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RESEARCH NOTE

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Impacts of the installation of basking banks on four UK reptile species in a before–after control–intervention experiment

Brian J. Pickles[1] | **Jenny Tse-Leon**[2]

[1]School of Biological Sciences, University of Reading, Reading, UK
[2]Froglife (Head Office), Brightfield Business Hub, Peterborough, UK

Correspondence
Brian J. Pickles, School of Biological Sciences, University of Reading, Whiteknights, Reading RG6 6EX, UK.
Email: b.j.pickles@reading.ac.uk

Abstract
Reptiles are often overlooked in conservation efforts. Hence, long-term population data is often unavailable, and evidence for effective conservation actions that improve reptile habitat remains scarce for most species. Here we used a before–after control–intervention (BACI) experiment to investigate the impact of basking bank creation on four co-occurring reptile species: European adder, barred grass snake, slow worm, and viviparous lizard. Long-term refuge monitoring at a UK wildlife reserve allowed population assessment before and after habitat modification. Only viviparous lizards were observed at basking banks within 12 months of construction. In subsequent years, barred grass snake observations increased near basking banks and slow worms were observed for the first time, while European adder observations increased away from banks and barred grass snake observations decreased away from banks. Our small-scale BACI study suggests basking banks attracted barred grass snakes from the surrounding area, which saw a corresponding increase in European adder sightings.

KEYWORDS
BACI, barred grass snake, conservation actions, ecological experiment, European adder, evidence, habitat management, habitat modification, slow worm, viviparous lizard

1 | INTRODUCTION

Globally, the need for improved conservation action to tackle reptile declines is gaining wider recognition (Böhm et al., 2013; Cox et al., 2022; Meiri et al., 2023; Roll et al., 2017). Reptile biodiversity is relatively understudied (Moura & Jetz, 2021) and reptile taxa appear to be under threat of extirpation and extinction at an increasing rate (Caetano et al., 2022; Gibbons et al., 2000; Kemp, 2019). Monitoring programs for reptiles are typically rare, tend to cover small areas, and are commonly underfunded, resulting in a lack of data despite the availability of suitable techniques (e.g., McDiarmid et al., 2012); hence, population trends are difficult to obtain for most reptile species. This is true even for common species, and reptiles remain one of the least recorded taxa.

The UK has six native reptile species and all are legally protected by the Wildlife and Countryside Act (1981) and section 41 of the Natural Environment and Rural Communities Act (2006). Reptiles are typically more cryptic than other vertebrate taxa such as birds, and investigation of reptile occurrence records from multiple UK databases, including both expert groups and public sightings, reveals that reptiles are the least recorded vertebrate taxon. In the Garden Wildlife Health database, 0.5% of all records were reptiles, compared to 6.9% amphibians, 8.1% mammals, and 76.9% birds (Garden Wildlife Health, 2023). In the National Biodiversity Network Atlas, reptiles tend to have 33%–66% fewer records than amphibians, an order of magnitude fewer records than mammals, and two orders of magnitude fewer records than birds (National Biodiversity Network (NBN) Trust, 2023).

In a study of global internet search trends for vertebrate taxa, Davies et al. (2018) found (i) low popular interest in reptiles (four reptiles in the top 100 most-searched taxa, 1.6% of reptiles represented in the top 1000 most-searched taxa) and (ii) lower public interest in a taxon corresponded to less funding. Hence, maintaining monitoring programs can be practically challenging for reptile conservation, which often depends on volunteers. Furthermore, reptile conservation practitioners must contend with little supporting evidence for the various practical conservation actions that are available to support their efforts.

How to improve habitats is a key practical question for conservation, but there is little information available for the UK or globally on individual reptile species let alone reptile assemblages. Before–after control–intervention (BACI) experiments are considered the most appropriate and robust approach for addressing the impact of management interventions (Christie et al., 2019) but they are rarely applied in conservation science (Christie et al., 2021). In a recent comprehensive summary, Sainsbury et al. (2021) reviewed the current state of conservation evidence for reptiles. Most existing evidence comes from a few studies conducted on a wide variety of species in different ecosystems on different continents. Notably, few published studies have considered the interactive effects of management interventions on multiple co-existing reptile species. Four studies provided exceptions to this general lack of information: hibernacula construction in England provided benefits for (1) European adders and viviparous lizards (Stebbings, 2000) and (2) European adders, barred grass snakes, and viviparous lizards (Whiting & Booth, 2012), whereas the addition of refuge logs generated positive effects on reptile abundance and species richness in (3) Australia (Michael et al., 2004) and (4) Spain (Márquez-Ferrando et al., 2009). Regarding practical management interventions for reptiles, there are no specific cases of creating landscape features that allow reptiles to gain direct access to sunlight for thermoregulation (i.e., "basking banks") listed in Conservation Evidence (https://www.conservationevidence.com/) and the closest appropriate categories are "Create or restore rock outcrops" (5 studies) and "Create artificial refuges, hibernacula, and aestivation sites" (11 studies). More studies of the impacts of conservation actions on reptiles are needed to build up the evidence base for different species, ecosystems, and climatic zones.

In this study, we used a BACI design to examine the impact of a practical management intervention on reptile abundance and diversity at a UK nature reserve with co-occurring populations of four reptile species: European adder (*Vipera berus*), barred grass snake (*Natrix helvetica*), slow worm (*Anguis fragilis*), and viviparous lizard (*Zootoca vivipara*). In July 2017, a single European adder was recorded at a location within the nature reserve where the species had never previously been recorded. Subsequently, funding was secured to carry out habitat works. In February 2019, basking banks were created with the goal of expanding the favorable habitat for the European adder and hopefully increasing their local population.

Here we used 5 years of survey data to study the impact of basking bank creation on habitat use by four co-occurring UK reptile species. Our aims were to examine whether and how observations of each reptile species changed in the years before and after habitat modification, in refuges (i) in the immediate area of the basking banks and (ii) in the nearest monitoring zone away from the basking banks. Briefly, we found that constructing basking banks led to (i) an increase in barred grass snake observations and a decrease in European adders in the immediate area of the banks and (ii) the reverse effect (more adder observations and fewer grass snake observations) in the unmodified area nearest to the banks.

2 | METHODS

2.1 | Site description

This study took place on a privately owned nature reserve near Peterborough, UK, managed by the charity Froglife on behalf of the landowner. It includes a mature woodland edged by alder (*Alnus glutinosa*) and dogwood (*Cornus sanguinea*) but is topographically varied and mostly comprises scrub, grassland, and multiple ponds. Scrub is dominated by bramble (*Rubus fruticosus*), hawthorn (*Crataegus monogyna*), gorse (*Ulex europaeus*), rose hip (*Rosa* spp.), and willow (*Salix* spp.). Due to the presence of multiple protected species, it is legally protected as a Special Area of Conservation, Site of Special Scientific Interest, and as a Natura 2000 site.

2.2 | Data collection

Reptile observations were collected using a fixed transect survey approach. In total, there were 182 sampling locations across the reserve grouped into seven "transects," with one tin refuge (approx. 50 cm^2) and one mat refuge (approx. 25 cm^2) per sampling location spaced <4 m apart; each location was separated by approximately 50 m. Reptile identity and abundance within ~4 m of refuges were collected in all weather conditions, except continuous heavy rainfall, every 2 weeks from the end of March to the beginning of October throughout 2017 to 2019 and 2021 to 2022. Most surveys happened between 0900 and 1500 on 1 day, but occasionally took two consecutive days when volunteer numbers were low. Long-term volunteers collected the data and were trained by experts in reptile identification. No data was collected in 2020 due to the UK's Covid-19 lockdown policy and staff furlough. Data collection included details on sex (M/F; European adders only) and life stage (juvenile/adult) of each observed reptile. It was not possible to track data on individual animals as mark–recapture methods are not used at this site.

2.3 | Habitat modification

In February 2019, during the winter period of brumation, one basking bank (Figure 1) comprising stones, soil, and discarded brick was installed at each of five existing sampling locations in a flat area of open terrain featuring grass with low scrub at the top of a roughly north-facing slope using a tracked backhoe (JC Bamford Excavators Ltd., UK). Each bank was a raised area of rock, brick, and bare earth with a roughly flat rectangular center (approx. 1 × 2 m) with the longest sides facing north/south and replaced a patch of grass. Bank height was ~50 cm with a ~45° downward slope.

2.4 | Experimental design

To assess how habitat modification affected local reptile populations, we divided data into: (i) time categories, where survey years were combined into "before" (2017 and 2018) and "after" (2019, 2021, and 2022) habitat modification, (ii) spatial categories, "bank" (five sampling locations each <4 m from a basking bank, $n = 10$ refuges) and "near" (five control sampling locations closest to basking banks but without habitat modification, $n = 10$ refuges). Each bank replicate was ~50 m from the next bank and each near replicate was ~70–110 m from a bank replicate. Like bank replicates, near replicates were also located on top of slopes covered with grass and low scrub.

2.5 | Statistical analyses

All analyses were conducted using R version 4.0.2 (R Core Team, 2020). We used the *glm.nb* function in R package "MASS" (Venables & Ripley, 2002) and the *Anova* function in R package "car" (Fox & Weisberg, 2019) to model differences in count data across all sampling locations in a given category. Collinearity was assessed using the *check_collinearity* function in R package "performance" (Lüdecke et al., 2021). Species were modeled separately as: Count ~ Location × Time

FIGURE 1 Basking bank construction in February 2019 (Photo provided by Froglife).

(where Location = bank/near; Time = before/after). To reduce zero-inflation, at each sampling location all counts from each survey and both refuges were combined, producing a yearly total for each species. Replicates were as follows: bank before, $n = 10$; bank after, $n = 15$; near before, $n = 10$; near after, $n = 15$. We used Fisher's exact test for count data to test the null hypothesis that there was no relationship between observations of reptile species and survey year (i) within the area of the basking banks (refuges $\leq$4 m) and (ii) within the closest monitoring area away from the basking banks ($70 \leq$ refuges ≤ 110 m). We used the *boxplot* and *mosaicplot* functions in R package "graphics" (R Core Team, 2020) to visually display the results.

3 | RESULTS

Over the five survey years, 96 reptiles were observed across the 20 refuges, 38 in the bank area and 58 in the nearby (control) area, including two reptiles on or beside a refuge, with the most sightings in 2017 and the fewest in 2022. Across the survey period, each species exhibited different temporal trends. European adder and barred grass snake sightings were mainly in July–September. Slow worms and viviparous lizards were seen throughout the year at low and high abundance, respectively. Slow worms were most common in April and September, whereas viviparous lizard sightings were more frequent in May–June and September. One European adder was a juvenile; adults were ~80% female.

3.1 | Impact of basking bank construction

In the area where basking banks were constructed, bank construction significantly increased observations of barred grass snakes and decreased observations of European adders (Figure 2a,b); there was no significant change in observations of slow worms or viviparous lizards (Figure 2c,d). After construction of basking banks in the basking bank area, in the nearby (control) area European adder observations significantly increased and barred grass snake observations decreased (Figure 2a,b); there was no significant change in observations of viviparous lizards or slow worms (Figure 2c,d). Hence, basking bank construction had significant interactive effects on the European adder ($p = .014$) and barred grass snake ($p < .001$) (Table 1). Slow worm observations were more frequent in the nearby (control) area than the basking bank area (Figure 2c; Location LR = 3.962, $p = .047$). The total number of viviparous lizard observations declined over time (Figure 2d; Time LR = 4.782, $p = .029$), but there was no significant impact of basking banks (Table 1).

Where basking banks were constructed, species observations and survey year were significantly related within bank area refuges (Fisher's exact test, $p > .001$). Before habitat modification, reptiles in bank area refuges were almost exclusively viviparous lizards (Figure S1a; Table S1), whereas 2 years after bank construction, barred grass snakes became dominant (Figure S1a; Table S1).

In the nearby (control) area, species observations and survey year were significantly related in nearby refuges (Fisher's exact test, $p > .001$). Before habitat modification, reptiles in nearby area refuges were primarily barred grass snakes and viviparous lizards, with a few slow worm sightings (Figure S1b; Table S1). After bank construction, in nearby area refuges, European adders replaced barred grass snakes, and viviparous lizards and slow worms fluctuated (Figure S1b; Table S1).

4 | DISCUSSION

Our small-scale BACI study of basking bank creation on local reptile populations revealed different responses to this intervention based on species identity and distance from banks. Barred grass snakes were the primary beneficiaries, going from no observations before bank creation to multiple sightings in bank refuges afterwards. In the nearby (control) area, barred grass snakes went from multiple sightings before bank creation to no observations in refuges after bank creation, whereas European adders were observed for the first time. Viviparous lizards were observed before and after bank creation, but observations declined reserve-wide in 2021 and 2022. Before basking bank creation, refuge observations in the bank area were dominated by viviparous lizards, and after the intervention, this changed to a mixture of barred grass snakes, viviparous lizards, and the first observation of slow worms in this part of the reserve.

The most frequently observed reptile species in the 20 refuges examined here were viviparous lizards (64% of all observations). Viviparous lizard observations within the bank and nearby areas made up 2%–17% and 2%–5% of the species' yearly reserve sightings, respectively. Observations remained high in the year after bank creation, but >2 years later, fewer viviparous lizards were seen in bank or nearby refuges; this decline was noted across the reserve, so it appears unrelated to the intervention. Slow worms were the most frequently observed reptile species across the entire reserve every year but were only found in small numbers within the 20 refuges examined here (<1% of their reserve sightings). Barred grass

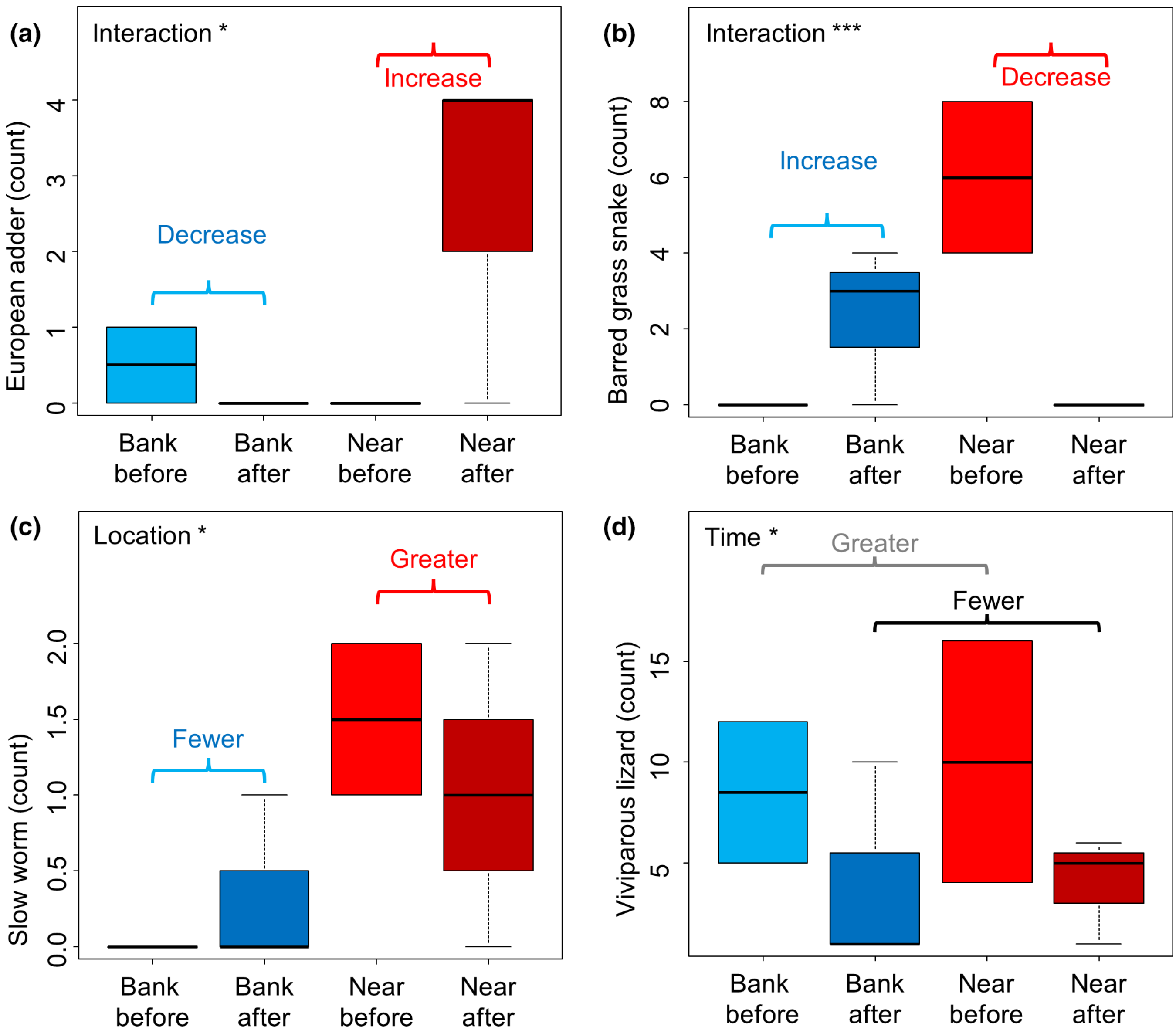

FIGURE 2 Boxplots showing mean counts of each reptile species under refuges in the immediate area of the basking banks (Bank) and in the surrounding area (Control) in the two survey years before and three survey years after habitat modification. (a) European adder (*Vipera berus*), (b) barred grass snake (*Natrix helvetica*), (c) slow worm (*Anguis fragilis*), and (d) viviparous lizard (*Zootoca vivipara*). Note significant interactive effects (panels a and b), significant location effect (panel c), and significant time effect (panel d). ***$p \leq .001$; *$p \leq .05$.

snakes were commonly seen in the nearby area prior to habitat modification (5%–17% of their reserve sightings) but were only observed in the bank area after basking bank creation; sightings were low across the reserve in 2022 with 60% in the bank area. Barred grass snakes commonly hunt fish and amphibians (>70% of their diet; Gregory & Isaac, 2004) and the reserve has many ponds; hence, the banks may be attractive places to warm up after hunting in water. While refuge sharing was not observed, some evidence suggests that barred grass snakes may prefer areas used by European adders (Brown, 1991). Hence, it seems unlikely that post-intervention partitioning of barred grass snakes into the bank area and European adders into the nearby area (10%–12% of their reserve sightings) represented a negative interaction between these species.

Imperfect detection is a well-known problem in ecological monitoring (Kéry & Schmidt, 2008; McArdle, 1990). In our study, bank creation may have reduced the number of sightings in refuges. Banks are composed of loosely piled rocks and bricks full of natural holes and crevices, which may be attractive due to opportunities for thermoregulation, predator avoidance, foraging, or individual life history differences (Recknagel et al., 2023). Banks may also provide shelter allowing torpor in conditions near a species' upper thermal limit, the

TABLE 1 Analysis of deviance results for interactive negative binomial GLMs performed separately for each reptile species (Model form = count data ~ location × time).

Species	Model term	LR Chisq[a]	Df	*p*-Value	R^2-value
European adder	Location	4.640	1	.031	.529
	Time	2.535	1	.111	
	Interaction	6.008	1	.014	
Barred grass snake	Location	0.212	1	.645	.616
	Time	2.127	1	.145	
	Interaction	19.459	1	<.001	
Slow worm	Location	3.962	1	.047	.235
	Time	0.024	1	.878	
	Interaction	1.243	1	.265	
Viviparous lizard	Location	0.043	1	.835	.139
	Time	4.781	1	.029	
	Interaction	0.044	1	.834	

[a]Likelihood ratio (Chi Squared).

effects of which are often unclear for temperate reptiles (Doucette et al., 2023), which may have taken place in the extreme heat of summer 2022 (37–40°C). Hence, reptiles may become harder to spot by using the basking banks themselves, rather than associated refuges, potentially leading to underestimates of their presence. Studies of bias and precision in biological surveys have shown that false-negative rates can be substantial (Tyre et al., 2003). For example, using plasticine models of barred grass snakes, Lock and Griffiths (2022) found that surveyors with little training missed 42%–48% of the models and an experienced surveyor missed 18%. We note that the number of highly trained volunteers taking part in surveys declined after 2019 following the 2020–2021 Covid-19 lockdowns. Furthermore, the extremely hot summer of 2022, which coincided with staff changes, may have led to lower reptile activity during the late morning/early afternoon period on survey days, possibly reducing overall detection rates in later survey years, although this would have affected both the bank refuges and the nearby refuges equally.

Studies like ours face challenges including monitoring effort, cost, collecting sufficient data for statistical analysis, detection difficulties, false-negatives, and many more. We encourage other research groups to engage with local conservation organizations to design small-scale practical BACI experiments that can inform future reptile management decisions. Further funding for long-term monitoring programs is also essential, especially where these are linked to active habitat management.

Although our 5 years of observational data need to be interpreted with care, basking bank creation was beneficial for the wider European adder population and benefitted barred grass snakes in an otherwise a poor year for their population. Slow worms were sighted following bank creation, whereas viviparous lizards were observed in the bank and nearby areas before and after the intervention. In summary, the short-term impact of basking bank creation was positive for barred grass snakes in the immediate area and positive for European adders in the surroundings. Continued monitoring will provide more insight into the longer term impact on population trends.

Practitioners interested in enhancing reptile habitats may find that basking banks are a simple intervention to add, providing sites for thermoregulation and predator avoidance. While we used a backhoe to create our banks, the same features could be created by volunteers using construction tools. We encourage reptile conservation practitioners to monitor target and control areas before adding interventions so that the impacts on local reptile populations can be assessed and reported with more confidence.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data are managed by Froglife and can be provided on reasonable request.

ORCID

Brian J. Pickles https://orcid.org/0000-0002-9809-6455

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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