarctica) [2, 3], mustelids have been introduced to islands throughout the South Pacific [4] as well as across Europe [5] and South America [6]. In Australia, the red fox *Vulpes vulpes* and feral cat *Felis catus* populate most of the mainland and many offshore islands [7]. Hedgehogs *Erinaceus europaeus* have been introduced to New Zealand and offshore islands in Europe, threatening ground-nesting birds [8, 9]. Control of alien predators has brought about improvements in the conservation status of some species of declining native taxa [10], but eradication of most aliens remains difficult outside closed, isolated populations such as offshore islands [11, 12].

Conservation managers and wildlife management agencies primarily use lethal control via trapping or poisoning to achieve conservation goals associated with reducing the density of introduced predators (for example [13]). Attracting target species to specific control devices or locations can be challenging, both for practitioners as well as researchers studying the ecological interactions and behaviour of predators.

Using odour cues to attract mammalian predators targets their intrinsic olfactory acuity, conserved from the earliest mammals [14], and encoded by the largest section of their genome [15]. Most mammalian predators use olfaction for a variety of purposes including social communication [16, 17], risk assessment (see [18, 19] and references within), disease avoidance [20], mate choice [21] and foraging [22, 23]. While food has been the traditional bait for enticing animals into a trap or to a location, other odours such as from conspecifics, competitors and predators, have also been shown to attract target species and may have broader uses in wildlife management [24–26]. To date the development of lures and baits has progressed in an ad hoc manner with ease of deployment, cost and practicality being the primary concerns, rather than assessments of overall long-term effectiveness or scientifically robust comparisons of alternatives, resulting in a preference for food-based baits and lures [27]. For example, peanut butter and cereal-based baits are commonly used to attract rodents to traps and monitoring devices globally despite having problems, such as field longevity and attraction to non-target species [27].

In our systematic map [28], we aim to collate and categorise evidence for olfactory attraction to baits and lures from the world's worst introduced predators (as listed by the IUCN ISSG) and identify knowledge gaps in the literature. We will include both baits (containing a food reward) and lures (no food reward) when it is the odour of the food-based bait that draws the target animals into the trap or monitoring device. From this broad evidence base, we aim to discover which ecologically-based hypotheses have been well tested, for example, that predators are attracted to food, but also where there are clear knowledge gaps and opportunities for further investigation, such as investigating whether eavesdropping on apex predator cues is a behaviour that can be exploited to develop new lures for mesopredators [25, 29]. For the first time, we hope to systematically examine a broad-base of evidence from a diverse range of species and locations around the world to gain a better understanding of how olfactory-driven behaviours could be exploited to mitigate the impact of introduced mammalian predators. Local food availability, breeding season, target species density and predator or competitor presence are all factors likely to affect the motivation of individuals to investigate an odour. For example, foraging motivation attracts individuals to investigate prey odours but may be dampened if highly nutritious food is readily available, reproductive motivation attracts males to odours of oestrous females but may be absent out of breeding season and territorial defence may drive individuals to investigate odours of conspecifics but primarily when competition for resources is high. Individual, species-specific and density-dependent behaviours may also affect responses.

Stakeholder engagement

Olfactory lures and baits are an extremely common tool in wildlife management globally, particularly when targeting mammals [27, 30, 31]. Yet, the behaviours that lead individual animals to be interested in different types of odours can be overlooked by wildlife managers when developing techniques for trapping or attracting target species [32]. Undertaking a broad assessment of the effectiveness of olfactory lures was discussed with an international group of behavioural ecologists in a Collaboration for Environmental Evidence (CEE) training workshop in October 2017. Subsequently, an Advisory Team was established (i.e., the co-authors), comprising experts in invasive mammals, behavioural ecology, animal cognition and conservation biology. The Advisory Team contributed to the search strategy and will be part of the consistency checking process. All Advisory Team members contributed to the lists of search terms, inclusion/exclusion criteria, literature, specialist websites and contact persons. Moreover, the complete Advisory Team ensured that the primary question turned out to be as relevant (for practitioners) and comprehensive (for a systematic map) as practically feasible.

Objectives of the systematic map

The objective of our systematic map is to collate, categorise and assess the quantity and quality of evidence that compares the effectiveness of different lure types for attracting invasive mammalian predators. Developing a broad systematic map is the first stage in assessing whether a specific systematic review is warranted for a subset of the evidence. The systematic map will be used to identify evidence clusters and knowledge gaps, as well as potential effect modifiers, and opportunities for future research into behaviourally and ecologically-relevant olfactory lures for invasive mammalian predators. It will also be used to assess whether any sub-topics identified within the systematic map warrant a more detailed systematic review.

Primary question

What olfactory lures have been evaluated for their effectiveness for attracting invasive mammalian predators?

The primary question can be broken down into the following 'PICO' components:

Population (P)	invasive terrestrial mammalian predators;
Intervention (I)	types of olfactory lure, i.e., the odour from and/or a substance used to lure an animal to a specific location such as a recording device or trap. Olfactory lures can be food substances, odours from conspecifics or heterospecifics, competitors, predators, prey or other non-food substances;
Comparator (C)	different types of olfactory lures and/or no olfactory lure;
Outcome (O)	measure of attraction to lure, including no attraction or repulsion;

Secondary questions

The primary evidence will be subdivided to further examine the evidence base for the following secondary questions, to better understand how many studies and the type of studies that examine likely effect modifiers or areas of heterogeneity associated with the primary question. The secondary questions will inform the categories required in the metadata to highlight gaps in the evidence base. The secondary questions are:

(a) Are food-based lures more effective for attracting invasive mammalian predators than other types of olfactory lures (for example, social odours or prey odours)?

This question examines "type of lure" as an area of heterogeneity, specifically food-based lures. For this question we will further categorise "food" as either:

i. "novel", a food that is different from that which animals would experience normally in their environment, for example peanut butter;
ii. "familiar", a food type that wild animals would experience in their environment, for example rabbit; or
iii. "similar", where the food used is a surrogate for a naturally occurring food, for example chicken as a surrogate for bird prey.

(b) What types of olfactory lures for attracting invasive mammalian predators have been tested in different environments (tropical compared to temperate compared to alpine compared to arid environments)?

This question examines whether environment type is an effect modifier. We will categorise the lure types against environment type, and include metadata variables that show the experimental design used in the test.

(c) What olfactory lures types are effective for attracting invasive mammalian carnivores compared to invasive mammalian omnivores?

This question examines whether diet-breadth is an effect modifier, and how well the evidence base addresses carnivores compared to omnivores.

(d) Does social structure (for example, social versus solitary) of the species influence the effectiveness of social odours as lures for invasive mammalian predators?

This question examines whether sociality of the species is an area of heterogeneity when examining the effectiveness of social odours as lures. Odour deposits are part of an open communication system and therefore allow otherwise solitary species to socialise with one another through chemical information [33].

(e) Are evolutionary novel or evolutionary familiar lures more effective for invasive mammalian predators? (for example, if a prey odour is to be used as a lure).

This question examines whether shared evolutionary history with a lure odour is an effect modifier.

Methods

Searching for articles

The search aims to capture an unbiased and comprehensive sample of the literature relevant to the question, whether published or unpublished. As many different sources of information will be searched as practicable in order to maximise the evidence collected (see below list of databases to be searched in English).

Search string

A list of relevant search terms for the two relevant elements of the question (PI) was generated by the team, and then supplemented by keywords from relevant studies (Table 1). Species or genera names of all invasive mammalian predators (including carnivores and omnivores, but not herbivores, frugivores or insectivores) recorded by the Global Register of Introduced and Invasive Species (GRIIS) as having "evidence of impact" were included in the search string (GRIIS data extracted October 2017). Limiting phrases were also included to ensure the search was returning relevant studies. The initial search string was formatted for Web of Science using Boolean-style operators. Simplified search strings will be developed for databases and search engines that do not accept or require the full search string proposed in Table 1. All alterations or changes to the search string will be recorded against the database searched, as well as the date that the search was conducted.

Table 1 The initial Boolean-style search string for Web of Science (WoS)

	Search String
P (population)	("invasive" OR "alien*" OR "introduced" OR "feral" OR "pest" OR "exotic") AND ("mammal*" OR "predator*" OR "Carnivor*" OR "Civettictus civetta" OR "Viverridae" OR "Civet" OR "Mink" OR "Mustelidae" OR "Neovison vison" OR "Hedgehog" OR "Erinaceidae" OR "Erinaceus amurensis" OR "Shrew" OR "Soricidae" OR "Suncus murinus" OR "Marten" OR "Martes foina" OR "Rat" OR "Rattus" OR "Rodent" OR "Muridae" OR "norvegicus" OR "Brushtail Possum" OR "Phalangeridae" OR "Trichosurus vulpecula" OR "Felis catus" OR "Felidae" OR "Cat" OR "Coyote" OR "Canis latrans" OR "Canidae" OR "Macaque" OR "Macaca fascicularis" OR "Cercopithecidae" OR "Dog" OR "Canis lupus familiaris" OR "Canis familiaris" OR "Dormouse" OR "Glis glis" OR "Gliridae" OR "Erinaceus europaeus" OR "Polecat" OR "Mustela putorius" OR "Vulpes vulpes" OR "Fox" OR "Ferret" OR "Mustela furo" OR "Macaca cyclopsis" OR "Jackal" OR "Canis aureus" OR "Tamarin" OR "Callitrichidae" OR "Leontopithecus" OR "Wolf" OR "Canis lupus" OR "Crocidura russela" OR "Martes melampus" OR "Weasel" OR "Mustela itatsi" OR "Mustela nivalis" OR "Marmoset" OR "Callitrichidae" OR "Callithrix jacchus" OR "Callithrix penicillata" OR "Paguma larvata" OR "Mouse" OR "Mus musculus" OR "Mus domesticus" OR "Muskrat" OR "Ondatra zibethicus" OR "Cricetidae" OR "Atelerix algirus" OR "Squirrel" OR "Sciuridae" OR "Callosciurus erythraeus" OR "Rattus exulans" OR "Raccoon" OR "Procyon lotor" OR "Procyonidae" OR "Nyctereutes procyonoides" OR "Chipmunk" OR "Tamias sibiricus" OR "Mustela sibirica" OR "Mongoose" OR "Herpestes javanicus" OR "Herpestidae" OR "Viverricula indica" OR "Coati" OR "Nasua nasua" OR "Lycalopex griseus" OR "stoat" OR "Mustela erminea" OR "Apodemus agrarius" OR "Macaca arctoides" OR "Tenrec" OR "Tenrec ecaudatus" OR "Tenrecidae" OR "Boar" OR "Sus scrofa" OR "Suidae" OR "pig" OR "wildcat" OR "Felis silvestris")
I (intervention)	AND ("lure*" OR "bait*" OR "trap*" OR "attract*" OR "capture" OR "entice" OR "control" OR "eradicate" OR "kill" OR "exterminate" OR "remove" OR "repel*") OR (odo*r OR olfact* OR smell OR scent OR nose)
C (comparator)	
O (outcome)	

Bibliographic databases

The following online bibliographic databases will be searched, using the institutional access provided by the University of Sydney. Where possible, searches will exclude articles from clearly irrelevant research fields, such as Physical Sciences and Arts, for example by adding SU = "Life Sciences Biomedicine" in Web of Science. Such specifications will be documented. Bibliographic databases will only be searched in English.

Databases to be searched:

1. ISI Web of Science Core Collection—Database for Scientific Literature and Data—(https://webofknowledge.com).
2. BIOSIS Previews via Web of Science (1926–present).
3. CABI: CAB Abstracts via Web of Science (1910–present).
4. Current Contents Connect via Web of Science (1998–present).
5. KCI—Korean Journal Database via Web of Science.
6. MEDLINE via Web of Science.
7. Russian Science Citation Index via Web of Science.
8. SciELO Citation Index via Web of Science.
9. Zoological Record via Web of Science.
10. ANR-Index: Agriculture and Natural Resources Index and Archive via Informit Online (1975–2007).
11. Agris (1975–present).
12. Conference Papers Index via Proquest.
13. ELIXIR: DPI's Electronic Library eXchange for Information Resources via Informit Online (1990–2010) (Australia).

14. ENDANGER: Threatened Species in Australia via Informit Online (1960-present).
15. Environment Complete via Ebsco.
16. EVA: Environmental Abstracts via Informit Online (1987–present).
17. Geobase via Engineering Village (1980-present).
18. National Library of Agriculture (US)—Agricola.
19. Scopus—Database for Peer-Reviewed Literature—(https://www.scopus.com).
20. BioRxiv—The Preprint Server for Biology—(https://www.biorxiv.org/).
21. ProQuest—Dissertation and Theses Dissemination and Ordering—(http://www.proquest.com/).
22. AHB: Australian Heritage Bibliography via Informit Online (1987–present).
23. Biological Sciences via Proquest (1982–present).
24. BioOne.1.
25. GreenFILE via Ebsco.
26. SAGE—Science and Geography Education via Informit Online (1990–present) (Australian).
27. PsycINFO via OvidSP (1806–present).
28. PubMed.
29. Dissertations and Theses Global via Proquest.
30. ScienceDirect.

The following search engines will also be used to search for relevant studies [34]:

1. Google Scholar (www.googlescholar.com).
2. Google (www.google.com).

A list of specialist websites and databases will be compiled and added to as new sources are encountered during the search process. The final list will be published as an Additional file 1 to the systematic map.

Specialist websites

The following specialist websites will be queried for relevant information on species of invasive mammalian predators:

- IUCN general publications (https://portals.iucn.org/library/dir/publications-list and https://www.iucn.org/theme/species/publications).
- IUCN Conservation Planning Specialist Group (http://www.cpsg.org/document-repository).
- Conservation Evidence (www.ConservationEvidence.com).
- US Federal Science database (https://www.science.gov/).
- Association of Zoos and Acquarium's (AZA) Animal Programs Database (https://www.aza.org/species-survival-plan-programs); Access through San Diego Zoo Global.

Additional searches

We will consult stakeholders within the network of our Advisory Team for relevant published and unpublished material. A request will be made on the ALIENS email group administered by the IUCN SSC Invasive Species Specialist Group for unpublished reports that contain relevant information, including those in languages other than English.

Adjustments to the search string (Table 1) will be documented. The total hits per unique search within each database will be recorded with the date of the search. If the mapping exercise runs for more than 2 years, updated searches will be run prior to completion and the results updated. The comprehensiveness of the search strategy will be assessed using a list of 25 benchmark articles known to the authors. The search strategy will be amended until it returns 100% of the benchmark studies, and published in the final systematic map. Review articles will not be used in the systematic map, however their reference lists will be checked to ensure the relevant literature is included in our search results. If the same intervention is documented in a published study and a grey literature source, both will be consulted, but only the one with the best description of methods and results will be included. In this case, it will be noted that a duplicate existed from another source. If one source contains more information about one method and the other source contains more information about a second method used, then the two sources will be combined for assessing the metadata metrics. The library of studies will be assembled in an excel spreadsheet.

Article screening and study eligibility criteria

i. Article screening

The study screening process will be conducted using CADIMA (https://www.cadima.info), an online, open source platform developed to facilitate the preparation of systematic reviews [35].

The inclusion and exclusion criteria will be applied by one reviewer to all potential studies. Studies will be screened using the title and abstract at the same time. Where there is insufficient information to make decisions regarding study inclusion, relevance to the next stage of the review process (full text assessment) will be assumed. A second reviewer will examine a random subset of 25% of the reference list from title and abstract (up to a maximum of 300 references) to assess repeatability of the selection criteria. Consistency checking will be undertaken before the screening process. Kappa analysis [36, 37] will be applied to ensure that there is 'substantial' agreement between the two reviewers, i.e. a resulting Kappa value of 0.6 or above is required. Disagreement regarding inclusion or exclusion of studies will be resolved by consensus or following assessment by a third reviewer. If the Kappa value is low, the reference list will be reassessed against adjusted inclusion and exclusion criteria. A similar subset of references will be reassessed by a second reviewer with Kappa analysis.

All studies identified as relevant at the screening stage will proceed to full text assessments. Full texts will be retrieved via open source platforms and institutional access, where possible, or by contacting authors to request a copy. Consistency checking will be undertaken before the full text assessment as more than one reviewer should undertake this process. Articles authored by the systematic reviewers will be assessed for inclusion or exclusion by an independent reviewer.

Should relevant reports or papers be identified that are in languages other than English, we will seek to have the data extracted and entered into our database by a researcher proficient in the appropriate language.

ii. Eligibility criteria

Initially all studies that pass the eligibility criteria for Population and Intervention will be included:

- Eligible subjects: species of introduced predatory terrestrial mammal that have been listed on the Global Register of Introduced and Invasive Species (GRIIS) by the IUCN SSC Invasive Species Specialist Group as having a negative impact on native animal species. Subjects can be captive or wild for the study to be included in the mapping exercise.
- Eligible intervention: use of an olfactory attractant, bait or lure of some sort, that may or may not contain food, to capture or entice individuals to a particular site or trap.

Where studies are deemed to be relevant at the full text stage based on Population and Intervention criteria, they will also be assessed based on the presence of Comparator and Outcome criteria to determine the study's suitability to be included in the map:

- Eligible comparator: the study must include a comparison of the attraction of animals to different types of olfactory baits/lures or between a bait/lure and a control (no bait/lure) or between an olfactory bait/lure and a non-olfactory bait/lure, for example a visual or auditory lure.
- Eligible outcome: initially, any outcome that includes a measure of attraction or repulsion will be considered for inclusion in the systematic map.
- Eligible study design: studies should include comparisons between the effectiveness of different baits/lures using experimental procedures that ensure independence between sites and control for learning effects if using the same subject individuals. However, we will use the metadata to assess the proportion of studies that include appropriate comparisons and controls.

A list of articles excluded at the full text assessment stage with reasons for exclusion will be provided as an Additional file 1 to the systematic map.

Study validity assessment

Reviewers will assess the quality of the study based on hierarchies of evidence adapted from models of the systematic review process used in other fields, such as medicine and public health, for example a randomised control trial is weighted higher than site comparison study [38, 39] (Table 2). This information will be included in the metadata and consistency checking will be undertaken prior to data extraction.

Data coding strategy

Metadata on the following variables will be collected from each study included in the systematic map. Where necessary, metadata will be coded according to the subvariables shown:

Table 2 Study validity categories. From [41, 42]

Quality	Replication	Sample selection	Other sources of bias
High	Well-replicated (> 10 individuals per group)	Random	None
Medium	Moderate level of replication (5–10 individuals per group)	Not stated but clearly random	Potential confounder
Low-Poor	Poorly replicated or not stated (1–4 individuals per group)	Purposive or not stated	Clear confounder e.g., repeated measures on same individuals

- Citation.
- Study duration.
- Study location (Continent, Country, State—if identified, Locality e.g. Island—if identified).
- Study timing (season and reproductive season).
- Study ecosystem (arid/temperate grasslands/temperate forest/tropical/urban).
- Study context (island/mainland).
- Predator name (common and latin names).
- Predator status (introduced/native).
- Study subject context (wild/captive and free-ranging/pen trials).
- Study subject origin (captive-bred/wild caught).
- Olfactory attractant/s type (novel food/familiar food/similar food/prey odour/prey live/prey dead/conspecific odour/conspecific reproductive odour/conspecific territorial odour/predator odour/competitor or heterospecific odour/ecologically irrelevant/water).
- Olfactory attractant (name).
- Olfactory attractant evolutionarily familiar (yes/no).
- Olfactory attractant ecologically familiar (yes/no).
- Food reward (present/absent).
- Study design (randomised control/repeat exposure/choice experiment).
- Experimental procedure (no interference/trapping/y-maze/cafeteria choice).
- Learning effects—repeated exposures per subject (yes/no).
- Sample size per treatment.
- Study validity assessment.
- Source of study.
- Predator social behaviour (group-living/solitary).
- Territorial behaviour (yes/no).
- Diet breadth (carnivore/omnivore).
- Local food availability (high/medium/low/unknown/NA).
- Target species density (high/low/unknown/NA).
- Density of competitive species (high/low/unknown/NA).
- Density of predatory species (high/low/unknown/NA).

The meta-data for all studies assessed will be included as Additional file 1 in the final publication. Should sufficient detail not be included in the study itself, we will contact the lead and corresponding authors directly. All extracted metadata will be incorporated into a standardized spreadsheet which will record each study's design, statistics used, sample size etc., and used as the basis for the systematic map of the evidence that exists. Consistency checking will be undertaken at the start of the process.

Study mapping and presentation

The evidence will be collated in a database and presented as a systematic 'heat' map to illustrate the number and type of studies that address the effectiveness of different types of olfactory lures to attract introduced predators. Summary 'maps' (or tables) collating the number of studies by species, or geographic area, or lure type in the database will be published on the Environmental Evidence website [40]. If appropriate, the summary statistics may be presented on a GIS map to show where the hotspots of research are located. Each systematic map will be accompanied by a narrative synthesis to explain the type of evidence presented in the map, its limitations and strengths, and where knowledge gaps exist. The narrative synthesis will include quantitative descriptions of the evidence found, focussing particularly on the robustness of the evidence associated with study designs and significant knowledge gaps, and include descriptive statistics on the proportion and number of studies that investigate different aspects of the primary and secondary questions. Recommendations for sub-topics that may warrant a systematic review based on the collation of a significant evidence base will be made based on the results of the heat maps and narrative synthesis. Similarly, unrepresented or underrepresented subtopics that warrant further primary research will be identified from the systematic map.

The systematic maps and accompanying narrative syntheses will be accessible from the Environmental Evidence website. Our methods adhere to the ROSES guidelines and follow CEE standards of best practice for systematic maps.

Additional file

Additional file 1. Metadata from all the studies assessed in the systematic map.

Authors' contributions

CJP wrote the first draft of the paper. All authors contributed to the writing of the final draft of the paper. All authors read and approved the final manuscript.

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Acknowledgements

We sincerely thank Biljana Macura for training CJP and ALG in the methods of systematic evidence synthesis. This training was made possible with support from the support from the Jacob Blaustein Center for Scientific Cooperation, The Swiss Institute for Dryland Environmental & Energy Research, the Mitrani Department of Desert Ecology, and Ben-Gurion University of the Negev. We also thank Christian Köhl for advice on using CADIMA.

Competing interests
The authors declare that they may be an author of studies that will be included in this systematic mapping exercise. Where one of the authors studies is being considered, a non-author reviewer will be required to cross-check the metadata entered and have the final authority on how the study is characterised within the systematic map.

Availability of data and materials
The datasets generated and/or analysed during the current study are available at the CADIMA website (http://www.cadima.info).

Consent for publication
Not applicable.

Ethics approval and consent to participate
Not applicable.

Funding
A.L.G is funded by a Clark endowed postdoctoral fellowship, gifted to San Diego Zoo Global. Publication costs were funded as part of a workshop in collaboration with Ben Gurion University and Monash University.

About this supplement
This article has been published as part of Environmental Evidence Volume 8 Supplement 1, 2019: Using animal behavior in conservation management. The full contents of the supplement are available online at https://environmentalevidencejournal.biomedcentral.com/articles/supplements/volume-8-supplement-1.

Publisher's Note

Published: 13 June 2019

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