Evidence shortfalls in the recommendations and guidance underpinning ecological mitigation for infrastructure developments

Sara B. Hunter[1,4*], Sophus O.S.E zu Ermgassen[2], Harriet Downey[3], Richard A. Griffiths[2] & Caroline Howe[1]

1. Centre for Environmental Policy, 16-18 Princes Gardens, Imperial College London, London, SW1 1NE, UK
2. Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Canterbury, CT2 7NR, UK
3. Department of Zoology, University of Cambridge, David Attenborough Building, Cambridge, CB2 3QZ, UK
4. School of Life Sciences, John Maynard Smith Building, University of Sussex, Falmer, Brighton, BN1 9QG, UK

*Corresponding Author: sh848@sussex.ac.uk

Keywords: conservation policy; evidence-based conservation; ecological mitigation; human-wildlife conflict; no net loss; mitigation hierarchy

Abstract

1. In the UK and European Union, legal protection of species from the impacts of infrastructure development depends upon a number of ecological mitigation and compensation (EMC) measures to moderate the conflict between development and conservation. However, the scientific evidence supporting their effectiveness has not yet been comprehensively assessed.

2. This study compiled the measures used in practice, identified and explored the guidance that informed them and, using the Conservation Evidence database, evaluated the empirical evidence for their effectiveness.

3. In a sample of 50 UK housing applications, we identified the recommendation of 446 measures in total, comprising 65 different mitigation measures relating to eight taxa. Although most (56%) measures were justified by citing published guidance, exploration of the literature underpinning this guidance revealed that empirical evaluations of EMC measure effectiveness accounted for less than 10% of referenced texts. Citation network analysis also identified circular referencing across bat, amphibian and reptile EMC guidance. Comparison with Conservation Evidence synopses showed that over half of measures recommended in ecological reports had not been empirically evaluated, with only 13 measures assessed as beneficial.

4. As such, most EMC measures recommended in practice are not evidence-based. The limited reference to empirical evidence in published guidance, as well as the circular referencing, suggests potential 'evidence complacency', in which evidence is not sought to inform recommendations. In addition, limited evidence availability indicates a thematic gap between conservation research and mitigation practice. More broadly, absence of evidence on the effectiveness of EMC measures calls into question the ability of current practice to compensate for the impact of development on protected species, thus highlighting the need to strengthen requirements for impact avoidance. Given the recent political drive to invest in infrastructure expansion, high-quality, context-specific evidence is urgently needed to inform decision-making in infrastructure development.

1.Introduction

Infrastructure expansion, one of the most significant pressures on biodiversity worldwide (IPBES, 2019), currently threatens around a third of species on the IUCN Red List (Maxwell et al., 2016) and is set to accelerate in coming decades (McDonald et al., 2020). At a global level, the combined pressures of continued biodiversity loss and commitments to infrastructure expansion under the Sustainable Development Goals present an urgent need to mitigate the environmental impacts of development (zu Ermgassen et al., 2019). In line with global trends and national post-Coronavirus economic recovery strategies, the UK has invested heavily in infrastructure development, with the recently announced 'Project Speed' aiming to support development of schools, hospitals and transport infrastructure, as well as more than 200,000 new homes (Prime Minister's Office, 2020). Given that urbanisation is a dominant threat to UK wildlife (Hayhow et al., 2016), commitments to protecting and enhancing populations of native species (Eustice, 2020) could represent a conflicting objective. Hence, at a national level, there is a need to reconcile development with biodiversity conservation goals.

A widely used framework to resolve conflict between infrastructure expansion and conservation is the Mitigation Hierarchy. This mandates that development impacts should be avoided, minimised, remediated and offset, in order of decreasing preference (zu Ermgassen et al., 2019), with the aim of achieving 'No Net Loss' of biodiversity. Though the Mitigation Hierarchy can be applied to habitats or ecosystem services, it is often applied to species, for example, through the Australian Environmental Protection and Biodiversity Act (1999) and the US Endangered Species Act (1973). The EU Habitats Directive (1992) requires that development activities have no detriment to the 'favourable conservation status' of Schedule 2 species. Allowances can be made if there is 'no satisfactory alternative', in which case developers can obtain a license that permits otherwise illegal activities, demonstrating the steps made to ensure No Net Loss for local species populations (European Commission, 2007). This has been integrated into UK policy through the Conservation of Habitats and Species (EU Exit) Regulations (2019). UK species also receive some degree of protection under other legal instruments, including the NERC Act (2006), the Wildlife and Countryside Act (1981) and the Protection of the Badgers Act (1982).

In practice, policies that protect species from development impacts have resulted in the widespread implementation of ecological mitigation and compensation (EMC) measures, such as translocation (Germano et al., 2015) and construction of artificial roosting or nesting sites (e.g. bat boxes) (Regnery et al., 2013). The need for such measures in response to the predicted consequences of development are usually identified through Ecological Impact Assessment (CIEEM, 2017). Habitat-based 'biodiversity offsetting' has received global attention due to its controversial nature, practical challenges (Bull et al., 2013) and the ability to measure and observe its implementation (Bull & Strange, 2018). However, in the UK, species-based measures remain the most commonly applied mitigation actions (Treweek & Thompson, 1997) and, due to the integration of EU Habitats Directive into UK legislation, are likely to be applied to infrastructure developments going forward.

Evidence-based conservation, an approach that advocates systematic application of empirical evidence to conservation management (Sutherland et al., 2019), is widely regarded as a desirable decision-making approach. Originally adopted from clinical medicine, evidence-based conservation is now an emerging research field (Centre for Evidence Based-Conservation, 2020) and has been adopted by government agencies. For example, Natural England's recently published 'Science, Evidence & Evaluation Strategy' outlines their aim to become an 'evidence led' organisation (Natural England, 2020).

Evidence-based conservation has also delivered multiple databases that synthesise literature on intervention outcomes. For example, the Conservation Evidence initiative, launched in 2004, summarizes scientific evidence for the effects of conservation 'actions', defined as 'any intervention used to manage, protect, enhance or restore wildlife or ecosystems' (Sutherland et al., 2019). Using expert elicitation, its 'synopses' provide estimates for the effectiveness of actions, based on a systematic search and review of literature quantitatively assessing intervention outcomes (Sutherland et al., 2019). These synopses, organised by subject area or taxa, are periodically updated to reflect newly available evidence. Conservation Evidence also maintains a discipline-wide repository of literature that meets this inclusion criteria (*Ibid*).

Despite these efforts, evidence shortfalls remain a barrier to making informed EMC recommendations (Hill & Arnold, 2012). Singh et al. (2020) also found that assuming ecological mitigation measures are effective without evidence-based justification is a global issue. Whilst there are multiple studies evaluating individual EMC measures (e.g. Nash et al., 2020), there are few comprehensive reviews. Where conducted, they generally point to evidence paucity, exacerbated by limited post-development monitoring, and an inability of EMC measures to compensate for impacts. For example, Lewis et al. (2016) found no published literature supporting the effectiveness of great crested newt mitigation. Stone et al. (2013) identified a significant reduction in post-development bat abundance across 300 derogation licenses, whilst Lintott & Mathews' (2018) analysis of post-development reports revealed that only 52% of lofts created as licensed compensation contained bats. Issues surrounding EMC effectiveness have also been highlighted beyond the UK, for example, in France (Regnery et al. 2013). The potential mismatch between research focus and practice, known as the 'thematic gap' (Habel et al., 2013), combined with poor integration of such evidence into conservation practice (Sutherland & Wordley, 2017) is likely to exacerbate the detrimental impacts of development on wildlife populations.

Accessibility of evidence is also a barrier to bridging the gap between research and conservation practitioners (Walsh et al., 2019). Cvitanovic et al. (2014), for example, found that scientific literature accounted for only 14% of information cited in marine protected area management plans. Thus, an important intermediary step takes the form of secondary publications (*ibid*). Information within published guidance has become part of standard practice for development mitigation (Downey et al., 2021). As such, local authorities and licensing bodies generally expect ecological consultants to follow methods outlined in guidance (Natural England, 2016). However, the degree to which recommendations in guidance documents are themselves supported by evidence remains unclear.

Consequently, the aim of this study was to explore the perceived evidence gap (Hill & Arnold, 2012) in EMC by systematically tracing measures back to their evidence base. We used a sample of ecological reports associated with UK housing developments, submitted between 2011 and 2020, to quantify the measures used in practice. The evidence supporting these measures was then investigated through examination of supporting guidance and comparison with the Conservation Evidence database. A focus on housing developments was chosen due to the significant biodiversity impact of this industry (Maxwell et al., 2016) and the recent drive for housing expansion in the UK (Prime Minister's Office, 2020). Only species-specific (as opposed to habitat-specific) measures were explored, due to the context of sustained population declines of UK 'priority species' (Hayhow et al., 2016) and hence the need to reconcile development with species conservation in particular.

2.Materials and Methods

2.1 Developing a Database of Mitigation and Compensation Measures

To develop the database of recommended EMC measures applied to housing developments, data were extracted from a sample of planning applications made to two adjacent local planning authorities in South-East England, Maidstone & Swale Borough Councils. Though all local authorities must make recent planning applications publicly available, these areas were selected based on the availability of planning applications spanning more than five years, and the ability to apply specific search criteria to their shared planning portal. Protected species legislation is universally applied across the UK, so the patterns elicited from our sample should be representative across the country.

Relevant documentation was reviewed for every large (>10 dwellings) housing development granted planning permission in the two councils during the 9-year period 2011-2020 (Table S1). Planning applications were only included if they comprised relevant ecological reports, restricted to Ecological Impact Assessment, protected species surveys, Ecological Mitigation Plans or Preliminary Ecological Appraisal, due to their requirement for impact assessment and EMC measure recommendation (CIEEM, 2017). Where multiple documents were available, a decision tree was utilised (Fig. S1), corresponding to the number and rigour of ecological surveys required by each report type (*ibid)*.

EMC measures recommended in each ecological report were identified and recorded, based on typologies defined both *a priori* (in line with Conservation Evidence 'actions', to enable subsequent effectiveness assessment) or inductively through the data extraction process (Table S2). Development metadata (size, number of dwellings, location) were also extracted from planning application forms.

2.2 Identifying and Exploring Guidance

Data on the guidance supporting recommended measures was also extracted from ecological reports. Guidance documents, cited either in bibliographies or as in-text references supporting specific measures, were recorded. As guidance was mostly species- or taxon-specific, guidance present in bibliographies was assumed to support all measures recommended for the taxon of focus. This assumption is justified by the reported reliance on published guidance by ecological consultants (Downey et al., 2021).

Whilst the recommendations given in guidance may be supported by evidence, this can be unclear, due to a lack of thorough referencing. Therefore, to assess the 'evidence-transparency' of the guidance documents (Rutter & Gold, 2015), those documents that were publicly available (31 of 37) were screened for availability of supporting literature, in the form of either in-text references, by-chapter bibliographies, general bibliographies or further reading lists.

By reviewing this literature, we were then able to assess the evidence supporting guidance recommendations. We utilised a standardised data extraction protocol to minimise the subjectivity of assessment. To minimise reviewing citations irrelevant to EMC, citations in chapters relating to other activities, such as surveys, and in-text references supporting actions unrelated to EMC were excluded from review. All references in general bibliographies and further reference lists were reviewed, as it was not possible to link citations to particular recommendations.

All supporting texts were classified into 'evidence type' categories (Table 1). References that supported particular guidance recommendations in-text were also assigned a category denoting the level of support given to the corresponding assertion, as well as whether these references related to empirical evidence for intervention effectiveness, empirical evidence for intervention mechanism or non-empirical texts (Table S4). For supporting texts taking the form of empirical evaluation of EMC measure effectiveness, study design (After; Before-After; Before-After Control-Impact; Randomized Controlled Trial) was determined, using definitions outlined by Christie et al. (2019). Subsequent critical review utilised the 'hierarchy of methodology', in which studies with more robust experimental designs are assigned greater weight (Pullin and Knight, 2003).

Table 1: *Typologies, along with illustrative examples, of 'evidence type' categories assigned to cited texts. The only category that demonstrates evidence for EMC measures is 'Empirical Evidence for the Effectiveness of EMC Measure'.*

Evidence Type Category	Description	Example
Guidance on protected species management	Guidance on the management of PS, related to development mitigation or general management.	Hutson, A M (1987) *Bats in houses*. The Bat Conservation Trust, London.
Guidance on habitat management	Guidance on the management of a particular habitat.	English Nature (1996) *Managing ponds for wildlife.* English Nature, Peterborough.
Guidance on surveys	Guidance on conducting protected species surveys.	Froglife (2001) *Advice Sheet 11: Surveying for (Great Crested) Newt Conservation.* Froglife, Halesworth.
Guidance on legislation	Guidance legislation relating to one or more protected species.	The Mammal Society (ND) *Badger Persecution and the Law.* The Mammal Society, Dorset.
Background on species ecology	Provides general information or guidance on the ecology, behaviour or morphology of a particular taxa or species.	Beebee & Griffiths (2000) *Amphibians and Reptiles.* Collins, London.
Background on population & distribution	General information about the geographic distribution and population status of particular taxa or species.	Arnold (1995) *Atlas of amphibians and reptiles in Britain.* HMSO Books, London.
Empirical evidence for species ecology	Empirical evidence for the behaviour, ecology or morphology of a particular taxa or species.	Cooke (1996) Studies of the great crested newt at Shillow Hill, 1984-1986. *Herpetofauna News*, 6, 4-5.
Empirical evidence for conservation status	Empirical evidence for the conservation status of particular taxa or species.	Beebee (1975) Changes in the status of the great crested newt (*Triturus cristatus*) in the British Isles. *British Journal of Herpetology*, 5, 481-486.
Empirical evidence for impact	Empirical evidence for the impact of development on a particular taxa or species.	Stone et al., (2012) Conserving energy at a cost to biodiversity? Impacts of LED lighting on bats. *Global Change Biology,* 18 (8), 2458-2465.
Empirical evidence for survey method effectiveness	Empirical evidence for the efficacy of survey methods for a particular taxa or species.	Griffiths & Raper (1994) *A review of current techniques for sampling amphibian communities.* JNCC, Peterborough.
Empirical evidence for the effectiveness of emc measure	Empirical evidence for the effectiveness of one or more EMC measures.	Morris (1990) Use of nest boxes by the dormouse *Muscardinus avellanarius. Biological Conservation,* 51 (1), 1-13.
Other	Any other supporting text.	ILP (2003) *Domestic Security Lighting, Friend or Foe.* Institution of Lighting Engineers, Rugby.

To visualise the relationship between texts cited by different guidance, quantitative citation networks (Portenoy et al., 2017) were developed by converting reference data into network objects using the R Studio v3.5.2 *network* package (Butts et al., 2019). Networks, in which texts and citations were represented as nodes and edges, respectively, were then plotted via the 'ggnet2' function of the R Studio v3.5.2 *GGally* package (Schloerke et al., 2020), using a Fruchterman-Reingold algorithm. Analyses were restricted to bat and amphibian and reptile guidance, as these were the only groups with over five associated guidance documents. Texts categorised as 'Other' evidence type, which were unrelated to EMC, were excluded from networks.

2.3 Evaluation of Empirical Literature Supporting Mitigation and Compensation Measures

To evaluate the empirical support for EMC, measures identified in ecological reports were compared to the Conservation Evidence synopses for terrestrial mammals (excluding bats and primates), bats, birds and amphibians (Sutherland et al., 2019). EMC measures present in our database were searched for and if available, their effectiveness category and the literature supporting this assessment were recorded.

As a Conservation Evidence reptile synopsis was unavailable, studies within their literature repository were reviewed to assess EMC measures for this taxon. Whilst this does not represent a comprehensive literature search, as studies are added from journals (300 English and 300 non-English) upon publication (Sutherland et al., 2019), this provided the most up-to-date and specific overview of recent available evidence. Data from studies evaluating reptile EMC were extracted using the aforementioned standardised template, with additional descriptive categories, study outcome and variable assessed, enabling basic evidence synthesis. Study location and target taxon indicated relevance to EMC application, whilst study design enabled assessment of internal validity (Christie et al., 2019; 2020).

3.Results

3.1 Developing a Database of Mitigation and Compensation Measures

Planning application search yielded 139 results, 50 of which were selected for review. Fifty-three applications were excluded as they were amendments of other applications; 36 had no relevant ecological report. Of those reviewed, only seven had an associated Ecological Impact Assessment; 32 had a Preliminary Ecological Appraisal; 24 had one or more protected species surveys and 10 had an Ecological Management Plan. Developments outlined in these applications comprised 3,783 dwellings across a total of 183.9 ha. As this study is focused on the planning application stage, some of these developments may not have been implemented.

We identified 446 EMC measures from the ecological reports (77% mitigation, 23% compensation), yielding a total of 65 unique measures across eight taxa: birds (8 different measures), bats (16), reptiles (12), great crested newts (11), badgers (4), hedgehogs (8), dormice (5) and invertebrates (1). These are not exclusively Schedule 2 protected species, indicating that multiple legal instruments were considered in the recommendation of EMC. On average, nine measures were associated with each development.

Birds were addressed by the highest number of ecological reports (86%), followed by bats (75%) and reptiles (52%). However, bat-specific measures made up the largest proportion (34.5%) of total measures (Fig. 1). Although birds were most frequently addressed, 20 ecological reports recommended only one bird-related measure, namely conducting vegetation clearance outside of the breeding season. This measure was also recommended for 80% of developments, as all breeding birds fall within the Wildlife and Countryside Act 1981, therefore this measure could represent 'standard practice'. The group with the highest mean number of measures was great crested newts (4.31) followed by bats (4.02).

Bat-specific lighting measures were the most common overall (199/446), largely reflecting the high number of ecological reports in which bats were addressed. Some measures were frequently recommended for specific taxa: for example, where reptiles and great crested newts were addressed, translocation was recommended in 69% and 77% of ecological reports, respectively; where badgers were addressed, all ecological reports recommended covering excavations overnight and providing means of escape. Again, this suggests that some measures represent standard practice for UK developments. See SI for data on all recorded measures.

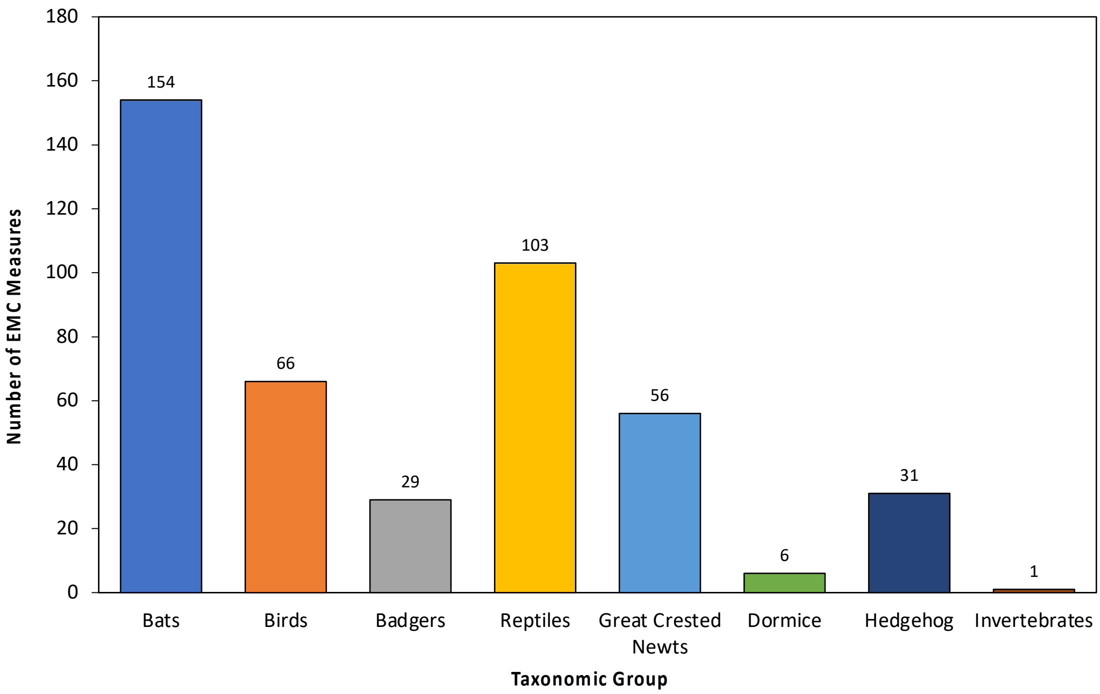

***Figure 1**: Total number of mitigation and compensation measures (446) relating to each species group.*

3.2 The Identity and Nature of Supporting Guidance

Across all reviewed ecological reports, 37 different guidance documents were referenced, resulting in 56% of EMC measures being transparently supported by guidance. Overall, 31/37 of these publications were publicly accessible, ranging in publication date from 1994 to 2019, with 71% published pre-2011.

Over half (16/31) of reviewed guidance related to bats. Whilst one document addressed barn owls (Ramsden & Twiggs, 2009), no other bird-related guidance was identified. The most commonly cited guidance was Mitchell-Jones (2004), followed by Herpetofauna Groups of Britain and Ireland (1998).

Most guidance documents (24/31) contained supporting evidence as in-text references to literature, bibliographies or further reading lists. However, as some guidance related to general species conservation, the number of references relating to EMC was relatively low. For example, Edgar et al. (2010) referenced 52 supporting texts with only three related to EMC measures (Table 2). In addition to formal references, five documents provided evidence as case-studies or anecdotes.

Table 2*: Details of the 8 most frequently cited guidance documents identified in ecological reports. References contained in bibliographies were not separated into those EMC-related or not, as they were not linked to particular recommendations in text.*

Guidance Document	Number of Citing Ecological Reports	Target Taxa	Supporting Evidence	References (total)	References (EMC Related)
Mitchell-Jones, A.J. **(2004)** *Bat Mitigation Guidelines.* English Nature, Peterborough.	14	Bats	Further Reading List	10	NA – all references in bibliography
HGBI **(1998)** *Evaluating Local Mitigation/ Translocation Programmes: Maintaining Best Practice and Lawful Standards.* Herpetofauna Groups of Britain and Ireland (HGBI), Halesworth.	12	Reptiles & Amphibians	Bibliography	5	NA – all references in bibliography
English Nature **(2001)** *Great Crested Newt Mitigation Guidelines.* English Nature, Peterborough.	8	Great Crested Newts (*Triturus cristatus*)	Further Reading List	64	NA – all references in bibliography
Bat Conservation Trust and the Institute of Lighting Engineers **(2009)** *Bats and Lighting in the UK.* Bat Conservation Trust, London.	6	Bats	Bibliography	14	NA – all references in bibliography
Gent, T. & Gibson, S. eds. **(1998)** *Herpetofauna Workers Manual*. JNCC, Peterborough.	5	Reptiles & Amphibians	In-Text References	257	4
Edgar, P., Foster, J. and Baker, J. **(2010)** *Reptile Habitat Management Handbook*. Amphibian and Reptile Conservation Trust, Bournemouth.	4	Reptiles	In-Text References	52	3
Bat Conservation Trust and the Institute of Lighting Engineers **(2008)** *Bats and Lighting in the UK.* Bat Conservation Trust, London	4	Bats	Bibliography	14	NA – all references in bibliography
Gunnell, K. **(2012)** *Landscape and Urban Design for bats and biodiversity.* Bat Conservation Trust, London	4	Bats	In-Text References	36	24

3.3 The Nature of Supporting Literature in Guidance

Although more recent guidance utilised more recent supporting texts (Fig. 2), the majority of supporting literature was published over 20 years ago (Fig. 2). Although this does not determine the ‘quality’ of evidence, it suggests that more recent evidence, if available, is not assimilated into guidance and hence, is not informing practice. Nevertheless, even updated guidance often referenced identical supporting literature, including ‘Bats and Lighting in the UK’ (Bat Conservation Trust & ILP, 2008 & 2009)*;* ‘The Bat Workers Manual’ (Mitchell-Jones & McLeish, 1999 & 2004) and ‘The Herpetofauna Workers Manual’ (Gent & Gibson, 1998 & 2003), suggesting that no efforts were made to update recommendations or no new evidence was generated.

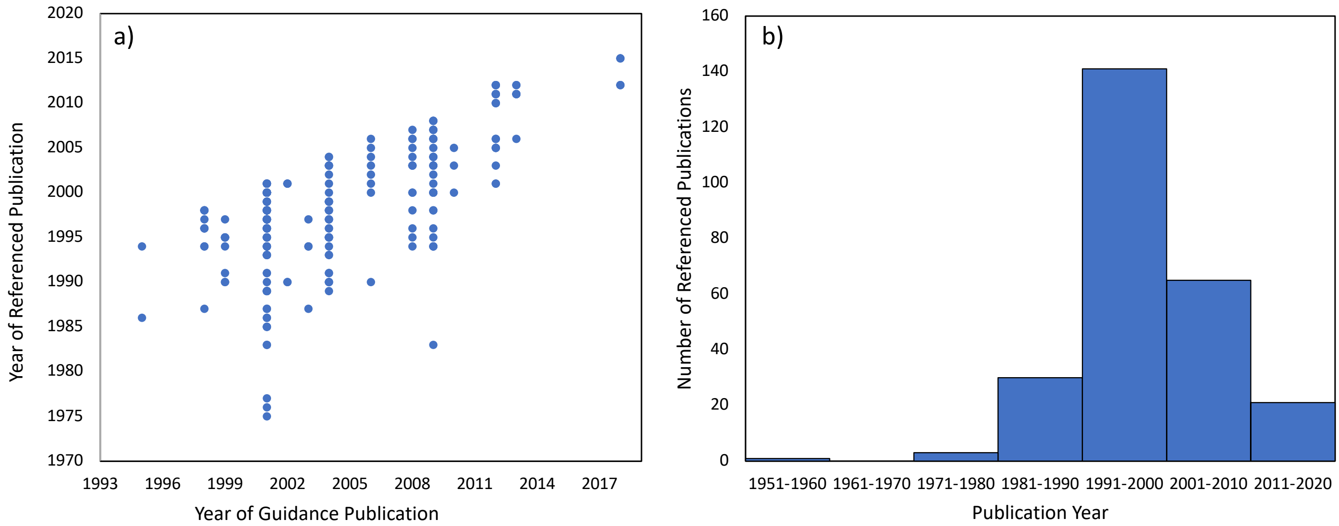

***Figure 2:** The frequency of publications dates across all referenced literature. a) Scatter plot of the year of guidance publication against the year of referenced literature publication. b) Histogram illustrating the frequency of publication dates in all literature referenced in guidance.*

In total, 272 texts referenced by guidance documents were reviewed, of which the most common ‘evidence-type’ (34.2%) was guidance for protected species management (Fig. 3). Notably, the guidance supporting the highest number of EMC measures (HGBI, 1998) only referenced six texts, which all took the form of other guidance documents. Empirical evidence for the effectiveness of EMC measures made up only 8.8% of referenced texts overall. This evidence type made up a greater proportion of in-text references (25%) compared with references in bibliographies and further reading lists (4%).

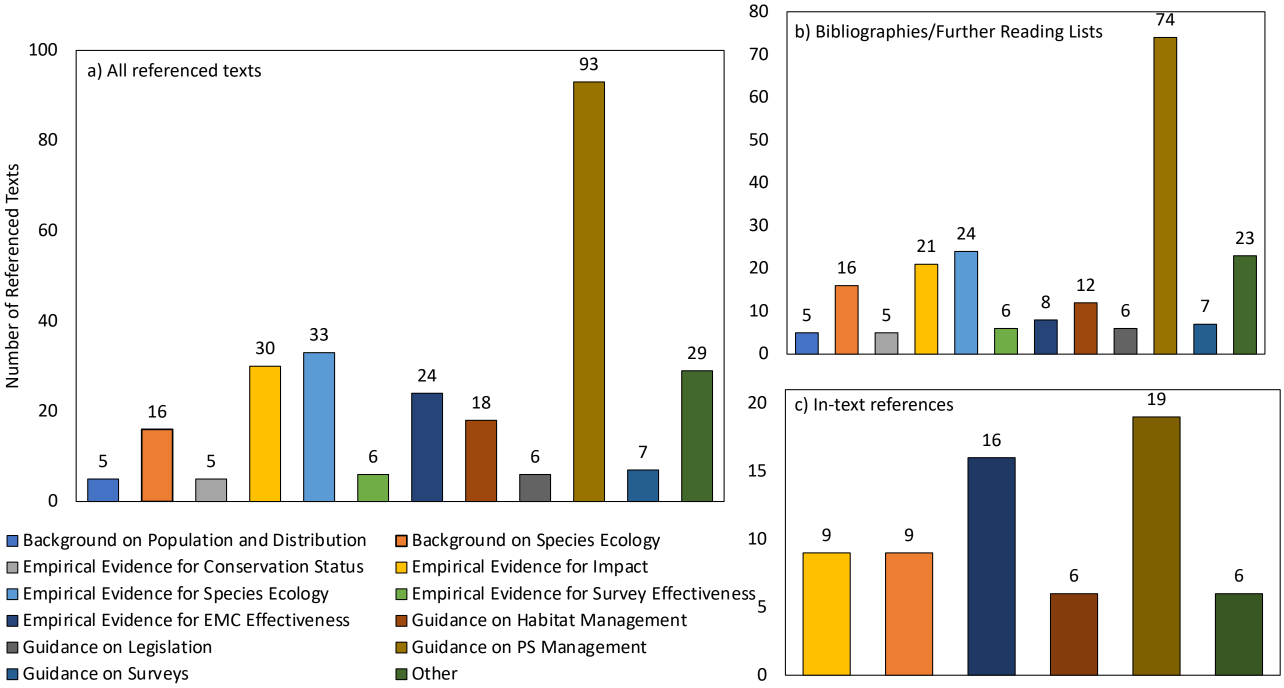

***Figure 3**: The frequency of each 'evidence type' across all referenced texts (a), broken down into bibliographies and further reading lists (b) and in-text references (c). For the definitions of each evidence-type, see Table 1.*

Our review of cited evidence for EMC effectiveness found that 'Before-After, Control- Impact' studies only accounted for 2/24 references, and only one literature meta-analysis (Oldham & Humphries, 2000) was referenced across all guidance (see SI). Hence, there is an absence of the most robust study designs and evidence synthesis in supporting literature. All referenced studies took place in Europe and involved UK protected species and are therefore relevant to recommendations made in guidance.

The majority of in-text references (60/65) provided support, either clear or ambiguous (SI), for recommendations. However, only 19 of these provided evidence for EMC measures effectiveness, whilst 18 provided evidence for the mechanism of the intervention. Thus, whilst recommendations may be based on understanding of the target species, they are rarely based on evaluation of the EMC measures themselves. The remaining references all took the form of other guidance publications, whose recommendations were the same as those made in text (Fig. 3).

3.4 Citation Networks

The citation networks developed from guidance reference data illustrate that there is 'circular referencing', in which each original guidance document (those in ecological reports) referenced at least one other original guidance document (Fig. 4). For example, Gent & Gibson (1998) (5, Fig. 4a) was referenced by 4/6 original guidance documents. The exception is Edgar et al. (2010), which did not reference any other original guidance documents (7, Fig. 4a). Both networks show an overlap between texts referenced between different guidance, potentially due to a limited pool of evidence from which to draw from. Comparison of the two networks also reveals that although there was more bat-related guidance, there were more texts supporting amphibian and reptile EMC.

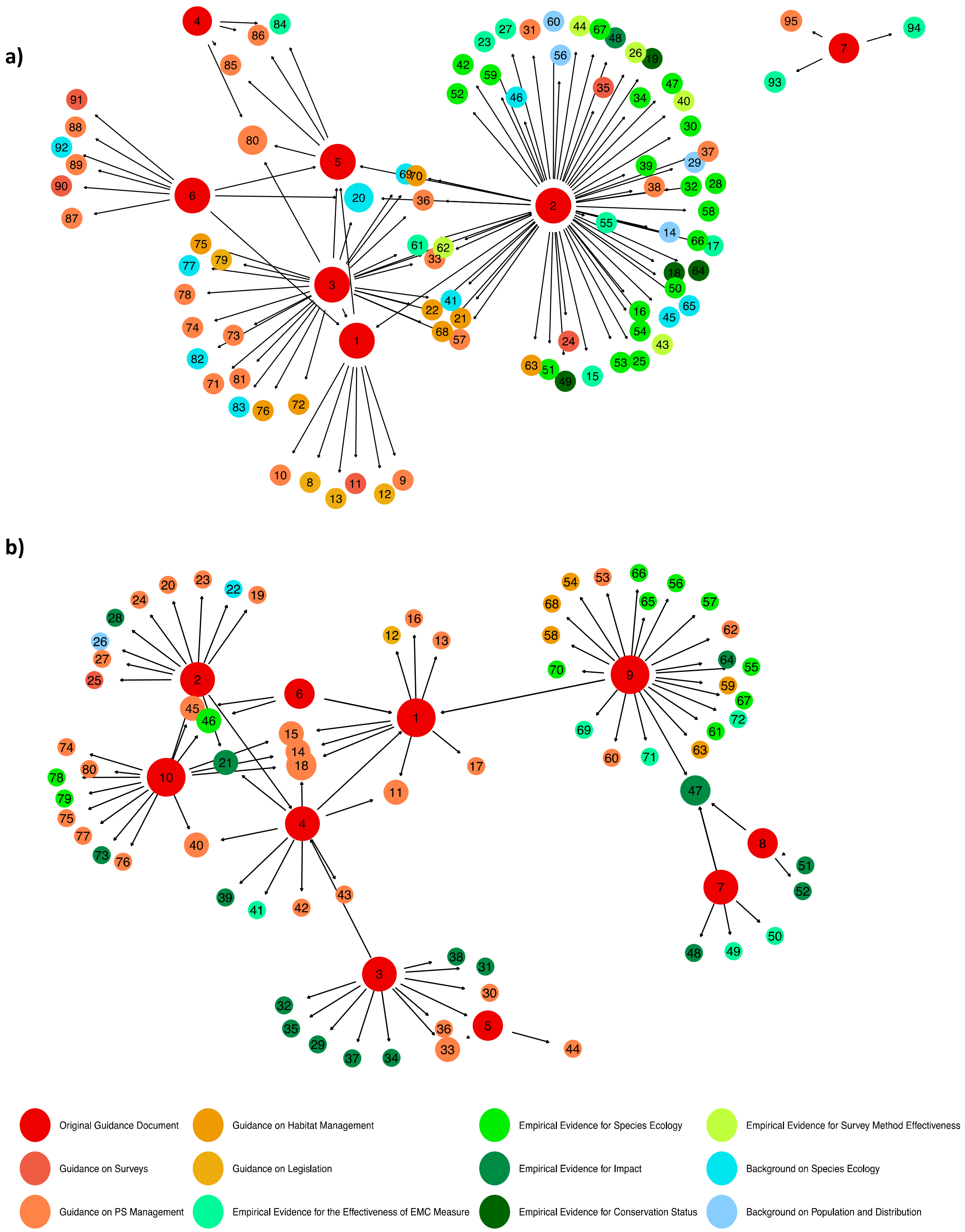

Figure 4: *Citation networks in which nodes represent both original guidance documents, restricted to bat (a) amphibian & reptile-related (b) guidance, and their supporting literature. Node colour corresponds to 'evidence type' whilst relative node size corresponds to its degree. Directed edges represent citations. In a) nodes 1-10 are guidance documents identified in ecological reports. In b) nodes 1-7 are guidance documents identified in ecological reports. See SI for the identity of all node numbers.*

3.5 Empirical Support for Measures

A review of the Conservation Evidence synopses for bats, mammals, birds and amphibians revealed that 30/52 unique EMC measures were either not assessed or had no associated evidence; eight had unknown effectiveness. Thirteen measures were assessed as beneficial or likely beneficial, accounting for only 29% of the 446 measures recorded (Fig. 5).

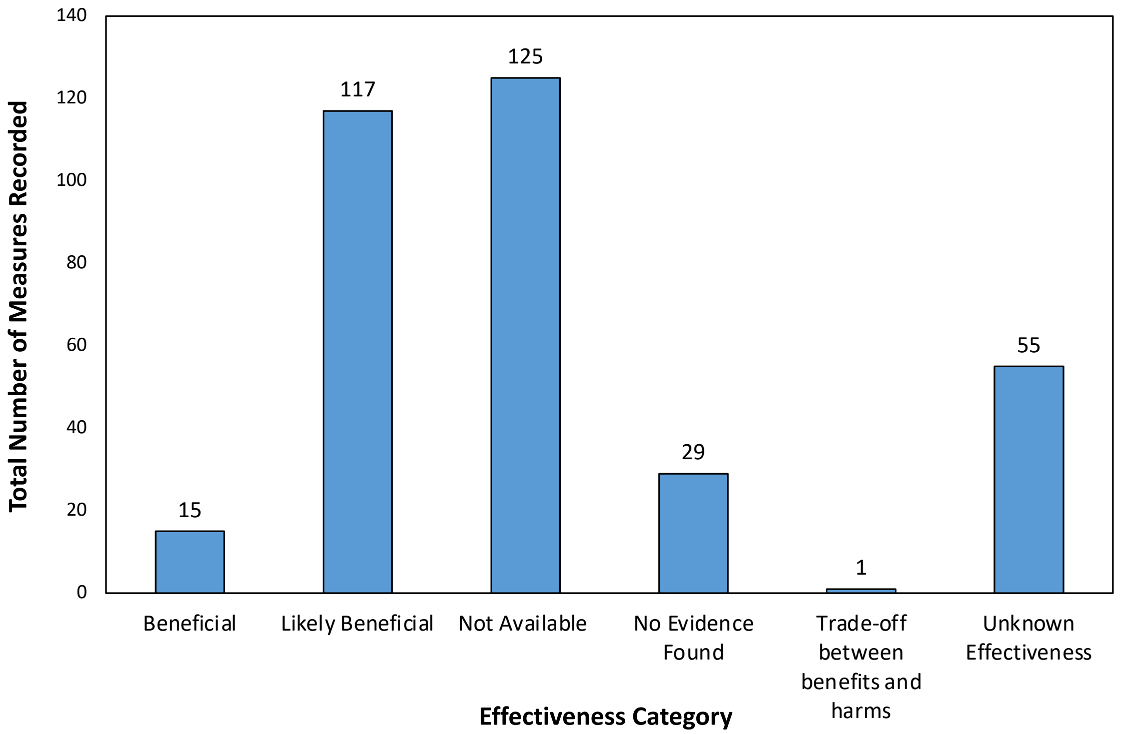

Figure 5: *Frequencies of each effectiveness category (excluding Reptile measures) as count of total recorded measures in ecological reports.*

A search of the literature available on the Conservation Evidence discipline-wide repository for reptiles resulted in six studies evaluating the success of reptile translocation and three evaluating hibernacula construction (Table 3). These studies also included two non-systematic literature reviews (Germano & Bishop, 2009; Dodd & Seigel, 1991), both of which found variable translocation success. Hibernacula studies all assessed behaviour as a success indicator, suggested to be a poor indicator of conservation success (Whiting & Booth, 2012), whilst translocation studies assessed population response. Only 3/9 studies found measures to be effective, whilst most produced inconclusive results.

Table 3: *Key details of all literature assessing the effectiveness of reptile EMC measures, available on the Conservation Evidence discipline-wide repository. The final column 'overall assessment' outlines the assessment that the study author makes about the intervention.*

Study	Location	Study Design	Intervention Assessed	Key Results	Overall Assessment
Whiting & Booth (2012)	UK	Before-After	Hibernacula	Hibernacula were used by individuals during and post development	Effective
Showler et al. (2005)	UK	Before-After	Hibernacula	At least three lizards and three adders had hibernated in the constructed bank	Inconclusive
Stebbings (2000)	UK	After	Hibernacula	Hibernacula were used by several reptiles	Effective
Nash et al. (2020)	UK	Before-After	Translocation	No recaptures of translocated individuals at 50% of sites	Inconclusive
Whitmore et al. (2012)	New Zealand	After	Translocation	All juveniles and 4/9 adults identified one year after translocation; breeding population established	Effective
Germano & Bishop (2009)	N/A	Review	Translocation	42% of translocation projects were successful; 29% had uncertain outcomes	Inconclusive
Cook (2002)	USA	Before-After	Translocation	17/40 amphibian and reptile translocations resulted in established breeding populations	Inconclusive
Reinert (1991)	USA	Before-After	Translocation	Of 262 snakes released, 6 were recaptured the year after and one recaptured two years after the translocation	Not Effective
Dodd & Seigel (1991)	N/A	Review	Translocation	Only 19% of translocations classified as successful; 58% not classified due to insufficient data	Inconclusive

4. Discussion

4.1 Overview

Our study reveals key insights into the variety of recommended EMC measures, the empirical evidence for their effectiveness, and the guidance and supporting literature underlying these measures. The UK Government's commitment to rapid housing expansion (Prime Minister's Office, 2020), alongside promises to avert further wildlife declines, illustrates the urgent need for effective EMC to reconcile these goals. If measures fail to mitigate impacts of development on protected species, the impacts of ambitious construction programmes could greatly exacerbate population declines (Clarke et al., 2013; Torres et al., 2016; Carter et al., 2020). However, there was insufficient evidence for their ability of nearly half of EMC measures to compensate for impacts of developments. In addition, there are indications that evidence frequently fails to filter through into guidance, represented by findings that less than 10% of evidence cited by guidance documents was derived from empirical evaluations of measure effectiveness.

4.2 Is there sufficient evidence for the effectiveness of mitigation and compensation measures?

Despite the high frequency of EMC measures in ecological reports, over half of these measures had no or insufficient empirical evidence for their effectiveness. As opposed to a research-implementation gap (Knight et al., 2008) this evidence paucity points instead to a thematic gap (Habel et al., 2013), in which dissonance between research focus and conservation practice has impeded evaluation of EMC measures. Although identified in other areas of conservation (Braunisch et al., 2012) this gap may be particularly large for EMC due to the recommendation and implementation of measures by ecological consultancies, who may be working to different targets than those of mainstream conservation organisations. As such, conservation researchers may lack sufficient awareness of the scale of application and problems associated with EMC measures, which are likely to have emerged from development practice rather than evidence-informed conservation. This is demonstrated by the fact that mitigation measures are often excluded from standard conservation guidelines (Germano et al., 2015).

As well as the thematic gap, lack of high-quality evidence may be compounded by the challenges in utilising practitioner-generated evidence, such as post-development reports. Though monitoring is a legal requirement for protected species licensing, it is often not reported or carried out (Stone et al., 2013; Lewis et al., 2016). Moreover, the design of current monitoring systems, and the failure of standard survey protocols to account for variation in detectability (Griffiths et al., 2015), means compliance with license conditions is often a poor indicator of ecological outcomes (Stone et al., 2013).

For species not protected under the Conservation of Habitats and Species Regulations (2019), several of which were identified in our review, evaluating and reporting EMC outcomes is not a legal requirement. Where monitoring does occur, data are frequently inaccessible due to commercial sensitivities (Hill & Arnold, 2012) and poor information management systems (Stone et al., 2013). Natural England's 'Science, Evidence & Evaluation Strategy' (2020) has outlined a commitment to 'embed evaluation from the start of programmes and projects' and 'make available the evidence we generate', suggesting that this situation may improve. Academic initiatives, such as the *Conservation Evidence* journal, which requires articles to be written directly or in partnership with conservation practitioners (Spooner et al., 2015), may also improve the availability of context-specific evidence for EMC.

Conclusive estimates of effectiveness are also impeded by the nature of available evidence. The absence of controls, counterfactuals or rigorous experimental design has been found to be pervasive across conservation evaluation (Christie et al., 2019) . As such, of the reptile literature reviewed in this study, none took the form of 'before-after control-impact', one of the most robust study designs (*ibid*). The use of control sites in development-specific studies may be infeasible due to cost, legislative constraints and the large scale of some developments (Hill & Arnold, 2012). Hence, EMC effectiveness estimates are compounded by the challenge of producing both context-specific and scientifically robust evidence. Similarly, the data collection methods used can also hinder effectiveness estimates. For example, the effectiveness of bat boxes is unknown as all studies thus far have recorded usage, a poor indicator of conservation effectiveness (Burthinussen et al., 2020). Overall, both aspects of study design are likely to have contributed to a number of EMC measures having 'unknown effectiveness'.

4.3 Implications of the evidence gaps

Evidence gaps mean there is still a limited understanding of mitigation outcomes for protected species. Many measures were frequently recommended, despite insufficient evidence for their effectiveness. This corroborates findings that practitioners rarely utilise (Cvitanovic et al., 2014) - or have access to (Fuller et al., 2014) - primary empirical literature and therefore refer to recommendations made in guidance. On the other hand, it also suggests that EMC may represent a 'tick-box' exercise in which the long-term outcomes for protected species is not a priority (Walker et al., 2009). The cumulative impact of small-scale poorly mitigated developments could lead to detrimental population declines at the landscape scale (Torres et al., 2016). Thus, the small number of measures deemed to be beneficial raises questions about the ability of current practice to maintain 'favourable conservation status' of UK protected species in the face of increased infrastructure expansion (Prime Minister's Office, 2020). Under the EU Habitats and Wild Birds Directives (1992), policies supporting species-specific EMC are applied across Europe (Regnery et al., 2013) and practices such as translocation are also known to be used as mitigation in Australia, USA and South America (Germano et al., 2015). Therefore, the measures reviewed, and the conclusions drawn around their effectiveness, are likely to be of significance beyond the UK.

4.4 Is conservation guidance for ecological mitigation and compensation evidence-based?

As highlighted by Downey et al. (2021), the finding that 56% of EMC measures were supported by referenced guidance confirms the significance of guidance in conservation practice. However, exploration of the literature supporting this guidance found a general failure to cite empirical evidence in support of recommendations, the result being that most reviewed references were other secondary publications. Circular referencing among bat and amphibian and reptile guidance, coupled with the absence of integration of new evidence, points to 'evidence complacency', in which empirical evidence is not used to inform recommendations. Sutherland & Wordley (2017) highlighted that evidence complacency occurs in many areas of conservation policy and practice. However, in the case of protected species EMC, the interaction between limited practitioner-relevant evidence (Hill & Arnold, 2012) and limited resources allocated to guidance production, is likely to have contributed to these findings (Evans et al., 2016). The legislative requirement to implement measures also means that agencies, such as Natural England, are obligated to produce guidance despite the absence of evidence.

A large number of guidance documents referred to in ecological reports were published over ten years before the planning application citing them. Equally, Natural England released an updated set of Reptile Mitigation Guidelines in 2011 (most recent published in 2004) but retracted the document shortly after publication (Natural England, 2011), which indicates problems with updating guidance, potentially as a result of limited available evidence generating controversy, or resource constraints.

However, some organisations have been proactive at using evidence, such as The Bat Conservation Trust which published the most recent guidance (2018), utilised in-text references and relevant supporting literature. Stone et al. (2013) suggested that Natural England licensing is driven by process, rather than outcome. Thus, a lack of institutional ambition in the actual outcome of EMC for protected species may limit the drive to improve evidence use (Walker et al., 2009). Nevertheless, Natural England's Science, Evidence and Evaluation Strategy (2020) states that they will "*ensure that the best available evidence is central to all of our … advice"*, suggesting that integration of evidence into guidance may increase adoption of this strategy. In addition, training in evidence-use could also improve its application to EMC (Sutherland & Wordley, 2017).

Importantly, these conclusions are compounded by the lack of 'evidence-transparency' (Rutter & Gold, 2015), in which less than half of the reviewed documents referenced supporting literature in-text and seven provided no supporting literature. Further research is required to determine how evidence is actually used in the production of guidance. However, instances where both guidance and their recommended measures are unsupported by documented evidence (e.g. hedgerow planting for amphibians) do suggest that guidance is not directly informed by scientific evidence.

4.5 The Implications of Poor Guidance

Poor citing practices, such as circular referencing among bat and amphibian and reptile guidance, could have implications for EMC practice. Using the case study of black rats in Australia, Smith and Banks (2015) demonstrated how ambiguous citations can distort the evidence underpinning conservation interventions. Hence, pervasive citing of other guidance is likely to have led to the propagation of EMC measures that are not underpinned by empirical evidence. A key example is 'destructive search', which involves stripping vegetation and topsoil to identify animals remaining on the development site (Natural England, 2011). Despite its presence in multiple guidance documents, and the resulting recommendation in 18 ecological reports, this measure is not supported empirical evidence and was even suggested to be harmful by Natural England (2011) in their now retracted guidance.

The failure of publishers to update guidance also means that EMC measures known to be ineffective could continue in use, contributing to the research-implementation gap (Knight et al., 2008). Nash et al. (2020) found 'no confirmatory evidence' for the ability of reptile translocation to mitigate for development impacts. Without regular updates to guidance, improved understanding of EMC gained from such studies is unlikely to be integrated into practice.

4.6 Limitations and Directions for Future Research

Limitations

Though there are important implications of this study’s findings, there are some limitations to our results. The unavailability of a Conservation Evidence Reptile synopsis meant that the evidence for 23% of measures could not be comprehensively assessed. We recommend that future assessments of EMC effectiveness take into account Conservation Evidence synopses when updated or made available. Six guidance documents were also not publicly available, limiting the scope of this review stage.

We acknowledge that this study also omits some aspects of development mitigation that may contribute to their overall impact on biodiversity. In practice, quality of measure implementation, as well as the nature of the measures themselves, is a key determinant of mitigation success (Tischew et al., 2010). However, as most studies do not distinguish between the contributions of intervention design and implementation, the effectiveness estimates we reviewed could be biased by poor implementation. It should also be noted that the purpose of EMC, to minimise or compensate for specific development impacts, is distinct from other conservation actions. Hence, the appropriateness of EMC measures to development impacts and their scale of application is key to the achievement of ecological equivalence (Stone et al., 2013). Conservation Evidence takes a broad definition of effectiveness, ‘the intervention produces a desirable outcome’. Therefore, since we focused on the recommendation and effectiveness of individual EMC measures, rather than appropriateness of implementation, effectiveness estimates should not be interpreted as the actual biodiversity outcomes of the sampled developments.

Recommendations

Despite these limitations, there are some generalisable research and policy recommendations that emerge. Reiterating previous calls from practitioners (Hill & Arnold, 2012), we highlight the urgent need for more relevant evidence for EMC measure effectiveness. More testing of measures is required, as well as improved interrogation of data sources used in studies of EMC measure success. Particular consideration should be given to the use of grey literature, such as ecological consultant reports, which represent a largely inaccessible and unutilized, yet substantial evidence source (Haddaway & Bayliss, 2015). Many measures appear to be based on 'standard practice' and professional judgement. Though studies have explored evidence-use in other areas of conservation, such as protected area management (Cvitanovic et al., 2014), further research is required to better understand how ecological consultants use other sources of evidence, such as experiential knowledge, in the recommendation of EMC measures.

As well as future research directions, the results of this study highlight the need for key policy changes. Government agencies should ensure that guidance for protected species mitigation is regularly updated and based on comprehensive evaluation of empirical evidence. Equally, improving the design and compliance of post-development monitoring may improve the quality and quantity of data to inform evidence-based decisions (Walsh et al., 2015). We identified a lack of evidence for the ability of EMC measures to compensate for the impacts of development. To meet national biodiversity targets, development policies must therefore improve impact avoidance (Phalan et al., 2018), rather than implement measures that have not been shown to be effective.

5. Conclusions

We used a mixed-methods research approach to systematically trace ecological mitigation and compensation measures for protected species back to their evidence base. In doing so, we found that there is either no or insufficient evidence for the effectiveness of most measures recommended in ecological reports. This thematic gap, likely stemming from the different perceptions of outcomes by ecological consultants and other conservation practitioners, means the ability of EMC to compensate for the impacts of development is currently unknown. As less than 10% of the evidence supporting guidance recommendations is related to empirical studies of EMC success, guidance is unlikely to be 'evidence-based'. The use of application of EMC measures to protected species is widespread, so this paper demonstrates an original methodological approach that applies beyond the UK. To balance commitments to rapid housing development with conservation, there is an urgent need for effective EMC measures. Reconciling this conflict represents a significant challenge which will require substantial efforts to address both the availability of evidence and the way it is integrated into guidance.

Authors Contributions

SBH, SzE and CH conceived and designed the study. SBH collected the data, analysed the results and wrote the manuscript. SzE, CH, HD and RG contributed to the writing of the manuscript and gave final approval for publication.

Acknowledgements

Many thanks to Mike Dean, who provided valuable feedback on the manuscript. We also thank two anonymous referees for their detailed and insightful comments. SzE is supported through NERC's EnvEast Doctoral Training Partnership [grant NE/L002582/1], in partnership with Balfour Beatty.

Conflict of Interest Statement

Richard Griffiths is Trustee of Amphibian and Reptile Conservation Trust, Director of the Newt Conservation Partnership and Member of the Natural England Great Crested Newt Expert Licensing Panel. Harriet Downey is an Associated Editor of Ecological Solutions and Evidence but took no part in the peer review and decision-making processes for this paper.

Data Availability Statement

All data collected in our study is available on the Dryad online repository: https://doi.org/10.5061/dryad.sj3tx9658 (Hunter et al., 2021)

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