Amphibian and Reptile Conservation

RESEARCH REPORT 19/01A

Analysis of Jersey National Amphibian and Reptile Recording Scheme (NARRS) Data 2007–2018 (Report A)

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States of Jersey

amphibian and reptile conservation

Executive Summary

Between 2007 and 2018, volunteers have surveyed ponds and terrestrial habitat to record native amphibians and reptiles across the island of Jersey as part of the National Amphibian and Reptile Recording Scheme. We analyse these data to look at the distribution and status of these species and to inform future monitoring efforts.

812 surveys were undertaken by 67 surveyors across the 12-year period, with 48 reptile surveyors completing 440 reptile surveys and 43 amphibian surveyors achieving 372 amphibian surveys. A total of 159 1-km squares intersect Jersey. Of these, 60 were surveyed for reptiles and 47 for amphibians. Based on our estimates, there has been little change in western toad, agile frog, wall lizard and green lizard occupancy rates between the two survey cycles. However, both the palmate newt and slow worm have increased in estimated occupancy by 0.137 and 0.406 respectively. However, these increases are likely associated to improvements in detection rather than changes in their underlying distribution. All species occupancy models performed well, with the exception of the toad. This is likely due to its use of both urban and semi-natural habitats.

Toads were the most abundant amphibian recorded, followed by palmate newts and then agile frogs. For reptiles, green lizards were the most observed followed by slow worms, then wall lizards and in very few cases, grass snakes. Toads and palmate newts were widespread; though palmate newts were far less common. Comparably, agile frogs remain restricted to the south west of the island. Slow worms were the most widespread of Jersey's reptiles, whereas green lizards were predominantly recorded in along the east and west coastlines. Wall lizards were observed in a handful of coastal localities, and grass snakes were only observed in six 1-km squares during NARRS surveys. Additional data shows a wider, yet still restricted distribution for the grass snake, and indicates that current NARRS survey design is unsuitable for monitoring Jersey's grass snake population. For all species except the grass snake, estimated species detection was reasonably high. A number of variables were found to influence species occupancy and detection, and are described in detail in the main body of the report.

Species richness was greatest in coastal regions, and was generally higher in the second cycle - perhaps due to the greater observed occupancy rates of the slow worm and palmate newt. Habitat quality remained stable across both cycles, with few ponds yet to receive high (> 0.7) Habitat Suitability Index scores.

For greater confidence in the occupancy status of Jersey’s species, surveyors should carry out five survey visits at a site for widespread amphibians (toads and palmate newts), and six for widespread reptiles (slow worms and green lizards). As the agile frog, wall lizard and grass snake are rarer and / or more restricted in their distributions, we recommend that these are monitored with separate monitoring efforts to those used for the widespread species.

Volunteers contributed a significant amount of effort and subsequently data. However, with some exceptions, only large (50%) changes in species occupancy between the two survey cycles would be detectable, and only then for the toad and green lizard. A survey design with 50 survey sites per cycle would only be likely to detect population changes as measured by site occupancy of 50 or 30% in the widespread species (toad, palmate newt, slow worm and green lizard). Much larger numbers of survey sites would be required for the rare and restricted species. These rare and restricted species may be better monitored through species-specific survey efforts at a more detailed site-level. We recommend that future monitoring uses a greater number of refugia for reptile surveys - particularly for detecting slow worms. Sampling of all lizard species may also be improved by selecting sites via a 500 m grid rather than the 1 km grid that has been previously used. This will produce a larger number of sites across which comparisons can be made. Furthermore, the addition of water quality monitoring and amphibian disease screening may contribute valuable data on Jersey's amphibians and provide an additional avenue for detecting species declines and their causes. Further recommendations on future survey design are given in the partner report to this (Ward and Wilkinson 2019).

Acknowledgements

We are grateful to the Jersey Biodiversity Centre for sharing data, to those that participated in the stakeholder workshop and especially to the surveyors that have collected data over the last 12 years. Jersey Water also provided pond map data for which we are grateful.

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Contents

Tables and Figures

1. Study aims

This report analyses 12 years of data from the National Amphibian and Reptile Recording Scheme (NARRS) running in Jersey between 2007 and 2018, in order to determine changes in occupancy and distribution of Jersey's native herpetofauna. To meet these aims we have carried out the following:

A. Collation of all data (2007–2018) and input of remaining data from 2013–2018
B. Calculated pond occupancy rates for amphibians
C. Calculated square occupancy rates for reptiles
D. Assessed species richness by square
E. Analyses of pond quality and reptile habitat quality
F. Analyses of any detectable changes in status
G. Assessed confidence in results, suggesting amendments to enable detection of possible future changes
H. Provided recommendations

2. Introduction

The National Amphibian and Reptile Recording Scheme (NARRS, http://www.narrs.org.uk/) was launched in Jersey in 2007 by the States of Jersey Department of the Environment (now Natural Environment) as part of its integrated ecological monitoring programme. The scheme was developed by Amphibian and Reptile Conservation (ARC), and has been run in partnership with Natural Environment and Jersey Amphibian and Reptile Group (JARG) over a 12-year period in order to assess and detect changes in the conservation status of Jersey's native amphibians and reptiles. Though the scheme has been financed by the Government of Jersey (formerly the States of Jersey), it is dependent upon the survey efforts of volunteers and is therefore extremely cost-efficient.

Jersey is home to seven native amphibian and reptile species;

- three amphibians
    - the western toad (*Bufo spinosus*) (known locally as the crapaud),
    - the palmate newt (*Lissotriton helveticus*)*,* and
    - the agile frog (*Rana dalmatina*), and
- four reptiles
    - the slow worm (*Anguis fragilis*)*,*
    - the wall lizard (*Podarcis muralis*)*,*
    - the green lizard (*Lacerta bilineata*), and
    - the grass snake (*Natrix helvetica*, formerly *Natrix natrix*).

All seven species receive protection under the Conservation of Wildlife (Jersey) Law 2000 and the proposed Draft Wildlife (Jersey) Law 201-.

NARRS surveys are carried out in six-year cycles, meaning that two cycles have taken place so far in Jersey; 2007–2012 (cycle 1) and 2013–2018 (cycle 2). During these cycles, trained volunteers were allocated 1-km squares (monads) within which to carry out their surveys with the aim of generating sufficient data upon which conservation status can be assessed and changes in species' occupancy can be detected. To produce a robust dataset on which to base any conclusions, surveyors are required to carry out multiple survey visits using repeatable methods, and receive training in species identification, survey methods, health and safety, bio-security and how to correctly record their data.

This report presents, for the first time, the results of Jersey NARRS data collected between 2007 and 2018. It follows previous baseline assessments carried out on data from the first cycle (Wilkinson et al. 2014) and an interim assessment of data from 2007–2010 (Wilkinson and Arnell 2010). We analyse Jersey NARRS data separately to that from the UK and other jurisdictions due to the different community of amphibian and reptile species present. In some instances, supplementary data are presented where additional efforts have been undertaken to record amphibian or reptile species.

3. Methods

3.1 Study area

Study sites consisted of 1-km squares (monads), as previously used in Jersey (Wilkinson et al. 2014) and the UK (Wilkinson and Arnell 2013). In total, 159 1-km squares intersect with Jersey's terrestrial surface above the mean high water line. The unit of measure for amphibians was each pond surveyed, whereas for reptiles it was each 1-km square. However, for consistency, we often refer to 1-km squares for both amphibians and reptiles.

3.2 Study species

Jersey's native herpetofauna comprises three amphibian and four reptile species; the western toad or crapaud (*Bufo spinosus*), palmate newt (*Lissotriton helveticus*), agile frog (*Rana dalmatina*), slow worm (*Anguis fragilis*), green lizard (*Lacerta bilineata*), grass snake (*Natrix helvetica*) and wall lizard (*Podarcis muralis*). These species vary in their distributions, habitat preferences and detectability. Additional 'bycatch' or incidental species are also recorded during surveys.

3.3 Survey methodology

Surveys were carried out as described in the NARRS guidance (http://www.narrs.org.uk/). In brief, sampling areas within a selected 1-km square were identified (ponds or suitable reptile habitat) and visited multiple times. From 2007 to 2010 squares were selected randomly, whereas from 2011 onwards squares were surveyed when site access could be arranged and a volunteer was willing to survey the location. To maximise detectability, multiple survey methods were used. For amphibians, these were (i) visual searches, (ii) netting and (iii) torching. For reptiles, these were (i) visual surveys, (ii) artificial refugia checks and (iii) pre-existing refugia checks. Amphibian surveyors were directed to conduct surveys between January and May, with the aim of completing four surveys. In comparison, reptile surveyors were directed to undertake surveys between March and October, with the aim of conducting at least four surveys between March and June in optimal weather conditions in order to maximise detection.

In addition to the species observed, surveyors were also required to record data on survey conditions and habitat quality. Amphibian habitat quality was primarily assessed using the Habitat Suitability Index (HSI) developed by Oldham et al. (2000) for use with great crested newts (*Triturus cristatus*). Though this species is absent from Jersey, the HSI is considered a good indicator of habitat quality for amphibians and so we apply it in Jersey and evaluate its appropriateness in this report. There is currently no commonly used reptile equivalent to the amphibian HSI, though efforts have been made to develop them (Brady and Phillips 2012; Brady et al. 2014).

3.4 Data analysis

Data from the 12 years of NARRS in Jersey were used to calculate the following:

- amphibian pond occupancy rates
- reptile 1-km square occupancy rates
- amphibian detectability
- reptile detectability
- species richness per 1-km square
- changes in occupancy between survey cycles
- differences in habitat quality between survey cycles
- differences in survey effort between survey cycles
- optimal survey design for inferring species absence
- optimal survey design for detecting population trends

3.4.1 Software and Data

Analyses were carried out in the freeware known as ‘R’ (R Core Team 2018), using the ‘unmarked’ (Fiske and Chandler 2011) and ‘AICcmodavg’ (Mazerolle 2016) packages as well as power analysis code developed by Guillera-Arroita and Lahoz-Monfort (2012). The ‘reshape2’ package was used to reshape data (Wickham 2007) and graphs were generated using the ‘ggplot2’ package (Wickham 2016). Maps were created in ArcGIS Pro v.2.2.4 (ESRI 2018).

Survey and mapping data were provided by Natural Environment, Growth Housing and Environment, Government of Jersey. Additional data were provided by the Jersey Biodiversity Centre and Jersey Water in the form of additional species occurrence records and maps of freshwater bodies respectively.

3.4.2 Step 1 – Occupancy and detection

Within this report we discuss occupancy (ψ) in two contexts; naïve and estimated. Naïve occupancy is the observed rate at which ponds or squares are occupied by the species of interest, whereas estimated occupancy incorporates the probability of detecting the species of interest and is likely to provide a more realistic occupancy measure.

We first calculated naïve occupancy rates for each species across the 12-year survey period and for each six-year survey cycle. We then calculated occupancy (ψ) and detectability (p) probabilities for each species in R (R Core Team 2018) using single-season models in the unmarked package (Fiske and Chandler 2011). Probabilities were calculated for each six-year cycle and for the full 12-year dataset using null models, where covariates are not included and both occupancy and detection are held constant across sites and surveys. We then incorporated covariates as described below using the full 12-year dataset only, to investigate the factors influencing occupancy and detection for each species. Occupancy probabilities were considered as the likelihood that a given species occurs in a particular square. These values were compared against the naïve occupancy estimates that did not incorporate detectability. When carrying out occupancy modelling we made the following assumptions: (i) survey sites were closed to changes in occupancy changes throughout the survey season (i.e. if a species is present at a site at any point during a survey season, that species must be present at the site throughout the whole survey season, or conversely, it must always be absent), (ii) species were not falsely identified (i.e. misidentified) and (iii) species detection at a given site was independent of species detection at other sites (i.e. whether a species was present or absent a site had no influence from the presence/absence status of the species at other sites).

Further comparison was conducted by evaluating the distribution of records originating outside of NARRS recording efforts. These included ad-hoc records submitted to the Jersey Biodiversity Centre (JBC), records collected during scientific research (e.g. Ward et al. 2017), Toadwatch (Wilkinson and Starnes 2016), agile frog monitoring (Ward et al. 2016) and efforts to gather data on particular focal species in some years (Wilkinson et al. 2014). These records were not filtered by geographical accuracy or certainty of identification; therefore, there may be inaccuracies in the data presented.

For the purposes of this analysis we did not separate observations of different lifestages, though we acknowledge that the detectability of a species can be influenced by its lifestage.

Covariates

A combination of site- (Table 1) and survey-level (Table 2) covariates were incorporated in to models to identify the variables influencing species occupancy and detectability. Continuous numeric covariates were assessed with both linear and quadratic effects. The covariates were assessed separately for each species during model building.

Site covariates

Amphibian site covariates consisted of the year and cycle a pond was surveyed, the Habitat Suitability Index (HSI) score for amphibian ponds and a further four metrics calculated using ArcGIS Pro. These were (i) the number of ponds within a 1-km square (Figure 2), calculated from ponds and reservoirs present in a mapping layer provided by Jersey Water, (ii) the presence of Sites of Special Interest (SSIs), the Jersey National Park or National Trust for Jersey sites within a 1-km square (square designation), (iii) the centroid longitude coordinates of each 1-km square and (iv) the centroid latitude coordinates.

Reptile site covariates were comprised of the year and cycle a square was surveyed and a set of landscape covariates calculated in ArcGIS Pro. Landcover classifications were first aggregated in to nine broad classes, derived from those described in Ward and Wilkinson (2018). These classes are shown in Table 3 and Figure 1. From these classes, we calculated (i) the dominant landcover type (calculated as the aggregated landcover type with the greatest combined area in a given 1-km square), (ii) the dominant landcover type relevant to reptiles (calculated as the aggregated landcover type relevant to reptiles (grassland, scrub, dune, heath or wetland) with the greatest combined area in a given 1-km square) and (iii) the amount of habitat potentially suitable for reptiles (calculated as the summed area across grassland, dune, scrub and heath landcover classes within a given 1-km square). The presence of SSIs, the Jersey National Park or National Trust for Jersey sites were also calculated, along with the centroid coordinates (longitude and latitude) of each 1-km square. Further variables recorded by surveyors (patch connectivity, patch size, transect length and whether a site contained a designation (e.g. SSI)) were excluded due to missing data (but note the alternative calculation of site designation made using GIS).

Survey covariates

Day of the year, survey duration, survey timing (start, middle and end) and surveyor experience of a particular group in years (where their first year surveying is year 1 and the groups are reptiles or amphibians) were evaluated as survey covariates for both amphibians and reptiles. Additional survey covariates for amphibian species were the number of survey methods used and air temperature. We also evaluated water temperature, water clarity and percentage of shoreline surveyed, but excluded these variables due to missing data. Start and end survey timings were recorded by the NARRS surveyors. Mid-survey timings were additionally calculated using the following equation:

$$mid.time = start.time + \frac{duration}{2} \qquad \text{Equation 1.}$$

Further reptile survey covariates were the number of artificial refugia checked during a survey, the number of pre-existing refugia checked during a survey, the total number of refugia checked during a survey (artificial plus pre-existing) and the weather during a survey.

Continuous numeric variables (e.g. extent of reptile habitat, number of ponds within a 1-km square) were z-standardised by subtracting the mean and dividing by the standard deviation using the *scale* function in R.

Covariate correlations

Correlations between variables were assessed using the *cor* function in R. Day of year and air temperature showed a strong correlation for the amphibian dataset ($R^2 = 0.74$) and so only day of year was retained. Strong correlations were also seen between survey start, mid and end timings of amphibian surveys ($R^2 = 1.00$). Therefore, we used the start time as a representation of amphibian survey timing in our analyses.

The number of artificial refugia checked in reptile surveys was highly correlated with the total number of refugia (those laid plus those pre-existing) ($R^2 = 0.92$). Therefore, only the total number of refugia was used as a covariate in our analyses. Strong correlations were also seen between survey start, mid and end timings of reptile surveys ($R^2 = 0.97$–0.99). Therefore, we used the start time as a representation of reptile survey timing in our analyses.

Model selection

We used a stepwise approach to model building, where the most suitable model(s) for detection for a species were first identified based on akaike's information criterion (AIC). Whilst incorporating the best detection model, we then identified the best occupancy model, again based on AIC. The best models were considered to be those with ΔAIC < 2, and where multiple models fit these criteria, occupancy estimates were model-averaged.

Model fit

Model fit was assessed using the Mackenzie and Bailey goodness of fit test with 1000 bootstrap simulations (MacKenzie and Bailey 2004). Likelihood-ratio tests were also used to compare the best models against the null model, where a value of < 0.05 was considered to indicate a significantly better performing model compared to the null model.

Table 1 Site covariates evaluated in occupancy models.

Covariate	Group[a]	Description
Landscape designations in square	A/R	Binary categorisation (**Y** / **N**) of whether the 1-km square contains at least one of the following site designations: Site of Special Interest (SSI), Jersey National Park (JNP) or contains land owned or managed by the National Trust for Jersey (NTJ). Calculated using GIS
Survey cycle	A/R	**1** (2007–2012) or **2** (2013–2018)
Survey year	A/R	Year of survey
Longitude	A/R	X-coordinates (JTM) for indexing spatial variability
Latitude	A/R	Y-coordinates (JTM) for indexing spatial variability
Habitat Suitability Index (HSI)	A	Habitat Suitability Index (HSI) calculated from up to nine factors. Score **0–1** (Oldham et al. 2000; ARG UK 2010)
No. ponds	A	Number of ponds in the survey square (calculated using GIS)
Dominant landcover type	R	The aggregated landcover type (see Table 3) with the greatest combined area (ha) in the grid square
Dominant landcover type relevant to reptiles	R	The aggregated landcover type (see Table 3) relevant to reptiles (grassland, scrub, dune, heath, wetland) with the greatest combined area (ha) in the grid square
Extent of reptile landcover types	R	Combined area (ha) of grassland, dune, heath and scrub aggregated landcover types within a grid square
Patch connectivity / isolation*	R	Connectivity / isolation of reptile habitat in the grid square, as recorded by the NARRS surveyor selected from one of four categories: **CL** – completely isolated from other areas; **IS** – isolated by sub-optimal habitat; **LC** – linked by corridors of good habitat; **PL** – part of a larger area of good habitat
Patch size*	R	Typical patch size of reptile habitat, as recorded by the NARRS surveyor selected from one of five categories: **<1 ha**; **1–5 ha**; **6–10 ha**; **11–50 ha**; **>50 ha**
Transect length*	R	Approximate length of survey route (km) in areas surveyed, as recorded by the NARRS surveyor

[a] Whether the variable was assessed for amphibians (‘A’), reptiles (‘R’) or both (‘A/R’).

* Variable excluded from analysis due to missing data

Table 2 Survey covariates evaluated as predictors of detectability.

Covariate	Group[a]	Description
Day of year	A/R	Julian day of survey (where 1 = 1st January)
Start time of survey	A/R	Start time of survey
Mid-time of survey**	A/R	Mid-time of survey (see Equation 1 for calculation)
End-time of survey**	A/R	End time of survey
Duration	A/R	Duration of survey in minutes
Surveyor experience	A/R	Number of years surveyor has carried out NARRS monitoring for that taxonomic group (where 1 = 1st year)
Air temperature**	A	Air temperature as recorded by NARRS surveyor (℃)
Water temperature*	A	Water temperature as recorded by NARRS surveyor (℃)
Number of methods	A	Number of survey methods used (visual survey, net, torch)
Water clarity*	A	Categorical measure of water clarity recorded by NARRS surveyor
Percentage shoreline surveyed*	A	Percentage of shoreline surveyed during a survey as recorded by NARRS surveyor
No. artificial refugia**	R	Number of artificial refugia checked during survey that had been laid by the surveyor
No. pre-existing refugia**	R	Number of pre-existing refugia checked during survey that had not been laid by the surveyor (e.g. refuse)
Total no. refugia	R	Combined total number of refugia checked during survey that had or had not been laid by the surveyor
Weather	R	Categorical weather condition as recorded by NARRS surveyor: **Poor**; **Moderate**; **Good**; **Very good**; **Excellent**

[a] Whether the variable was assessed for amphibians (‘A’), reptiles (‘R’) or both (‘A/R’).

* Variable excluded due to missing data

** Variable excluded due to correlations with other variables.

Table 3 Habitat types assessed by surveyors in reptile surveys, and calculated digitally from landcover maps using GIS. See also Figure 1.

Recorded by surveyors	Classes in Ward and Wilkinson (2018)	Aggregated classes
Arable farmland	(1) Arable	Arable & improved grassland
Bog/marsh/fen	(23) Wetland	Wetland
Brownfield	(6) Brownfield	Urban
Grassland – rough/long	(8) Coastal grassland (11) Dune grassland (13) Dune marram dominated (20) Semi-improved grassland (22) Unimproved grassland	Grassland Dune Dune Grassland Grassland
Grassland – short	(8) Coastal grassland (14) Garden (16) Improved grassland	Grassland Urban Arable & improved grassland
Herbs	(4) Bracken (21) Tall ruderal	Scrub Scrub
Lowland heath	(9) Coastal heath (12) Dune heath	Heath Heath
Manmade surfaces	(3) Bare ground (unnatural)	Urban
Moorland	–	–
Rock/bare ground	(2) Bare ground (natural) (15) Hottentot fig	Bare ground Bare ground
Sand dunes	(11) Dune grassland (13) Dune marram dominated	Dune Dune
Scrub – continuous	(19) Scrub	Scrub
Scrub – scattered	(19) Scrub	Scrub
Urban/suburban/industrial	(7) Building	Urban
Water/beach/estuary	(23) Wetland	Wetland
Woodland – coniferous	(10) Coniferous woodland	Woodland
Woodland – deciduous	(5) Broadleaved woodland	Woodland
Woodland – mixed	(17) Mixed woodland (18) Orchard / plantation	Woodland Arable & improved grassland

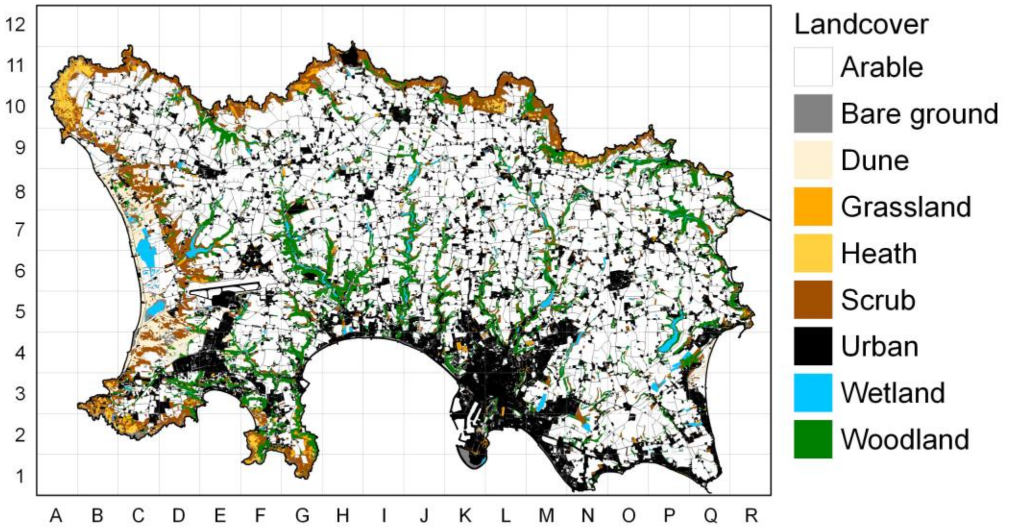

Figure 1 Aggregated landcover classes. Grid references are shown for orientation.

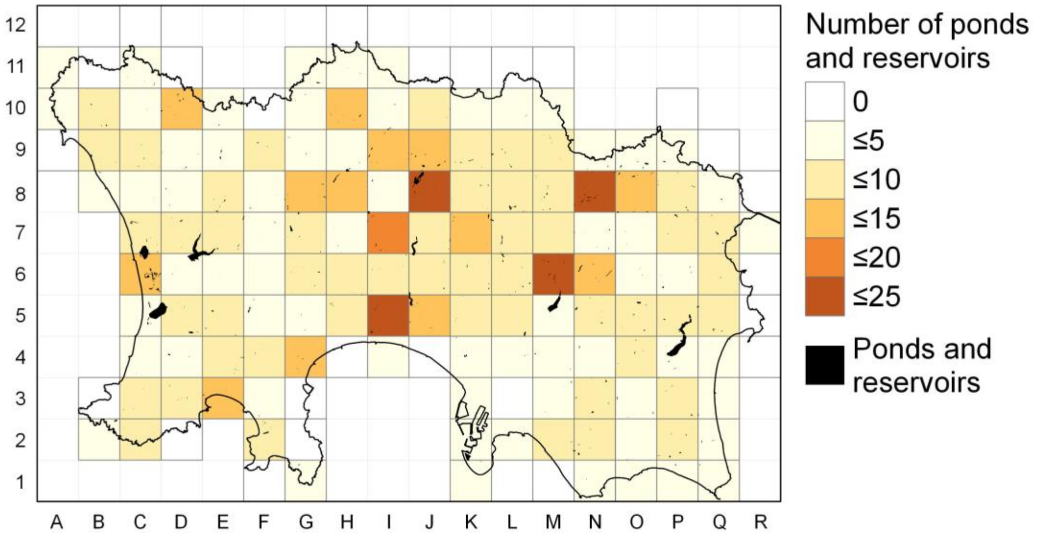

Figure 2 Number and distribution of ponds and reservoirs in each 1-km grid square. Grid references are shown for orientation. Data source: Jersey Water.

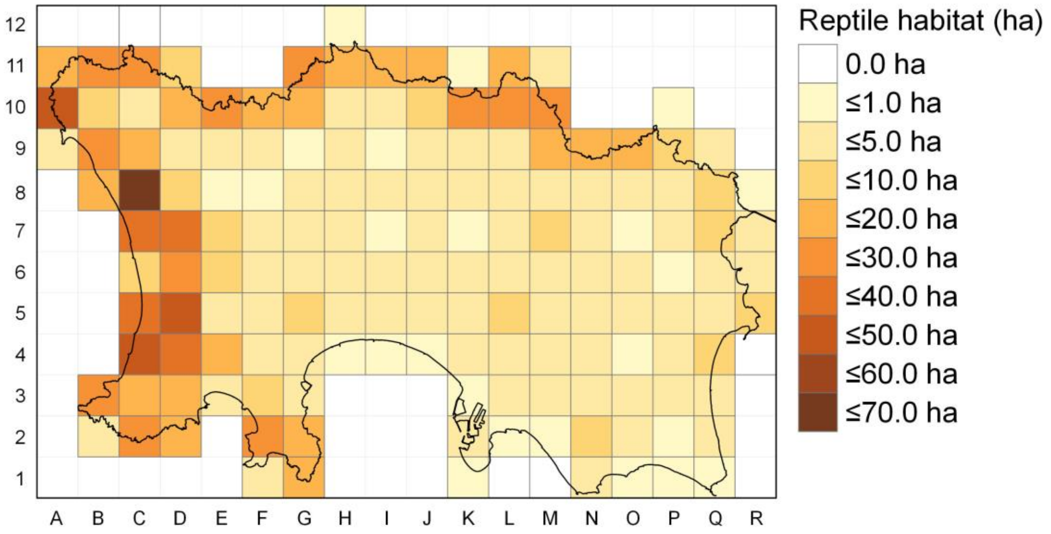

Figure 3 Total area (ha) of reptile habitat in each grid square, calculated as the sum of the areas of dune, grassland, heath and scrub habitats. Grid references are shown for orientation.

3.4.3 Step 2 – Species richness

The number of (i) amphibian and (ii) reptile species recorded in each square (naïve occupancy) was calculated for both the 12-year period and each of the two six-year cycles.

3.4.4 Step 3 – Habitat descriptors

The mean HSI and percentage of ponds achieving “good” (> 0.7) or “bad” (< 0.3) HSI scores were calculated for amphibians. Reptile habitat was assessed based on (i) the percentage of surveys in which reptile habitat was isolated (defined as habitat patches that were ‘completely isolated’ or ‘isolated by sub-optimal habitat’) and (ii) the patch size of suitable reptile habitat within the survey square.

3.4.5 Step 4 – Survey effort descriptors

Survey effort for amphibian surveys was quantified by (i) the survey duration, (ii) the total number of methods used across all pond surveys and (iii) the number of surveys conducted per pond. Survey effort for reptile surveys was quantified using three metrics; (i) survey route length, (ii) the number of artificial refugia laid and (iii) the percentage of key areas surveyed.

3.4.6 Step 5 – Survey design

To calculate the number of surveys (*K*) required to have 80%, 90% and 95% confidence that a species was absent from a site we used the following equation:

$$K = \log(1 - p^{*})\,/\log(1 - p) \qquad \text{Equation 2.}$$

where *p* is the detection probability, and *p** is the confidence that the species will be detected on one or more of the *K* survey visits (McArdle 1990). Estimates of detectability (*p*) were taken from (i) the null model and (ii) the top occupancy models, using the full 12-year dataset for both.

We then evaluated the statistical power of the sampling effort for each species between the two six-year survey cycles using a Wald test on the probability scale (Guillera-Arroita and Lahoz-Monfort 2012), with parameters from the null model of each species. To determine the most suitable future sampling design for detecting occupancy changes for amphibians and reptiles in Jersey, we then carried out a two-tailed power analysis in R. We used mean occupancy and detection values from the top occupancy models and set a significance level (α) of 0.1 due to the importance of detecting a change in occupancy. The number of sites required to detect proportional changes in occupancy were carried out for effect sizes (R) of

15%, 30% and 50%. The number of survey visits (*K*) was set to the highest rounded value required for 95% confidence of absence when detection covariates from the top occupancy models were set to their mean. Though we calculate estimates for all species, only *K* values from widespread species in each group (toads and palmate newts for amphibians, slow worms and green lizards for reptiles) were considered to be reliable due to the expectation of extremely high number for rare and restricted species.

4. Results

4.1 Survey summary

67 surveyors were involved in monitoring across the 12-year period.

Amphibians

43 surveyors surveyed a total of 97 squares for amphibians over the 12-year period, with 46 surveyed in the first cycle and 51 in the second (Figure 4). This equates to 47 unique squares over the 12-years, with 38 unique squares in the first cycle and 37 in the second. A total of 372 amphibian survey visits were carried out across the 12-year period, consisting of 142 in cycle 1 and 230 in cycle 2. Amphibian surveys were undertaken between Julian day (where day 1 is the first of January) 10 (10th January) and 271 (28th September), with a median day of 95 (5th April) and an interquartile range of 70–123 (11th March–2nd May). A total of 53 amphibian surveys were undertaken after day 151 (31st May), but the majority of amphibian surveys were carried out between February and May (Figure 5).

The majority of toad observations were between February and April, palmate newts between February and May, and agile frogs between February and March. Toads and palmate newts were recorded all the way through to September, whereas very few observations occurred after March. The numbers of individuals recorded and the number and proportion of sites at which they were recorded are given in Table 4. Toads and palmate newts were recorded a comparatively high number of times and at a larger proportion of sites compared to agile frogs which were recorded a moderate number of times but at few sites.

Reptiles

48 surveyors surveyed a total of 111 squares over the 12-year period, with 60 surveyed in the first cycle and 51 in the second. This equates to 60 unique squares over the 12-years, with 50 unique squares in the first cycle and 40 in the second (Figure 4). 440 reptile survey visits were made to the squares that were sampled, comprising 195 in the first cycle and 245 in the second. Reptile surveys were carried out between Julian day 61 (2nd March) and 353 (19th

December), with a median day of 165 (13th June) and an interquartile range of 129–230 (8th May–18th August). Only six reptile surveys fell outside of the preferred survey season of days 60–304, with the majority of surveys occurring between April and September (Figure 5).

Slow worms were mostly recorded between April and September, wall lizards between April and June, green lizards between April and September, and grass snakes between May and July. We note however that these observations may be associated to the higher number of surveys occurring during these months (Figure 5). The numbers of individuals recorded and the number and proportion of sites at which they were recorded are given in Table 4. Slow worms and green lizards were the most frequently recorded reptiles and occurred at a larger proportion of sites than wall lizards and grass snakes. Though wall lizards were recorded a moderate number of times, they were only observed in a handful of 1-km squares. Grass snakes were observed in a similar number of 1-km squares but were far less frequently encountered.

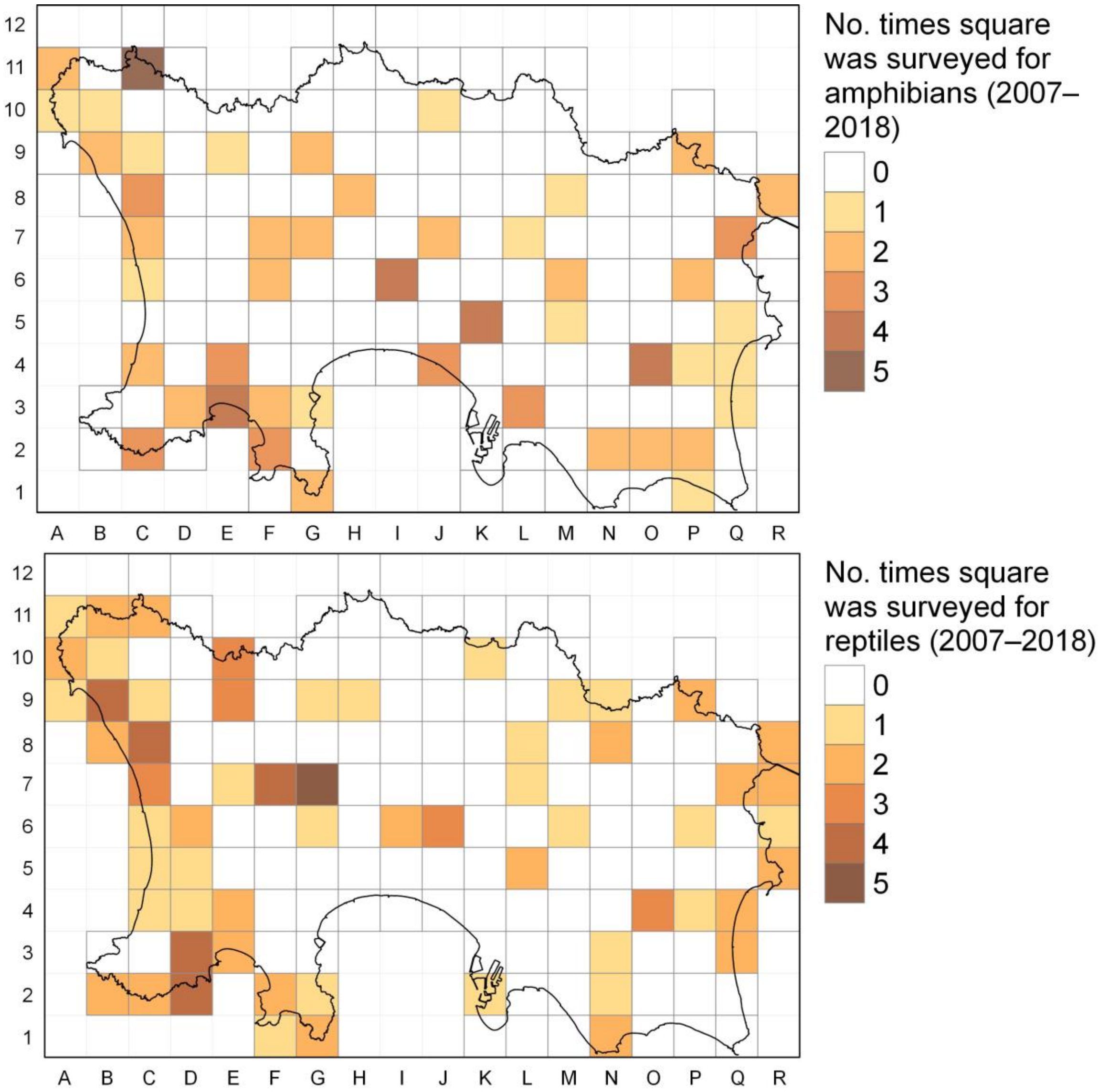

Figure 4 Number of times each 1-km square was surveyed for amphibians (top) and reptiles (bottom) (2007–2018). Grid references are shown for orientation.

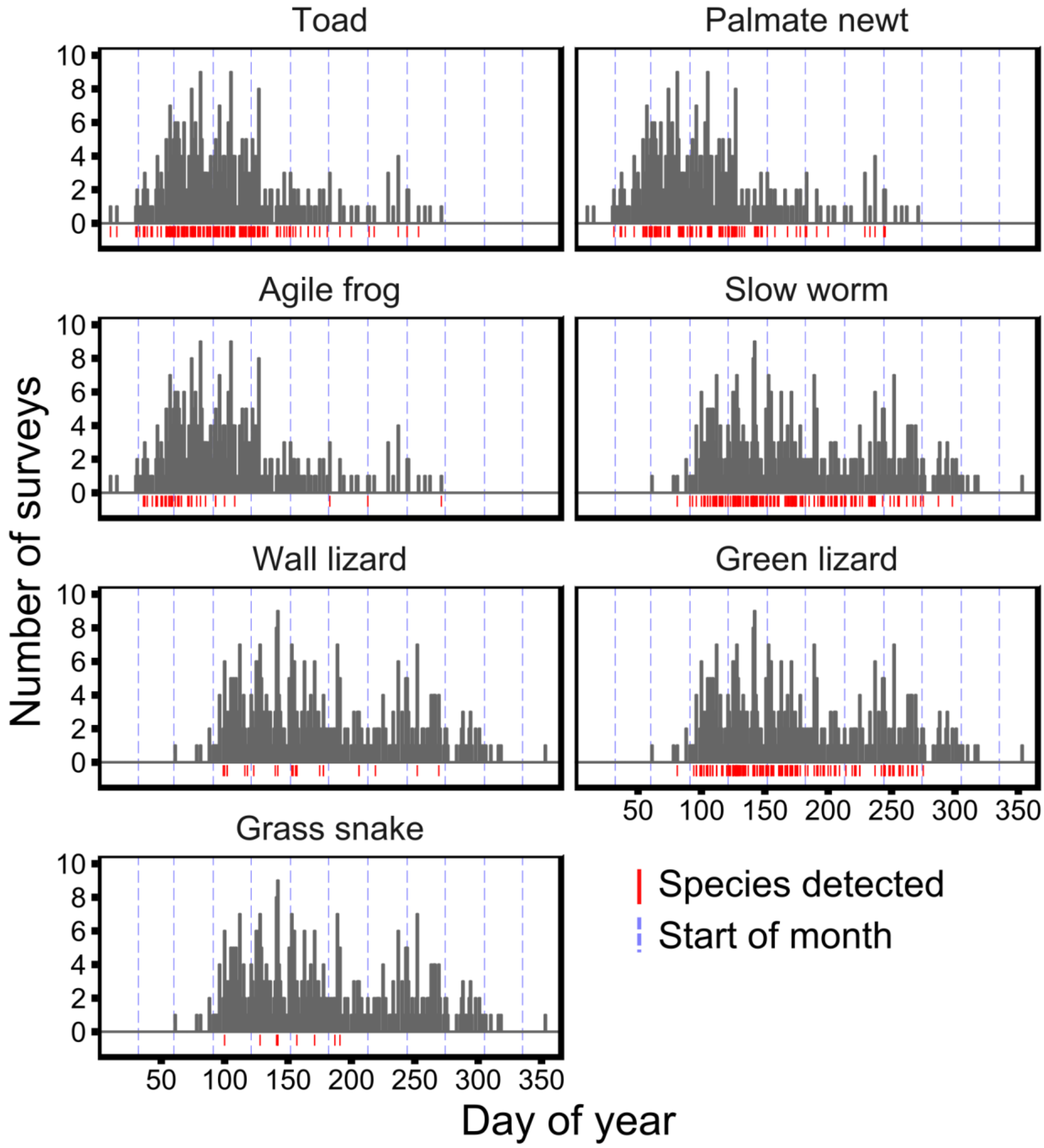

Figure 5 The number of reptile and amphibian surveys undertaken on each day of the year (2007–2018) and the days of the year on which each species were recorded (red vertical lines). Blue vertical dashed lines indicate the first day of each month for orientation.

Table 4 Number of individuals of each species observed during NARRS surveys and the number of sites that the species was observed at. The number of individuals is shown as the total number of adults, with the total of all lifestages shown in brackets. Numbers of individual amphibians in brackets should be treated with caution due to inaccuracies in counts of larva and eggs. Number of sites observed at in relation to the total number of sites surveyed are shown as percentages in brackets. Note that the number of sites the species was observed at may include repeats of the same squares and does not necessarily reflect occupancy rates.

Cycle	**Amphibians**			**Reptiles**			
	Western toad	Palmate newt	Agile frog	Slow worm	Wall lizard	Green lizard	Grass snake
Individuals							
2007–2012	740 (8416)	519 (771)	79 (136)	190 (225)	258 (37)	291 (328)	8 (8)
2013–2018	219 (4369)	296 (516)	71 (330)	235 (332)	110 (123)	320 (352)	3 (3)
2007–2018	*959* *(12785)*	*815* *(1287)*	*150* *(466)*	*425* *(557)*	*138* *(160)*	*611* *(680)*	*11* *(11)*
No. sites observed at							
2007–2012	26 (56.52%)	16 (34.78%)	5 (10.87%)	13 (21.67%)	5 (8.33%)	31 (51.67%)	5 (8.33%)
2013–2018	29 (56.86%)	24 (47.06%)	3 (5.88%)	31 (60.78%)	3 (5.88%)	24 (47.06%)	3 (5.88%)
2007–2018	*55* *(56.70%)*	*40* *(41.24%)*	*8* *(8.25%)*	*44* *(39.64%)*	*8* *(7.21%)*	*55* *(49.55%)*	*8* *(7.21%)*

4.2 Occupancy and detectability

4.2.1 Naïve occupancy

Amphibians

Naïve occupancy rates were fairly consistent between the two cycles with the exception of the palmate newt, which increased in the second cycle (Table 5). This may be explained by improvements in detection. Western toads were found across the island in both cycles (Figure 6). Palmate newts were also spread across the island (Figure 7), whereas agile frogs remained restricted to the southwest of the island (Figure 8).

Reptiles

Naïve occupancy rates were fairly consistent between the two cycles with the exception of the slow worm, increasing by more than 2.5 times from the first cycle (Table 5). This may be explained by improvements in detection due to the increase in refugia usage in the 2nd cycle (Table 11). Efforts to survey for reptiles were skewed towards coastal regions, particularly in the east and west. Slow-worms were shown to be widespread with an increase in naïve occupancy rates in the 2nd cycle (Figure 9). It is likely that improvements to survey practices will continue to improve our distributional knowledge of this species. Wall lizards were restricted to coastal localities (Figure 10), and were recorded in fewer squares in the 2nd cycle. However, NARRS is not well suited to monitoring wall lizards and we therefore discuss improvements later on. Green lizards were predominantly recorded in the east and west of the island (Figure 11). Grass snakes were poorly recorded by NARRS surveys, observed in a total of six 1-km squares (Figure 12). They are poorly suited to existing NARRS monitoring in Jersey, and we make suggestions for improvements later on.

Comparisons to supplementary records

The results from NARRS surveys and additional data sourced from the Jersey Biodiversity Centre (JBC) appear to be complementary to one another, with instances where NARRS efforts have resulted in species detection within a 1-km square but other data sources have not, and vice versa. The additional data from the JBC also helps to fill the gaps where NARRS efforts have not been undertaken.

Amphibians

Combining both data sources (NARRS and JBC records), the toad has a widespread distribution (Figure 6). The palmate newt is widespread with improved recording in the 2nd cycle (Figure 7), though the number of records is far fewer than for the toad. Additional records from the JBC made little difference to the suspected distribution of the agile frog (Figure 8).

Reptiles

The slow worm distribution recorded by NARRS matches fairly closely to data from the JBC, though there were multiple squares where NARRS had incorrectly recorded the species as absent (Figure 9). Where NARRS surveys took place, NARRS efforts did manage to record wall lizards where JBC records indicated them to be present. However, some squares containing the species remained unsurveyed across both NARRS cycles (Figure 10). The agreement between NARRS survey efforts and green lizard records from the JBC was very high, with very few misclassified squares (Figure 11). In contrast, NARRS efforts were very poor at detecting grass snakes in comparison to other, more intensive efforts (Figure 12) (Ward et al. 2017).

Table 5 Species occupancy (ψ) and detection (p) probabilities based on naïve observations (i.e. not incorporating detection probability) and on the null model (constant occupancy and detectability across sites and surveys). Naïve occupancy estimates are shown with data amalgamated from multiple years if a site was surveyed in multiple years within a single cycle, with the naïve occupancy rate where site repeats are included even when in the same cycle shown in brackets. Standard errors (SE) are shown in brackets for estimated occupancy and detection probabilities.

	Amphibians				**Reptiles**				
Cycle	*Bufo spinosus*	*Lissotriton helveticus*	*Rana dalmatina*	All amphibians	*Anguis fragilis*	*Podarcis muralis*	*Lacerta bilineata*	*Natrix helvetica*	All reptiles
Naïve occupancy									
2007–2012*	0.610	0.340	0.110	0.680	0.240	0.080	0.580	0.060	0.720
2007–2012	0.605 (0.565)	0.316 (0.348)	0.079 (0.109)	0.711 (0.696)	0.260 (0.217)	0.100 (0.083)	0.560 (0.517)	0.080 (0.083)	0.700 (0.633)
2013–2018	0.622 (0.569)	0.514 (0.471)	0.081 (0.059)	0.757 (0.745)	0.700 (0.608)	0.075 (0.059)	0.500 (0.471)	0.075 (0.059)	0.825 (0.784)
2007–2018	*0.702* *(0.567)*	*0.532* *(0.412)*	*0.064* *(0.082)*	*0.809* *(0.722)*	*0.550* *(0.396)*	*0.100* *(0.072)*	*0.550* *(0.495)*	*0.100* *(0.072)*	*0.800* *(0.703)*
Estimated occupancy (±SE)									
2007–2012	0.602 (0.082)	0.393 (0.081)	0.081 (0.045)	–	0.239 (0.062)	0.096 (0.041)	0.554 (0.068)	0.267 (0.216)	–
2013–2018	0.565 (0.074)	0.530 (0.089)	0.066 (0.037)	–	0.645 (0.073)	0.059 (0.033)	0.485 (0.072)	0.995 (0.241)	–
2007–2018	*0.566* *(0.057)*	*0.473* *(0.063)*	*0.074* *(0.029)*	–	*0.444* *(0.053)*	*0.077* *(0.026)*	*0.522* *(0.050)*	*0.301* *(0.249)*	–
Estimated detection (±SE)									
2007–2012	0.718 (0.055)	0.706 (0.069)	0.633 (0.179)	–	0.630 (0.068)	0.688 (0.137)	0.748 (0.049)	0.126 (0.106)	–
2013–2018	0.708 (0.045)	0.454 (0.051)	0.715 (0.067)	–	0.589 (0.042)	0.845 (0.102)	0.673 (0.045)	0.013 (0.008)	–
2007–2018	*0.709* *(0.036)*	*0.525* *(0.044)*	*0.702* *(0.063)*	–	*0.595* *(0.036)*	*0.769* *(0.085)*	*0.703* *(0.033)*	*0.075* *(0.066)*	–

* Values are from previous report (Wilkinson et al. 2014) and differ marginally from the values calculated in this report due to amendments to the dataset.

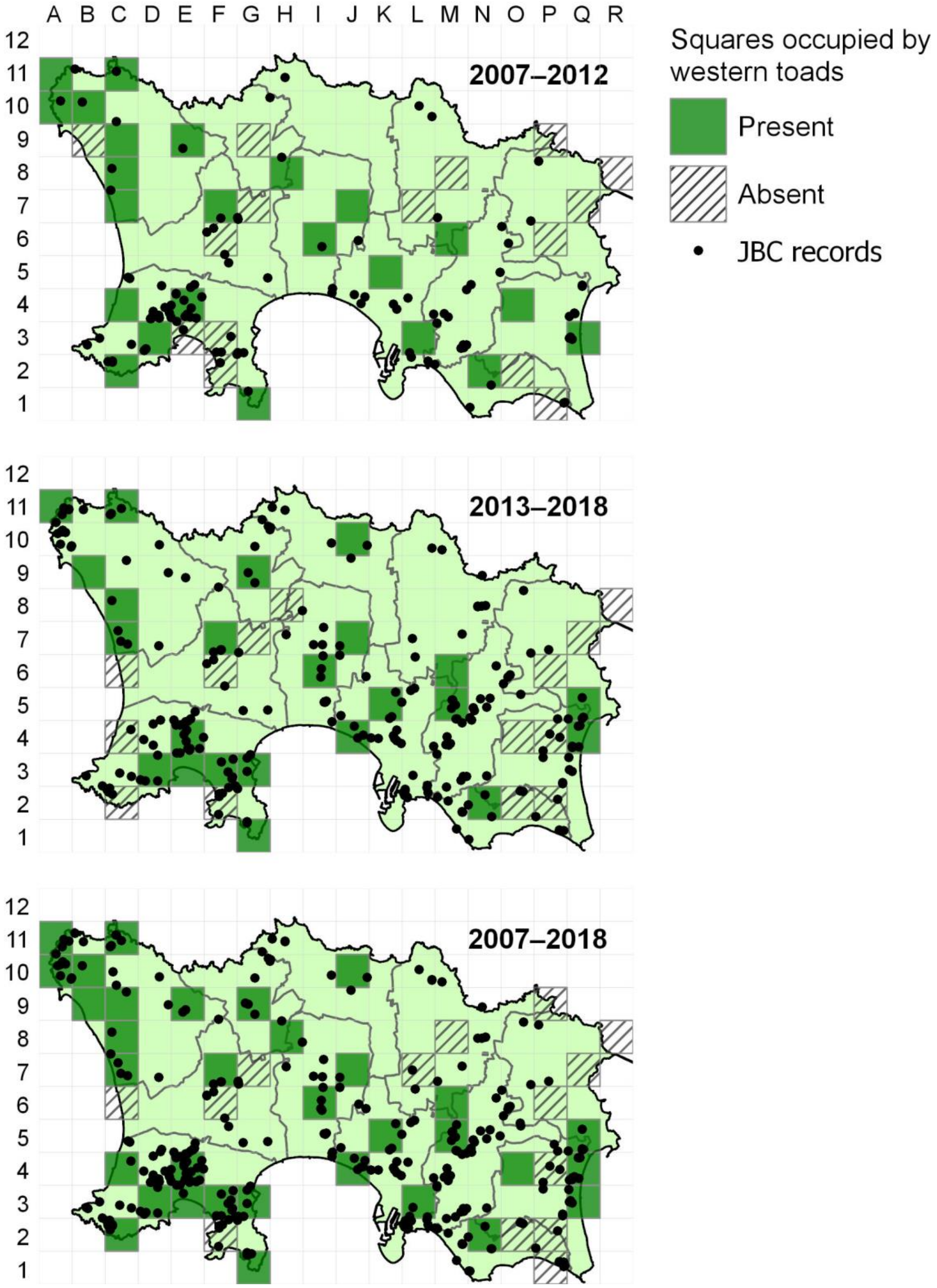

Figure 6 Square occupancy for western toads (*Bufo spinosus*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no western toads were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

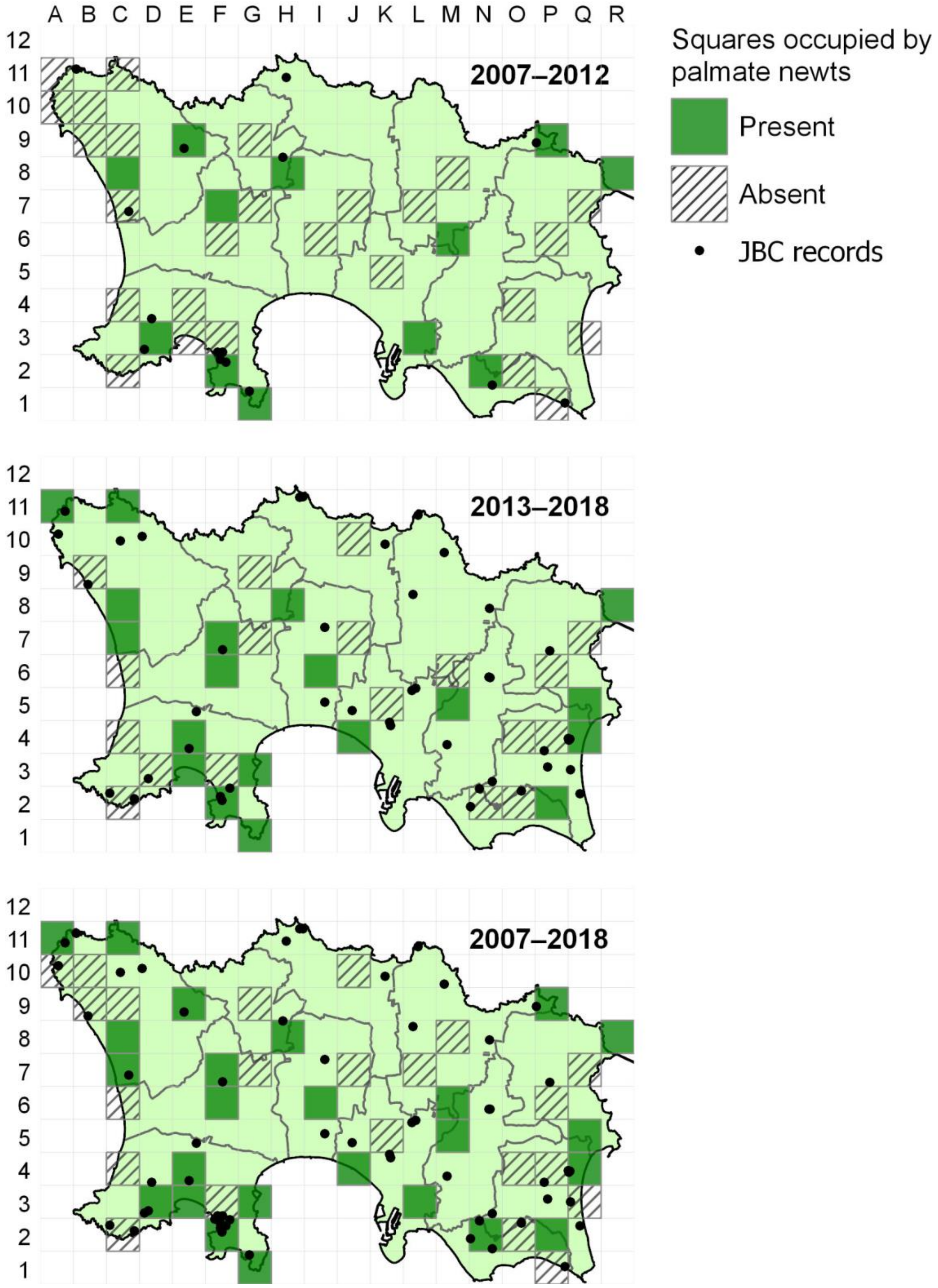

Figure 7 Square occupancy for palmate newts (*Lissotriton helveticus*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no palmate newts were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

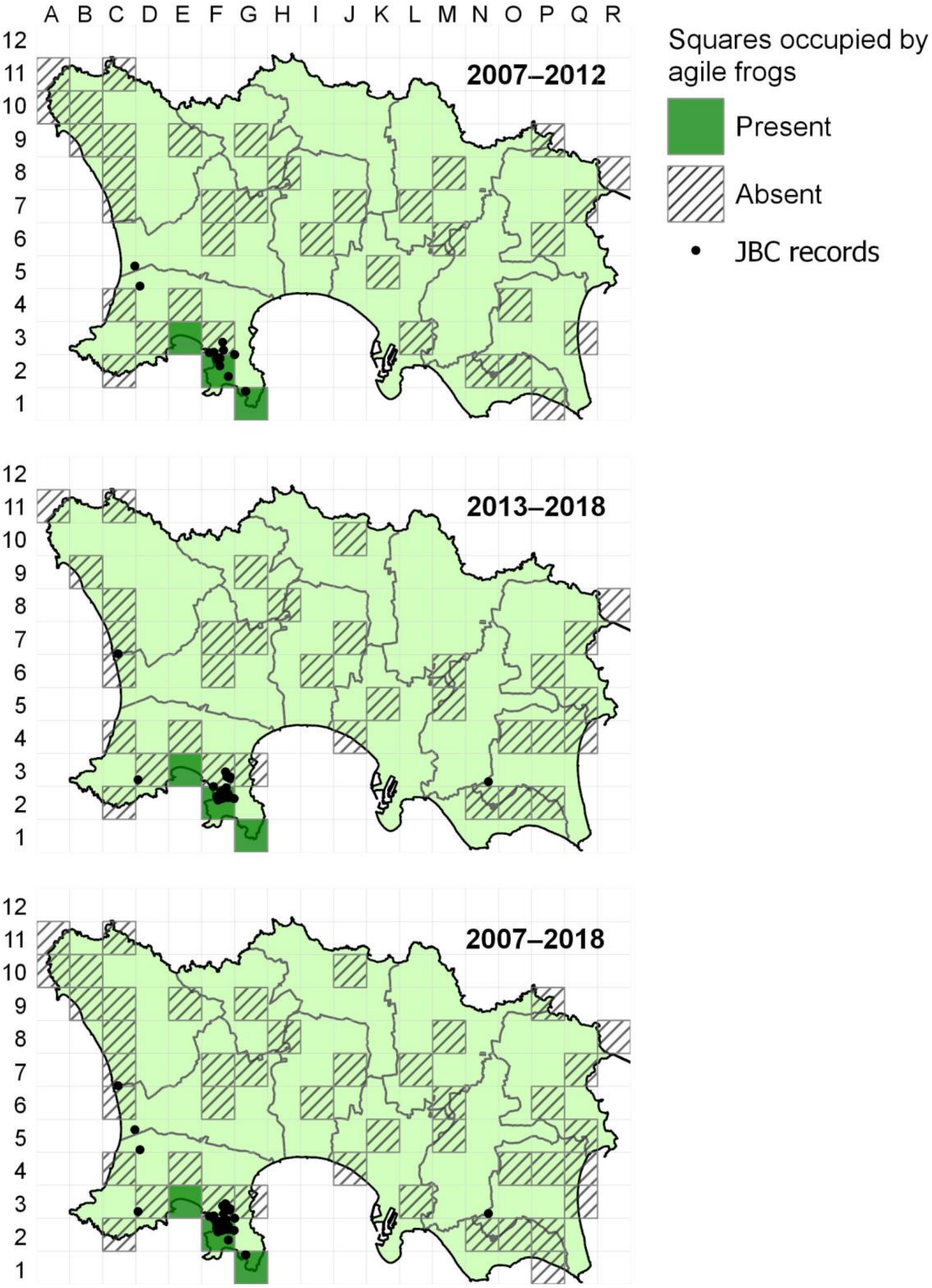

Figure 8 Square occupancy for agile frogs (*Rana dalmatina*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no agile frogs were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

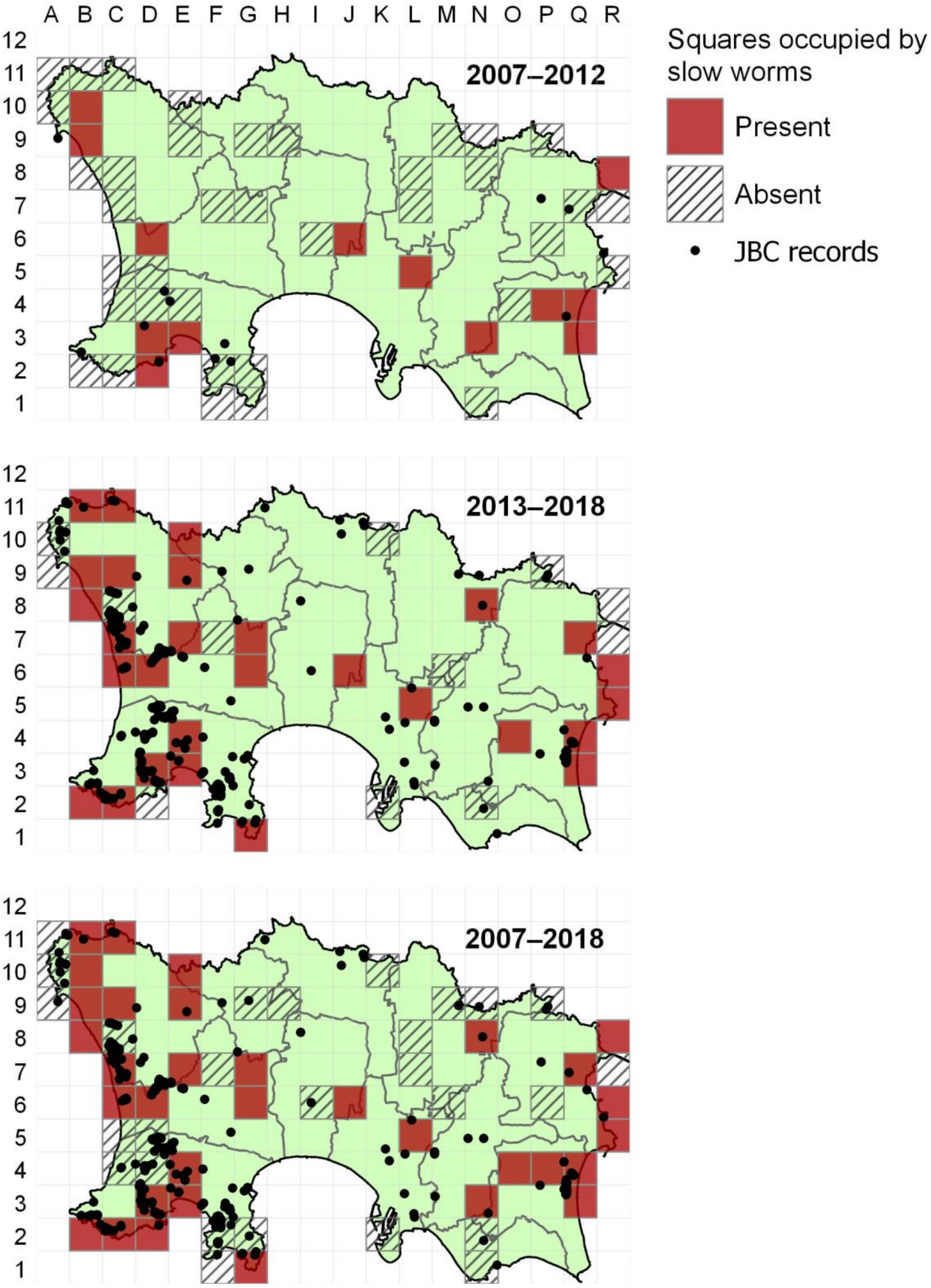

Figure 9 Square occupancy for slow worms (*Anguis fragilis*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no slow worms were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

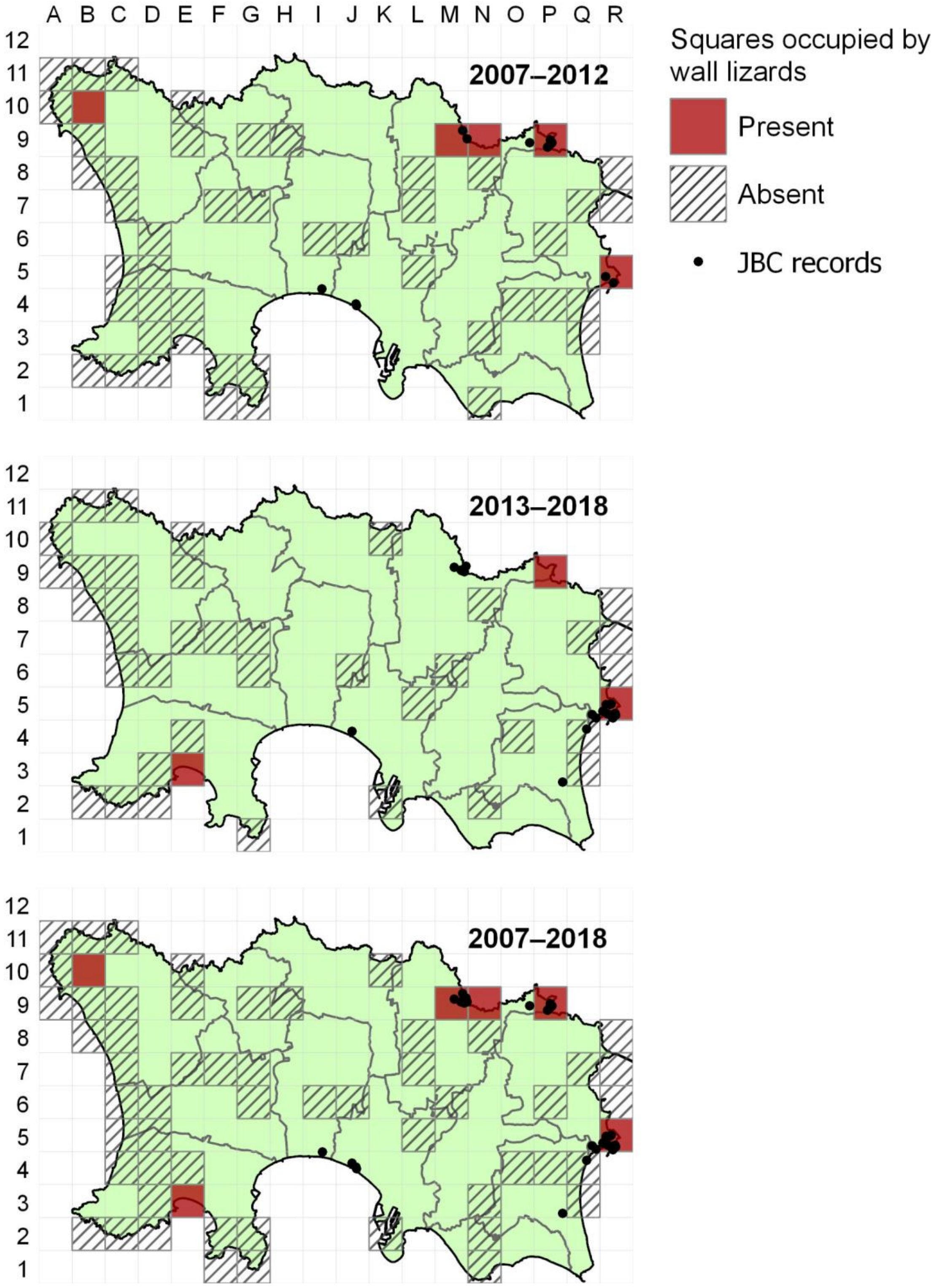

Figure 10 Square occupancy for wall lizards (*Podarcis muralis*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no wall lizards were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

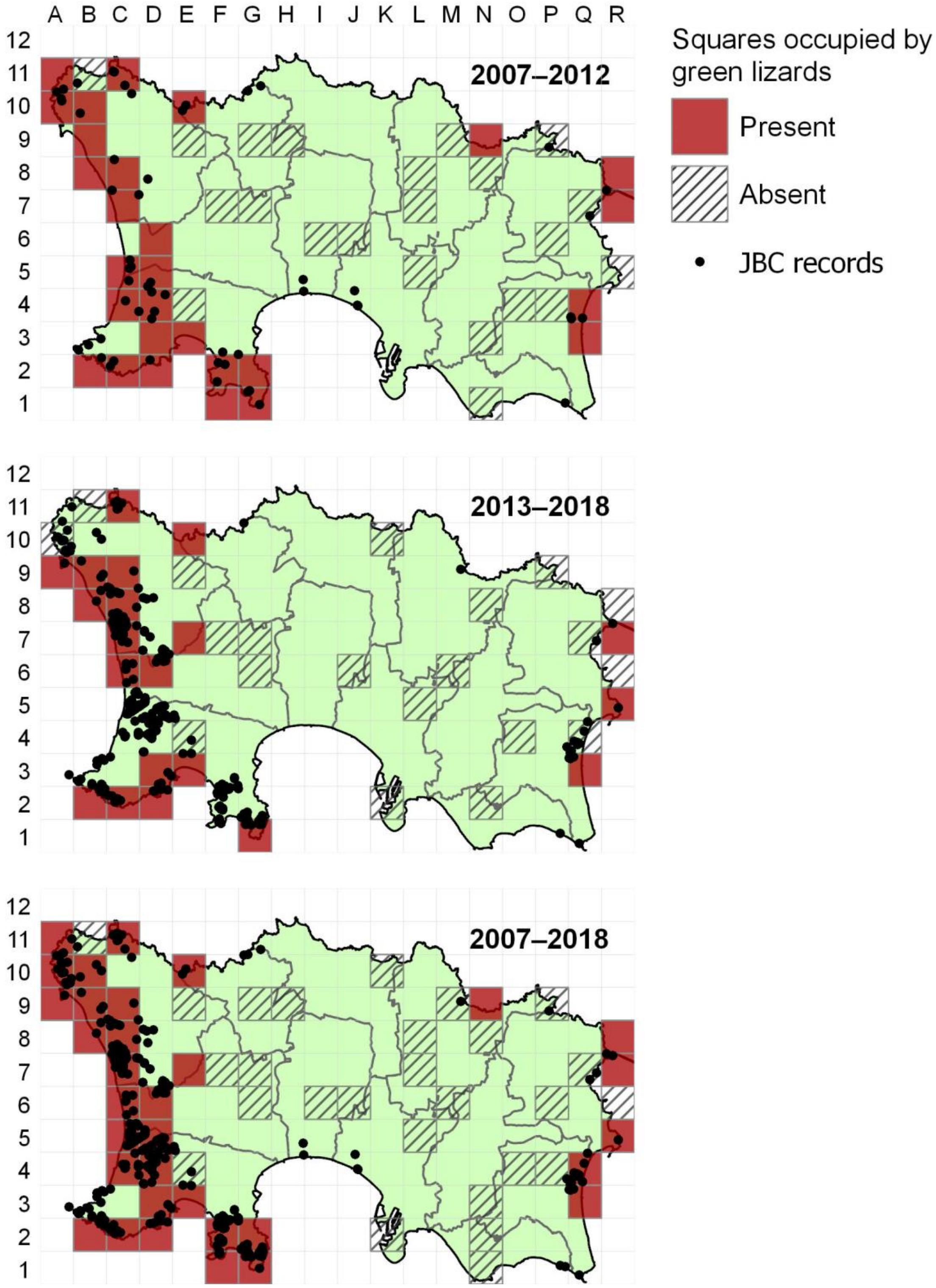

Figure 11 Square occupancy for green lizards (*Lacerta bilineata*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no green lizards were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

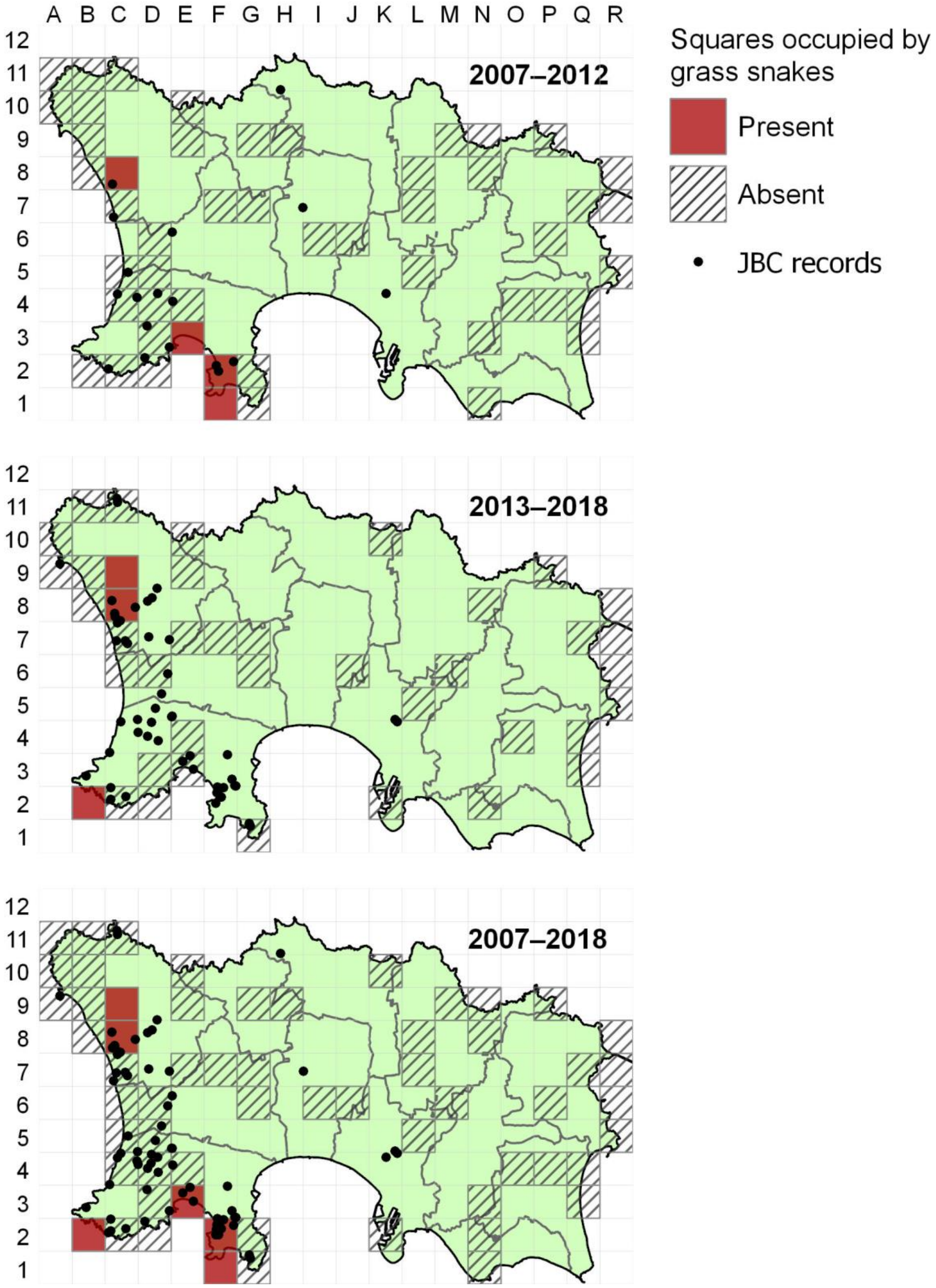

Figure 12 Square occupancy for grass snakes (*Natrix helvetica*) during NARRS surveys in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no grass snakes were detected are hatched. Filled circles indicate species records as stored on the Jersey Biodiversity Centre (JBC) database recorded within the given time period. Grid references are given for orientation.

4.2.2 Estimated detectability and occupancy

After excluding sites and survey visits with missing data, analyses were undertaken using data from 106 reptile sites (409 survey visits) and 85 amphibian ponds (313 survey visits).

Detectability

Using the null model, detectability of all species except for the grass snake was reasonably high. The grass snake, however, had an extremely low detection probability (Table 5). Models for the full 12-year dataset incorporating covariates showed improvements on the null model, and are presented in Table 6.

Amphibians

Toad detectability increased with survey duration until approximately 100 minutes where perfect detectability ($p = 1$) was achieved. Detection was also highest in surveys carried out from noon onwards, but apparently decreased with the number of survey methods used and surveyor experience (Figure 13). However, these latter two findings are likely an artefact of few surveys being carried out with multiple survey methods or by experienced surveyors. Overlapping confidence limits between the number of methods and similarly across the number of years experience also suggest these results to be unreliable.

The top model describing palmate newt detectability was comprised of survey duration, survey start time and day of the year. The only additional parameter in the top model set (ΔAIC < 2) was surveyor experience. Palmate newt detection increased with survey duration, though confidence limits were wide past approximately 50 minutes due to few surveys occurring for longer durations. Detectability also showed a steady increase with survey start time, with the greatest detection seen towards the end of the day. Finally, detection increased rapidly with day of the year (Figure 14).

A single top model emerged for agile frog detectability, consisting of survey duration, the number of survey methods used and surveyor experience. Detection increased with survey duration, peaking between 60 and 100 minutes but then decreasing beyond that. However, due to the limited dataset for this species no confidence limits were calculated and the decrease is likely associated to the fact that very few surveys had a duration exceeding 80 minutes – resulting in questionable predictions. Species detection was also suggested to increase with the number of survey methods used and decrease with surveyor experience (Figure 15), but again confidence limits were not calculated and the findings should be treated with caution for the reasons described above for the toad.

Reptiles

A single top model emerged for slow-worm detectability, suggesting it was influenced by the number of refugia checked, day of the year and surveyor experience. Detectability increased with the number of refugia checked up until approximately 15 refugia before plateauing and then decreasing past around 25 refugia. However, very few surveys incorporated more than 20 refugia which may explain this unexpected pattern. Slow worm detection also increased at the start of the year, peaking around day 160 (mid-June) before decreasing again over the course of the year. Detectability initially increased with surveyor experience, but decreased after three years of experience (Figure 16). This unexpected result may be due to a lack of surveys carried out by surveyors with more than three years experience.

The top model describing wall lizard detectability consisted of the number of refugia checked, survey duration and surveyor experience. However, due to the limited dataset and the unsuitability of NARRS for monitoring wall lizards, all model outputs were uninformative for this species. For example, detection was virtually zero for all numbers of refugia checked, highlighting their unsuitability for surveying this largely arboreal species. Other models in the top set ($\Delta AIC < 2$) included time of day and day of the year (Figure 17).

The top model describing green lizard detectability indicated influences of the number of refugia checked, the time of day (survey start time) and survey weather conditions. Other models in the top set ($\Delta AIC < 2$) included surveyor experience and survey duration as covariates. Green lizard detectability initially increased with the number of refugia checked but then apparently decreases after approximately five refugia. However, the detectability estimates have wide confidence limits, and it is unlikely that increases in refugia decrease detectability, but rather a combination of green lizards often being recorded in the absence of refugia, and that few surveys used more than 20 refugia. These effects were less obvious in suitable weather conditions – only showing decreases in detection at higher numbers of refugia which were poorly represented in the dataset. Species detectability also improved later in the day, though this effect was weaker in better weather conditions. Finally, detection also improved with a surveyor's interpretation of weather conditions, being highest in 'Excellent' and 'Very good' weather conditions. (Figure 18).

The top model explaining grass snake detectability suggested it to be influenced by the number of refugia checked and day of the year. Additional covariates in the top model set ($\Delta AIC < 2$) were surveyor experience and time of day. The results counterintuitively suggest that grass snake detectability decreases with refugia checks (Figure 19). However, due to few grass snakes being observed during NARRS surveys these findings must be treated with caution and we instead refer to the work of Ward et al. (2017) for more in depth analyses on detectability of Jersey’s grass snakes. Detectability also showed some improvement around day 150 (late May) but with wide confidence limits.

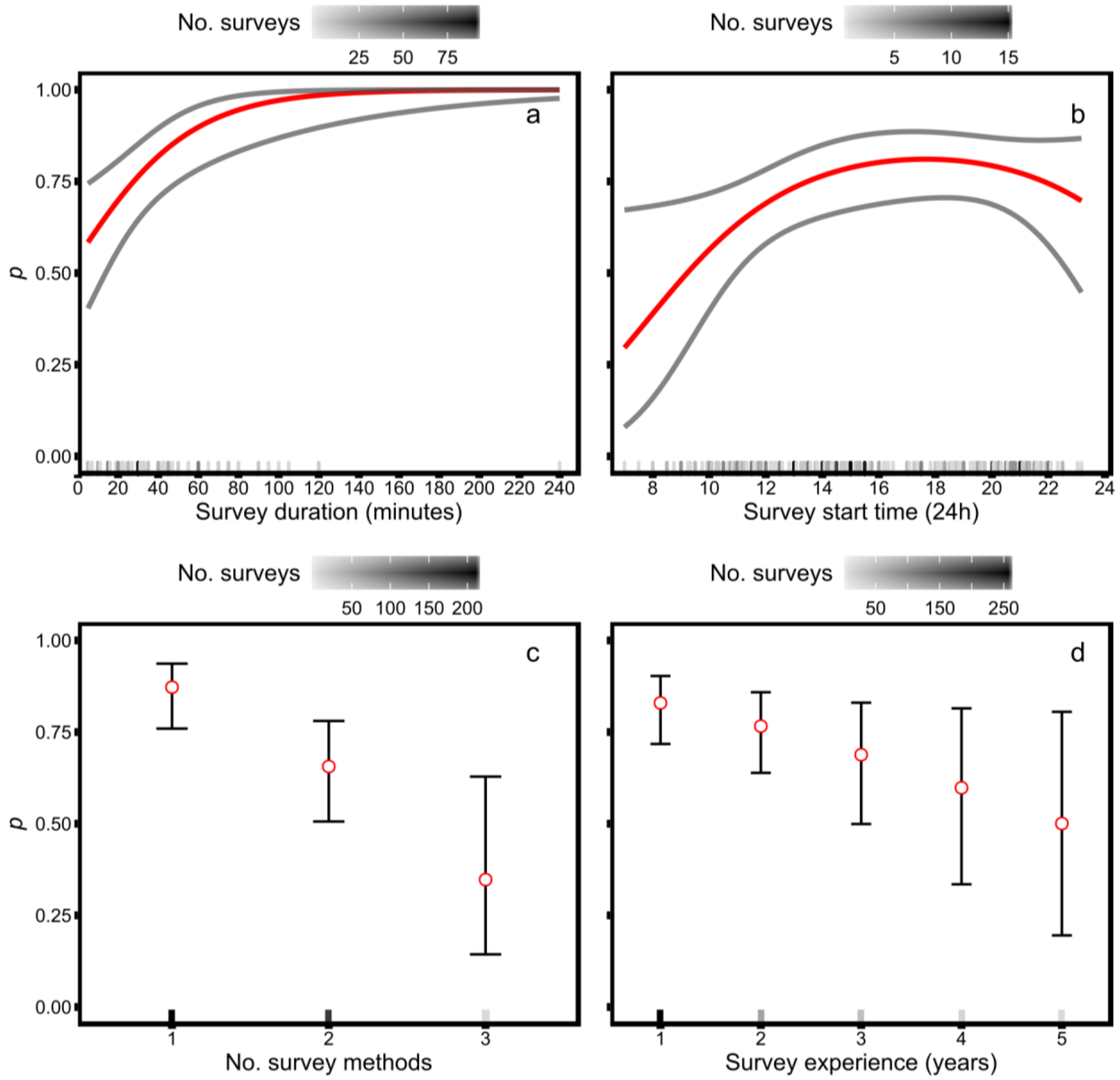

Figure 13 The response of toad (*Bufo spinosus*) detectability to (a) survey duration, (b) survey start time, (c) the number of survey methods used and (d) surveyor experience. The number of surveys carried out at each value are shown along the x-axis.

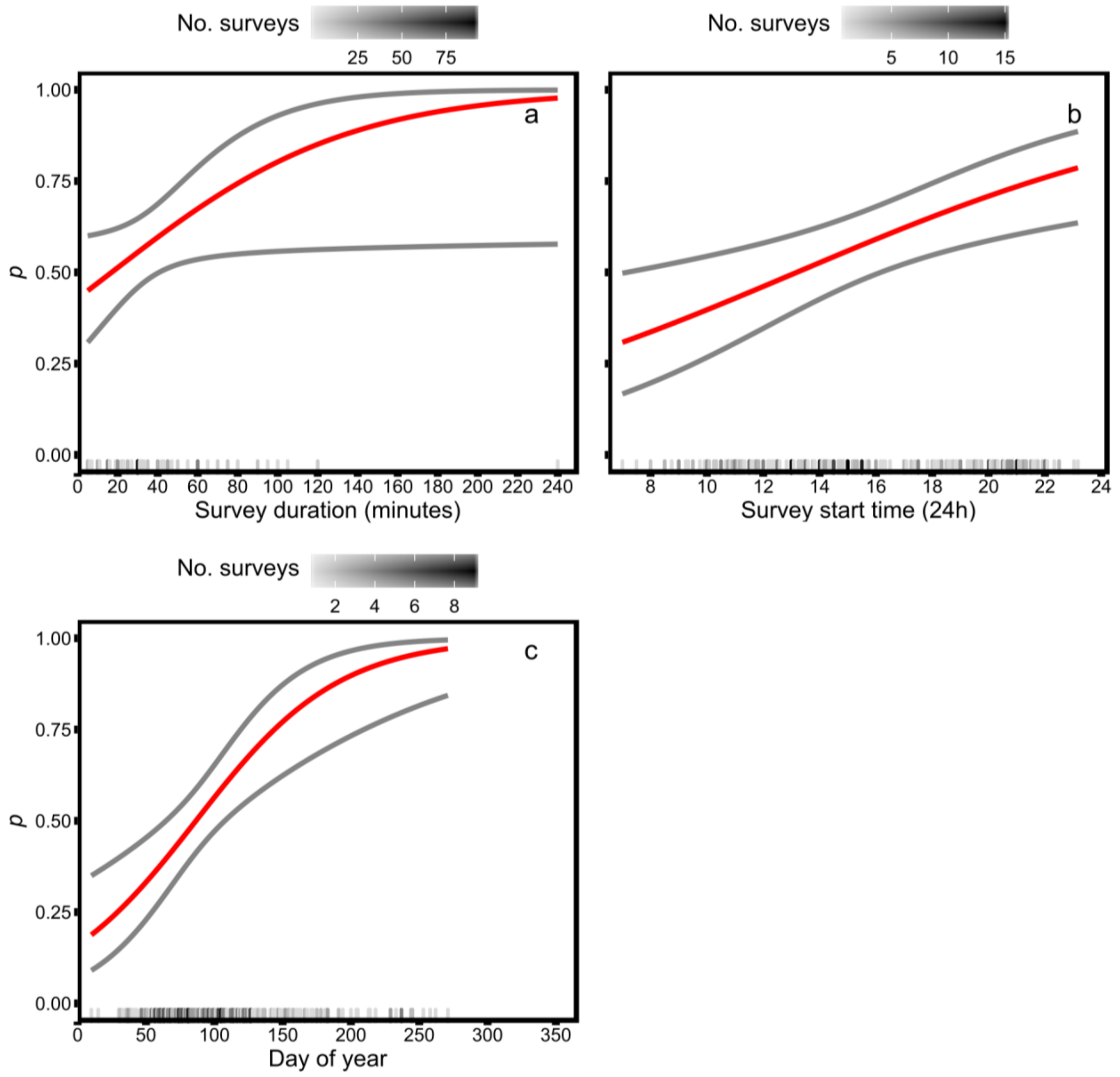

Figure 14 The response of palmate newt (*Lissotriton helveticus*) detectability to (a) survey duration, (b) survey start time and (c) day of the year. The number of surveys carried out at each value are shown along the x-axis.

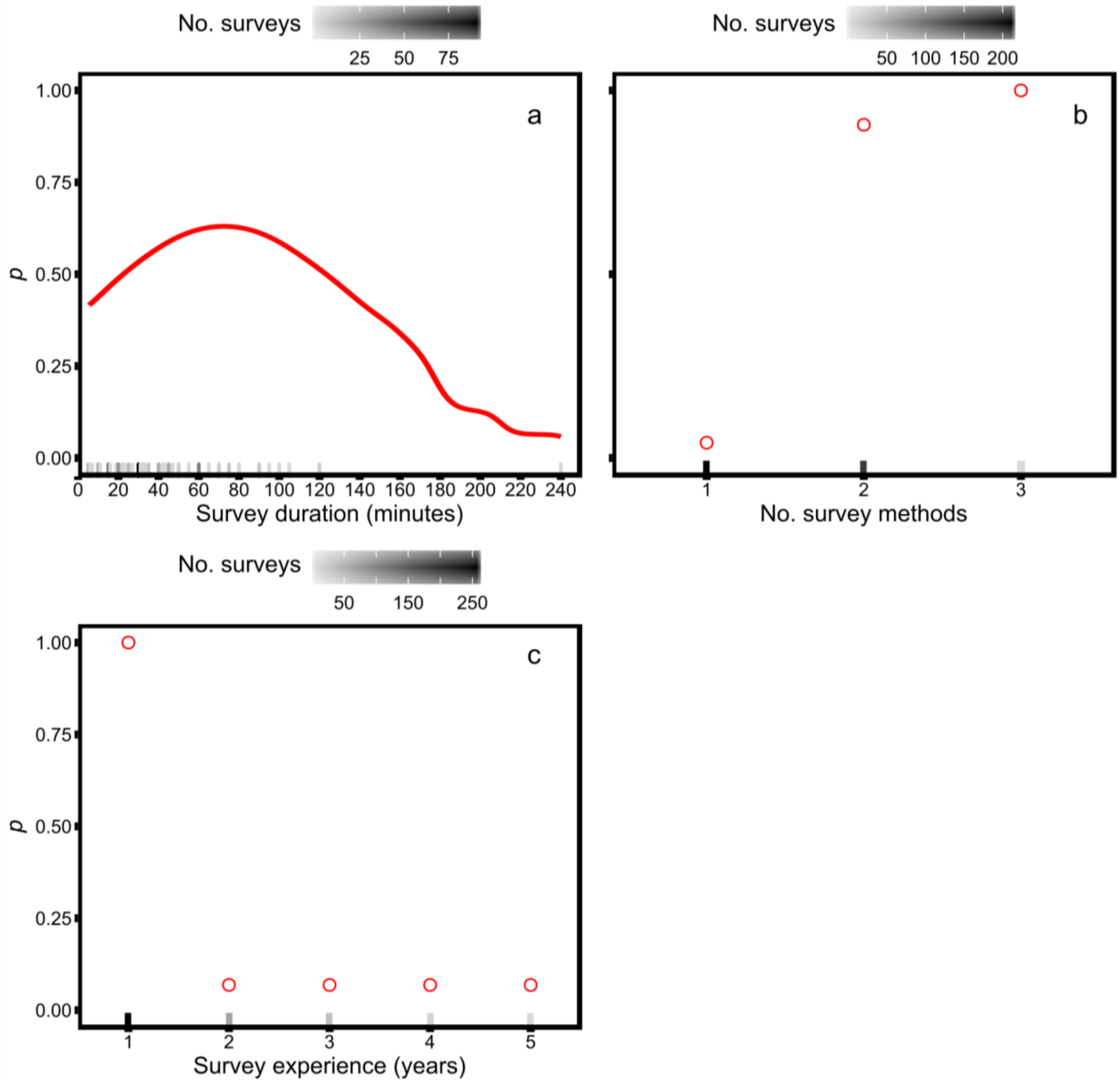

Figure 15 The response of agile frog (*Rana dalmatina*) detectability to (a) survey duration, (b) the number of survey methods used and (c) surveyor experience. The number of surveys carried out at each value are shown along the x-axis.

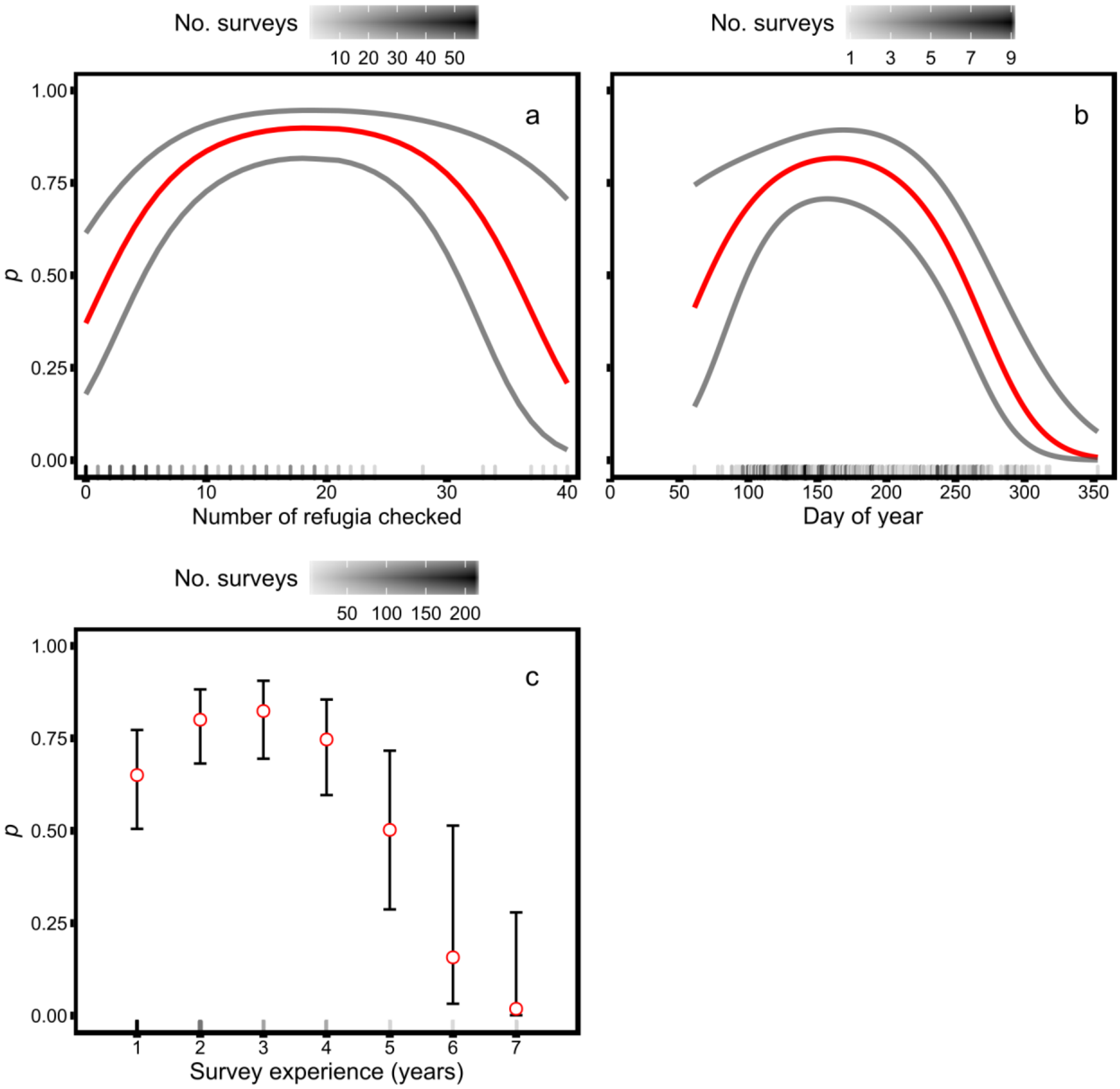

Figure 16 The response of slow worm (*Anguis fragilis*) detectability to (a) number of refugia checked, (b) day of the year and (c) surveyor experience. The number of surveys carried out at each value are shown along the x-axis.

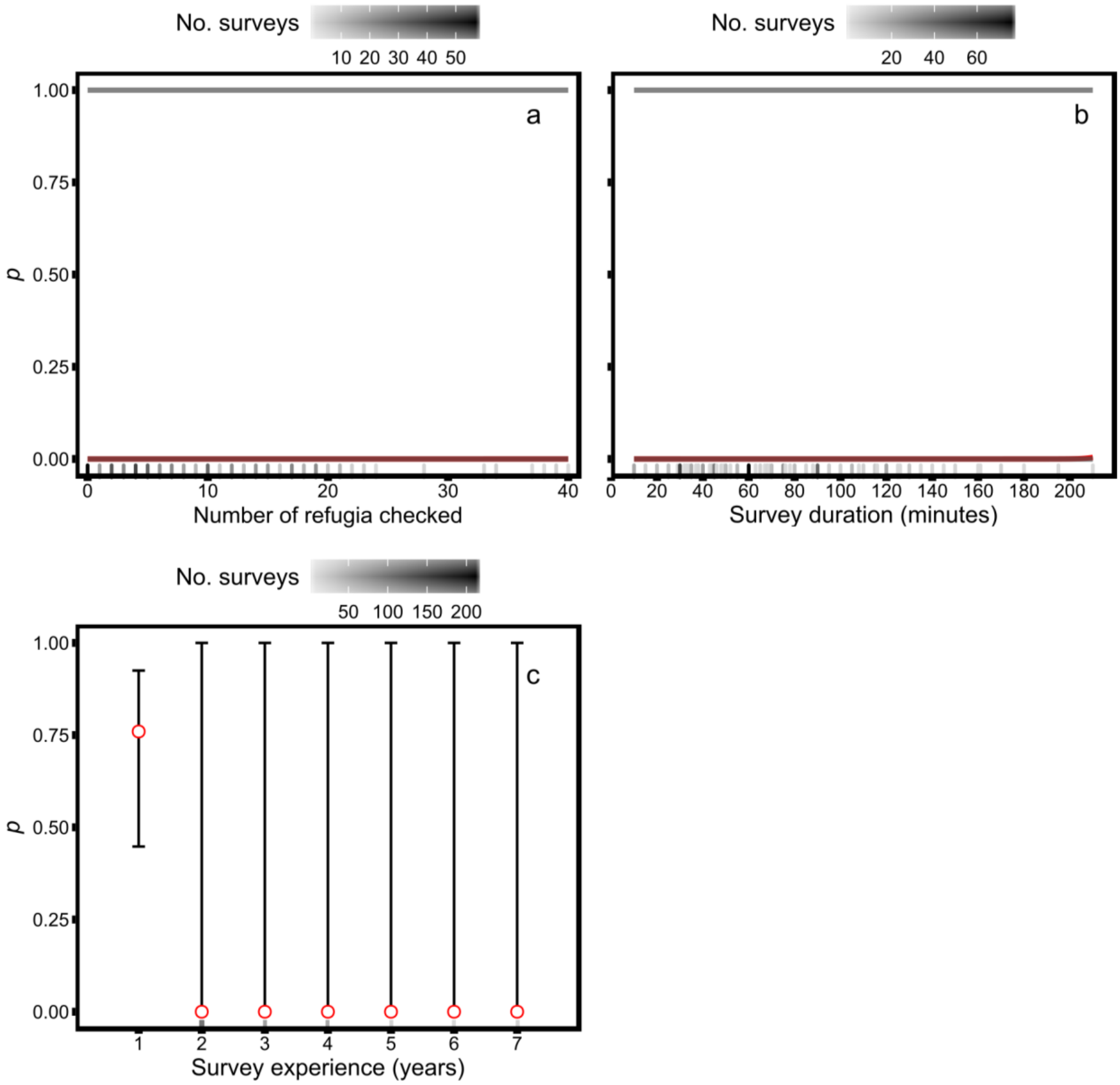

Figure 17 The response of wall lizard (*Podarcis muralis*) detectability to (a) the number of refugia checked, (b) survey duration and (c) surveyor experience. The number of surveys carried out at each value are shown along the x-axis.

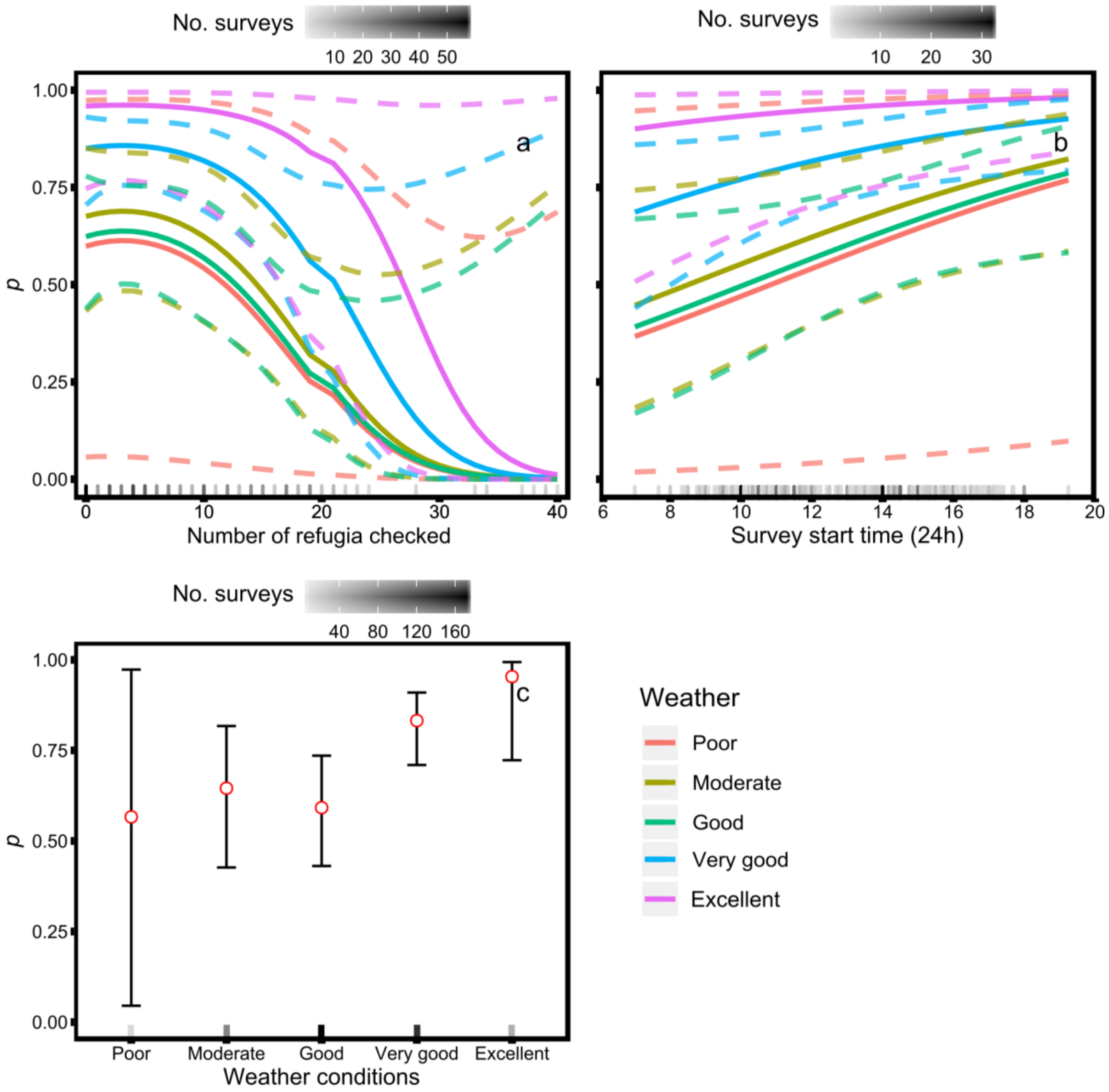

Figure 18 The response of green lizard (*Lacerta bilineata*) detectability to (a) the number of refugia checked, (b) survey start time and (c) survey weather conditions. Panels (a) and (b) show responses when survey weather conditions are varied. The number of surveys carried out at each value are shown along the x-axis.

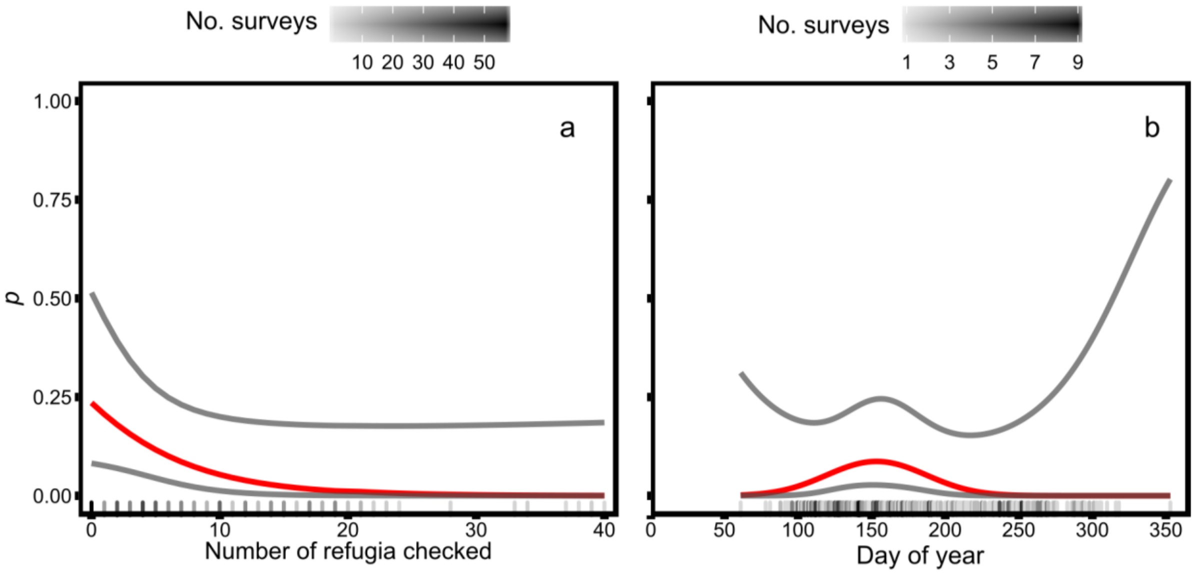

Figure 19 The response of grass snake (*Natrix helvetica*) detectability to (a) the number of refugia checked and (b) day of the year. The number of surveys carried out at each value are shown along the x-axis.

Occupancy

Amphibians

Based on the null model, occupancy was fairly consistent across cycles with the exception of the palmate newt. Occupancy estimates for agile frogs were extremely low, which fits our current knowledge of their restricted distribution.

Differences in estimated occupancy (based on null models) between the two cycles ranged between -0.037 and 0.015 (Table 5). The differences in naïve occupancy between cycles were very similar ranging from -0.002 to 0.000. The largest estimated change between cycles was a positive increase in occupancy for the palmate newt, with the other amphibian species showing marginal declines in occupancy.

Using the top detection model (ΔAIC = 0) for each species, occupancy was estimated using the full 12-year dataset. The top models are shown in Table 6. Pond occupancy by toads was best explained by longitude. However, the top model set also included effects of site designation, latitude, Habitat Suitability Index, the number of ponds in the 1-km square and the survey cycle. Occupancy showed very little change between cycles but a marginal improvement in occupancy probability if a pond occurred in a square containing a site designation. Occupancy increased marginally with latitude (heading north) but generally decreased with longitude (heading east) (Figure 20). The number of ponds in a survey square showed little effect on pond occupancy predictions, and only a slight positive influence of HSI score was observed (Figure 21).

The top palmate newt occupancy model was comprised of the Habitat Suitability Index, the number of ponds in the 1-km square and latitude. Additional covariates in the top model set were longitude and survey cycle. Palmate newt occupancy showed a slight decrease with increasing latitude (moving north) whereas longitude had little influence on occupancy estimates. Occupancy also decreased with the number of ponds in a survey square, though confidence limits were wide for squares containing many ponds. In contrast, a strong positive relationship between HSI score and occupancy was observed, but little change was predicted between cycles (Figure 22).

The best model describing agile frog occupancy consisted of longitude and latitude. Other models in the top set included the Habitat Suitability Index, the number of ponds in the 1-km square and site designation. Confidence limits for agile frog occupancy predictions were not calculated in some instances due to the restricted dataset for this species. Nonetheless, model predictions suggested latitude to have a large effect, where more southerly sites had a higher probability of being occupied. Sites containing high numbers of ponds in a 1-km square and those that achieved high HSI scores showed some improvement over those with lower values. There was little effect of longitude, survey cycle or site designation (Figure 23).

Likelihood ratio tests showed all species occupancy models to be significantly better ($p < 0.05$) than the null models. Goodness of fit tests also indicated models to have good fit to the data, with the exception of the western toad which showed poor fit (χ^2 = 207729208, p = 0.002, $\hat{c}$ = 35.25) and should therefore be treated with caution.

Reptiles

Based on the null model, occupancy was fairly consistent across cycles with the exception of the slow worm and the grass snake. Occupancy estimates for wall lizards were extremely low, which fits our current knowledge of their restricted distribution. However, grass snake occupancy was higher than expected, and the occupancy estimated for the 2nd cycle was extremely high (Table 5). Despite this, the large standard errors for the grass snake occupancy estimates suggest they must be treated with extreme caution. This issue can also be associated to the extremely low detection estimates for the species – introducing a large amount of uncertainty in to any calculations.

Differences in estimated occupancy (based on null models) between the two cycles ranged between -0.069 and 0.728; though excluding the unlikely grass snake estimates from the 2nd cycle reduced this latter figure to 0.406 (Table 5). The differences in naïve occupancy between cycles were very similar ranging from -0.060 to 0.440. Excluding the grass snake, the largest estimated change between cycles was a positive increase in occupancy for the slow worm, with all other species showing marginal declines in occupancy. As explained above, the large difference in estimated slow worm occupancy may be attributable to changes in detection rather than true changes in underlying species occupancy.

Using the top detection model (ΔAIC = 0) for each species, occupancy was estimated using the full 12-year dataset. The top models are shown in Table 6. The top slow worm model consisted of survey cycle and latitude, with site designation, extent of reptile habitat and longitude also featured in the top model set. Slow worm occupancy was generally higher in squares containing a site designation and increased in the 2nd cycle. Little effect was seen of the extent of reptile habitat in a survey square, whereas occupancy decreased with increasing latitude, suggesting higher occupancy rates in the south of the island (Figure 24).

The top model describing wall lizard occupancy was comprised of longitude and site designation. Additional covariates in the top model set were latitude, dominant habitat type, survey cycle, extent of reptile habitat and dominant reptile habitat type. Due to the restricted distribution of the species, all occupancy predictions had extremely large confidence limits and therefore must be treated with caution. Occupancy was suggested to show some increase with latitude (moving north) and latitude (moving east), but with little discernible effect of cycle, square designation or extent of reptile habitat within a square (Figure 25). The influences of different dominant habitat type and dominant reptile habitat type were unclear (Figures 26–27).

Green lizard occupancy was best described by a combination of longitude, dominant habitat type and latitude. The only additional covariate in the top model set was extent of reptile habitat. Occupancy was highest at low and high latitudes, particularly in the south of the island. Similarly, occupancy probabilities were highest at high and low longitudes – highlighting the importance of coastal areas. Green lizard occupancy generally increased with the extent of reptile habitat in the survey square, and was highest for squares where bare ground or scrub were the dominant habitat type (where bare ground primarily represents open sand dunes). However, confidence limits for the influences of dominant habitat types were wide, and could not be calculated for heath and scrub (Figure 28).

Grass snake occupancy was described by a single model containing both latitude and longitude. Model predictions showed little influence of latitude, whereas occupancy was predicted to be highest in the west of the island. However, confidence limits were between 0 and 1 due to the limited dataset on which predictions were based (Figure 29), and should therefore be treated with caution.

Likelihood ratio tests showed all species occupancy models to be significantly better ($p < 0.05$) than the null models. Goodness of fit tests also indicated models to have good fit to the data.

Table 6 Top detection (*p*) and occupancy (ψ) models for each of Jersey's amphibian and reptile species, using the full 12-year dataset.

Species	Model
Bufo spinosus	$p(Duration + No.methods + Experience + Start\ time^2)\psi(Longitude^2)$
Lissotriton helveticus	$p(Day + Start\ time + Duration)\psi(HSI + No.ponds + Latitude)$
Rana dalmatina	$p(No.methods + Duration^2 + Experience)\psi(Latitude + Longitude^2)$
Anguis fragilis	$p(ACOs^2 + Day^2 + Experience^2)\psi(Cycle + Latitude)$
Podarcis muralis	$p(Experience + ACOs + Duration^2)\psi(Longitude + Site\ designation)$
Lacerta bilineata	$p(ACOs^2 + Weather + Start\ time)\psi(Longitude^2 + Habitat + Latitude^2)$
Natrix helvetica	$p(ACOs + Day^2)\psi(Longitude^2 + Latitude)$

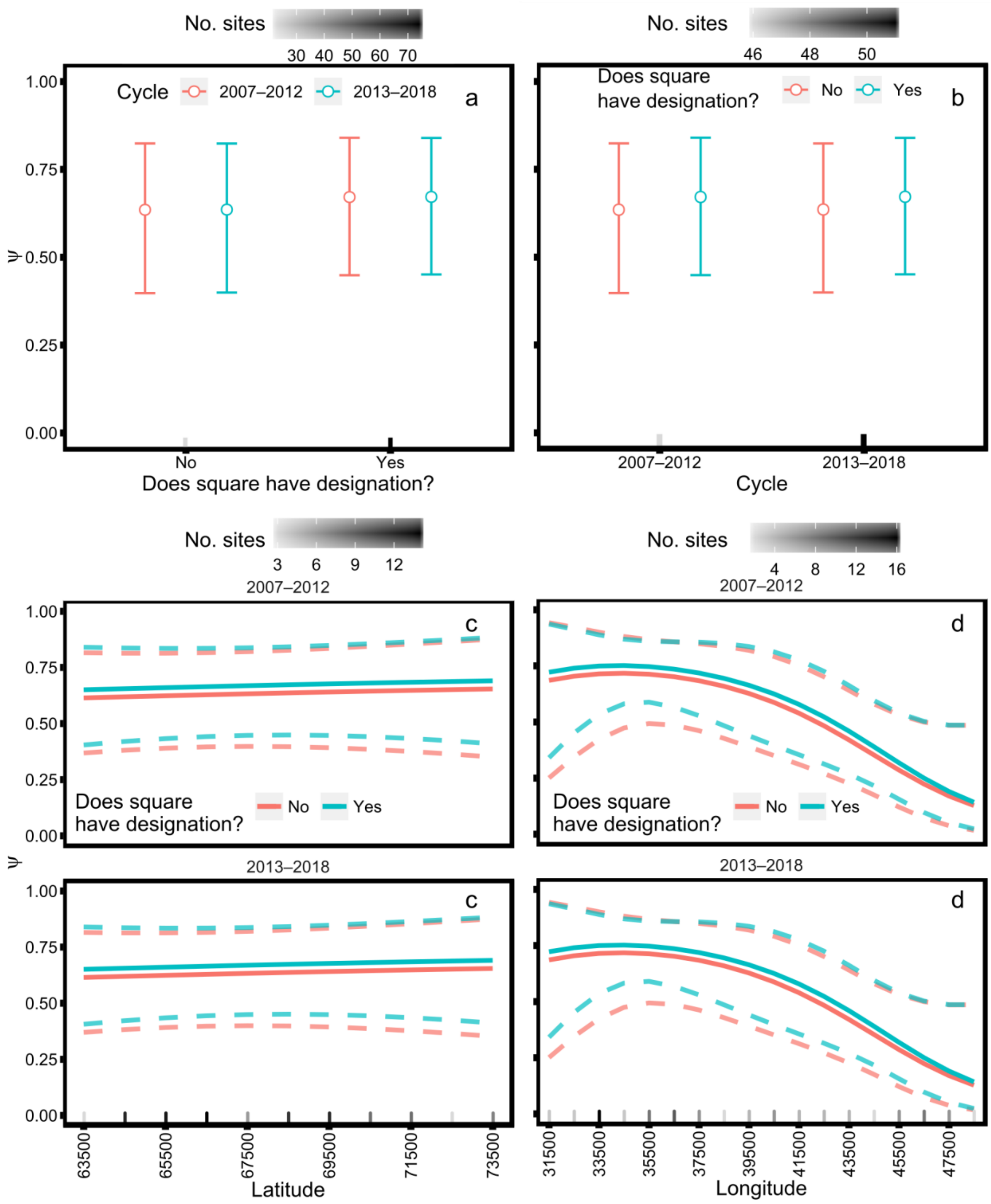

Figure 20 The response of western toad (*Bufo spinosus*) occupancy to (a) site designation within the square, (b) survey cycle, (c) latitude of square centroid and (d) longitude of square centroid. The number of sites surveyed at each value are shown along the x-axis.

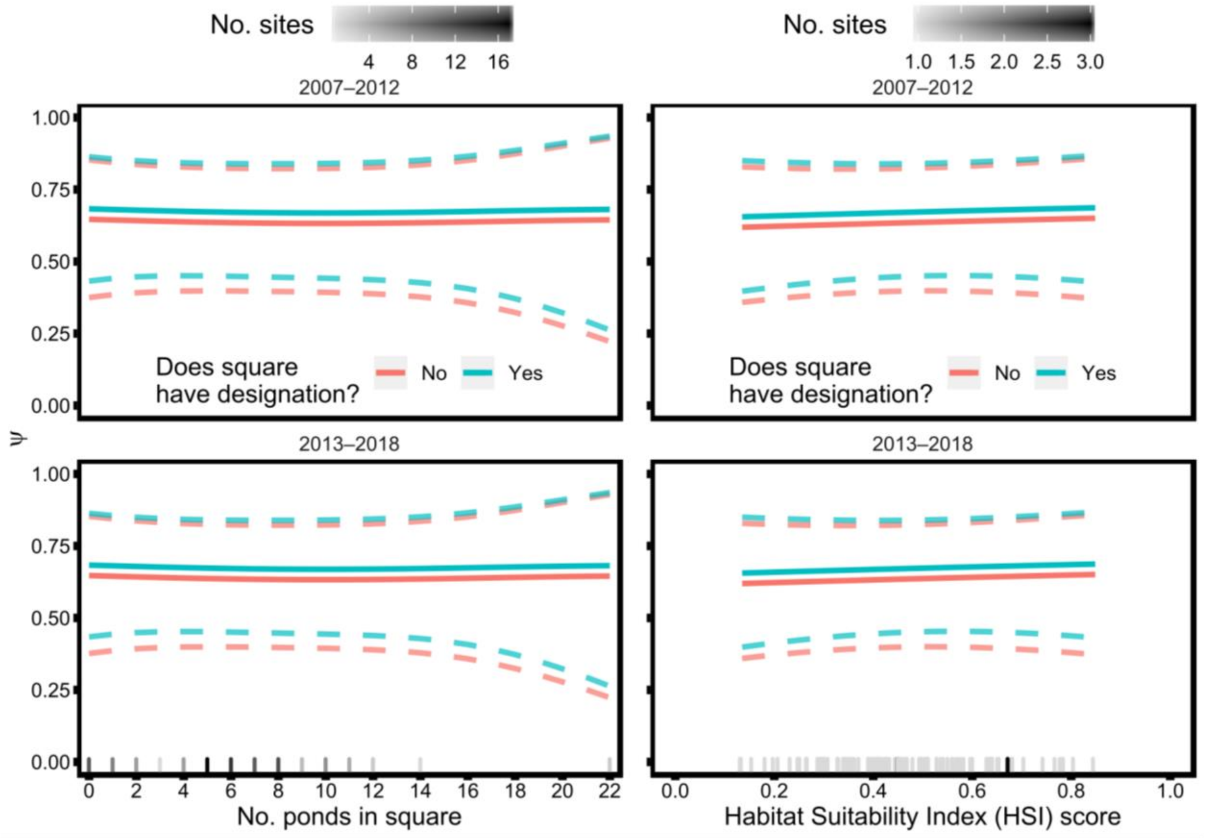

Figure 21 The response of western toad (*Bufo spinosus*) occupancy to (a) number of ponds within a square and (b) the habitat suitability index of the pond for each survey cycle (cycle 1 = top, cycle 2 = bottom). The number of sites surveyed at each value are shown along the x-axis.

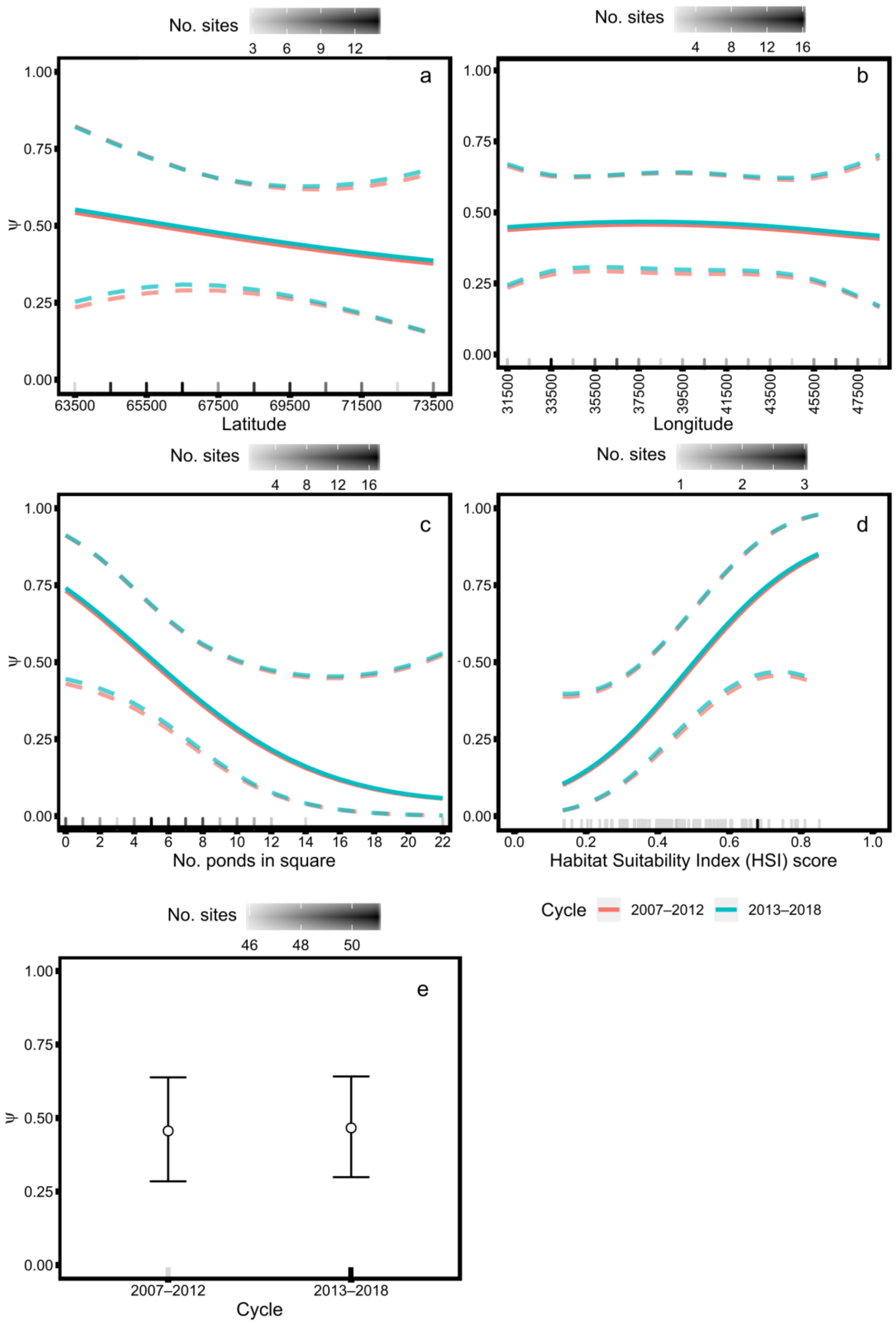

Figure 22 The response of palmate newt (*Lissotriton helveticus*) occupancy to (a) latitude of square centroid, (b) longitude of square centroid, (c) number of ponds within a square, (d) the habitat suitability index of the pond and (e) survey cycle. The number of sites surveyed at each value are shown along the x-axis.

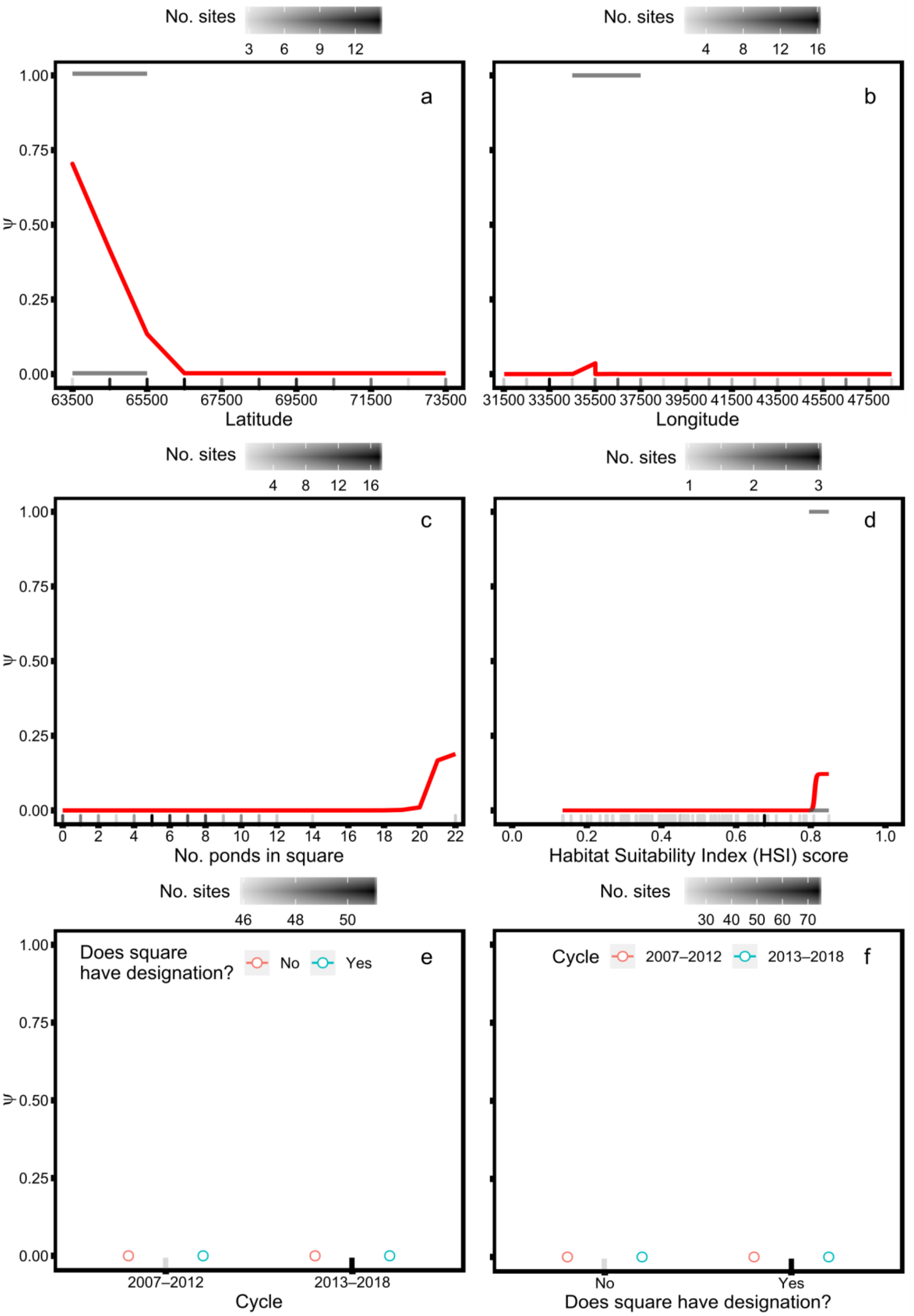

Figure 23 The response of agile frog (*Rana dalmatina*) occupancy to (a) latitude of square centroid, (b) longitude of square centroid, (c) number of ponds within a square, (d) the habitat suitability index of the pond, (e) survey cycle and (f) site designation within the square. The number of sites surveyed at each value are shown along the x-axis.

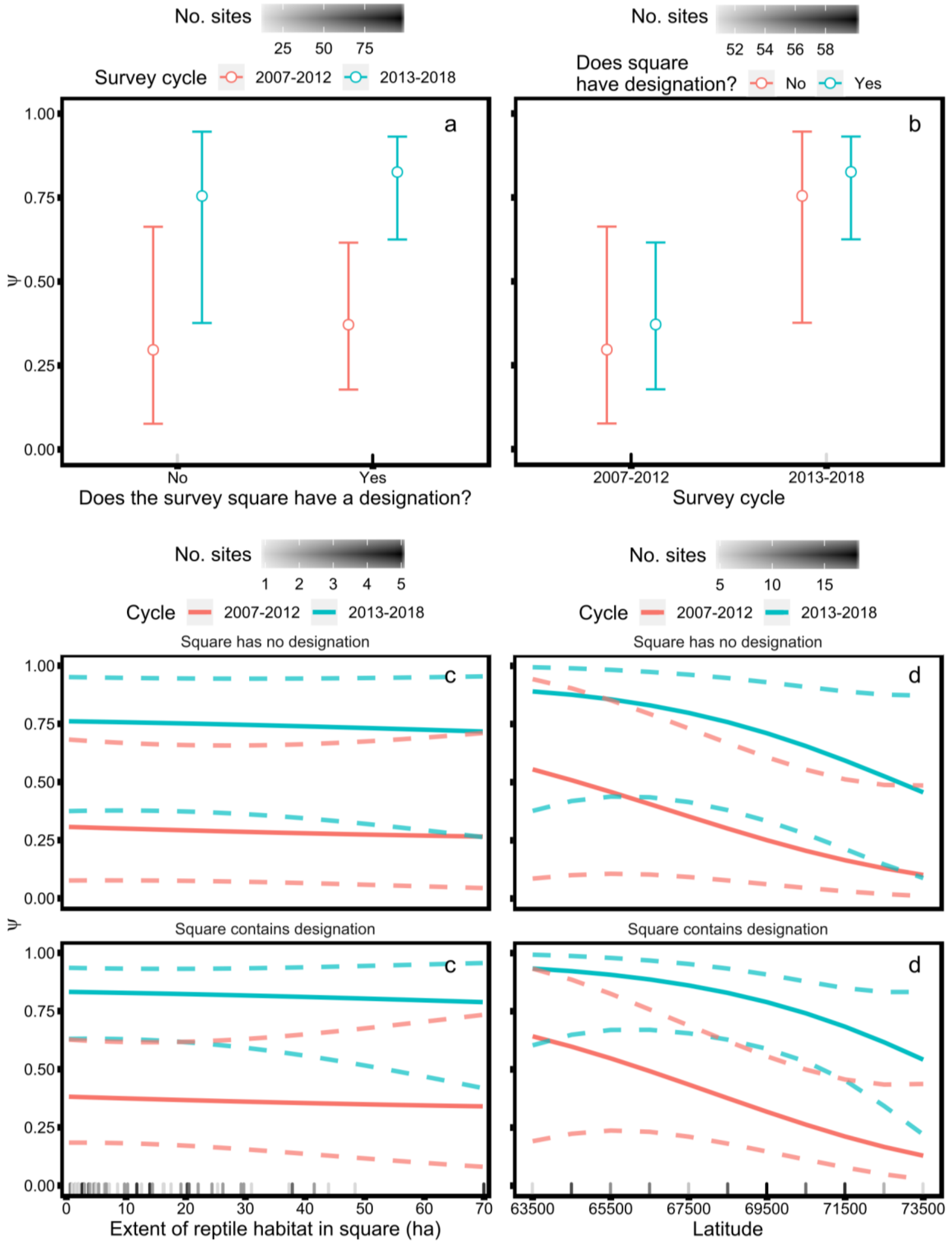

Figure 24 The response of slow worm (*Anguis fragilis*) occupancy to (a) site designation within the square, (b) survey cycle, (c) extent of reptile habitat within a square and (d) latitude of a square centroid. The number of sites surveyed at each value are shown along the x-axis.

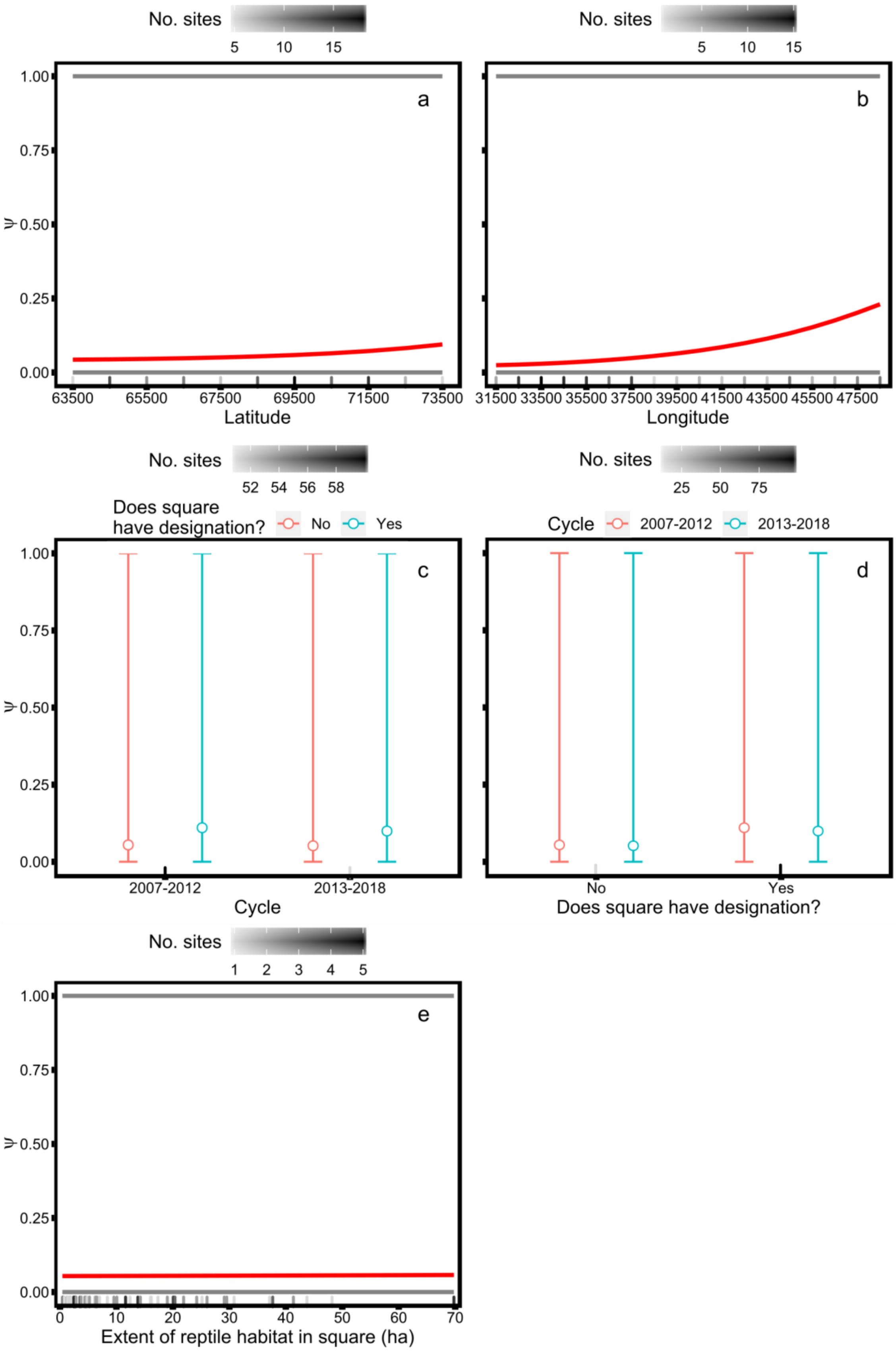

Figure 25 The response of wall lizard (*Podarcis muralis*) occupancy to (a) latitude of a square centroid, (b) longitude of a square centroid, (c) survey cycle, (d) site designation within a square and (e) extent of reptile habitat in a square. The number of sites surveyed at each value are shown along the x-axis.

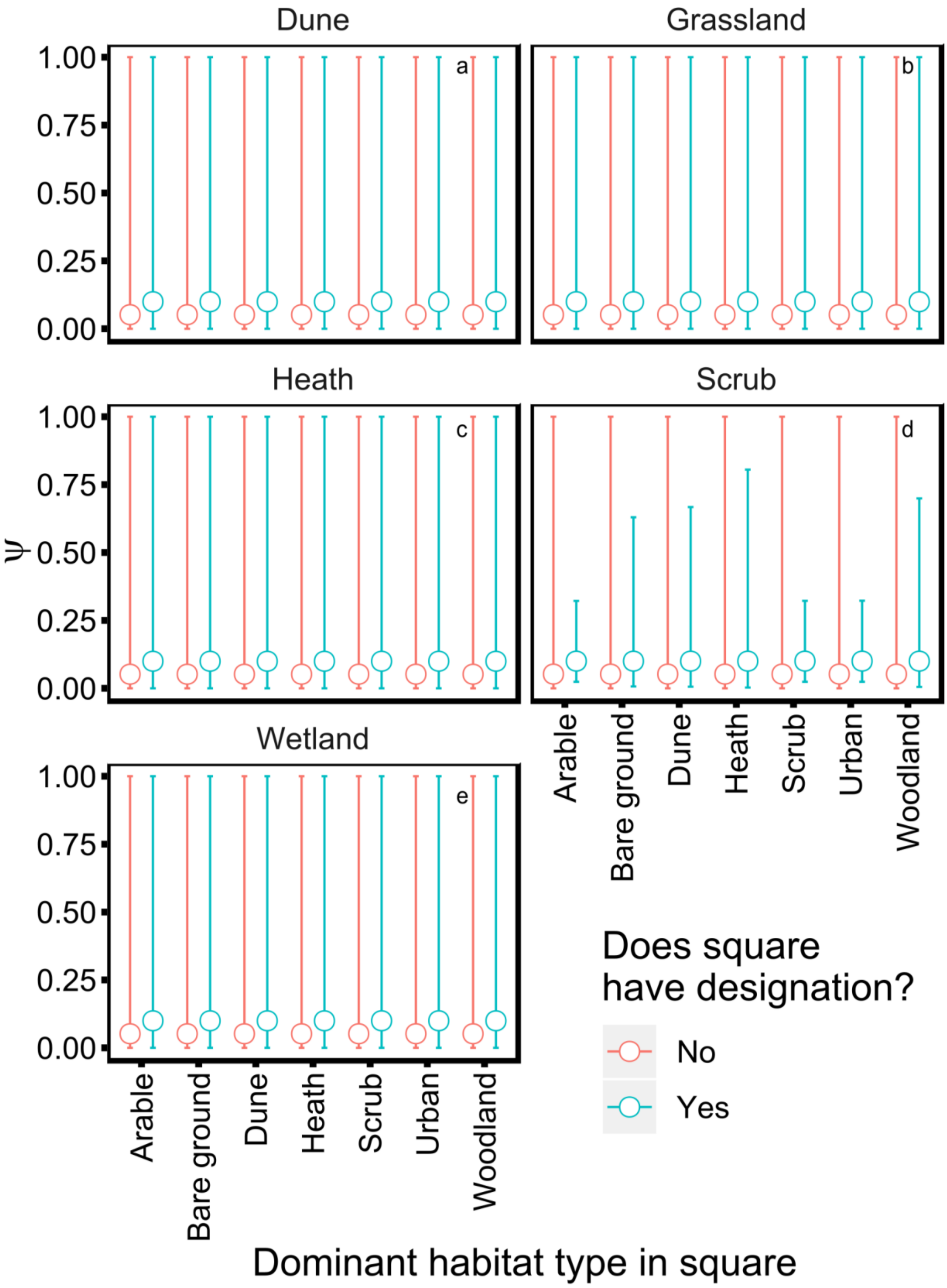

Figure 26 The response of wall lizard (*Podarcis muralis*) occupancy to dominant habitat type in a square when the dominant habitat type relevant to reptiles is (a) dune, (b) grassland, (c) heath, (d) scrub or (e) wetland. Differences between squares with or without site designations are also shown. The number of sites surveyed at each value are shown along the x-axis.

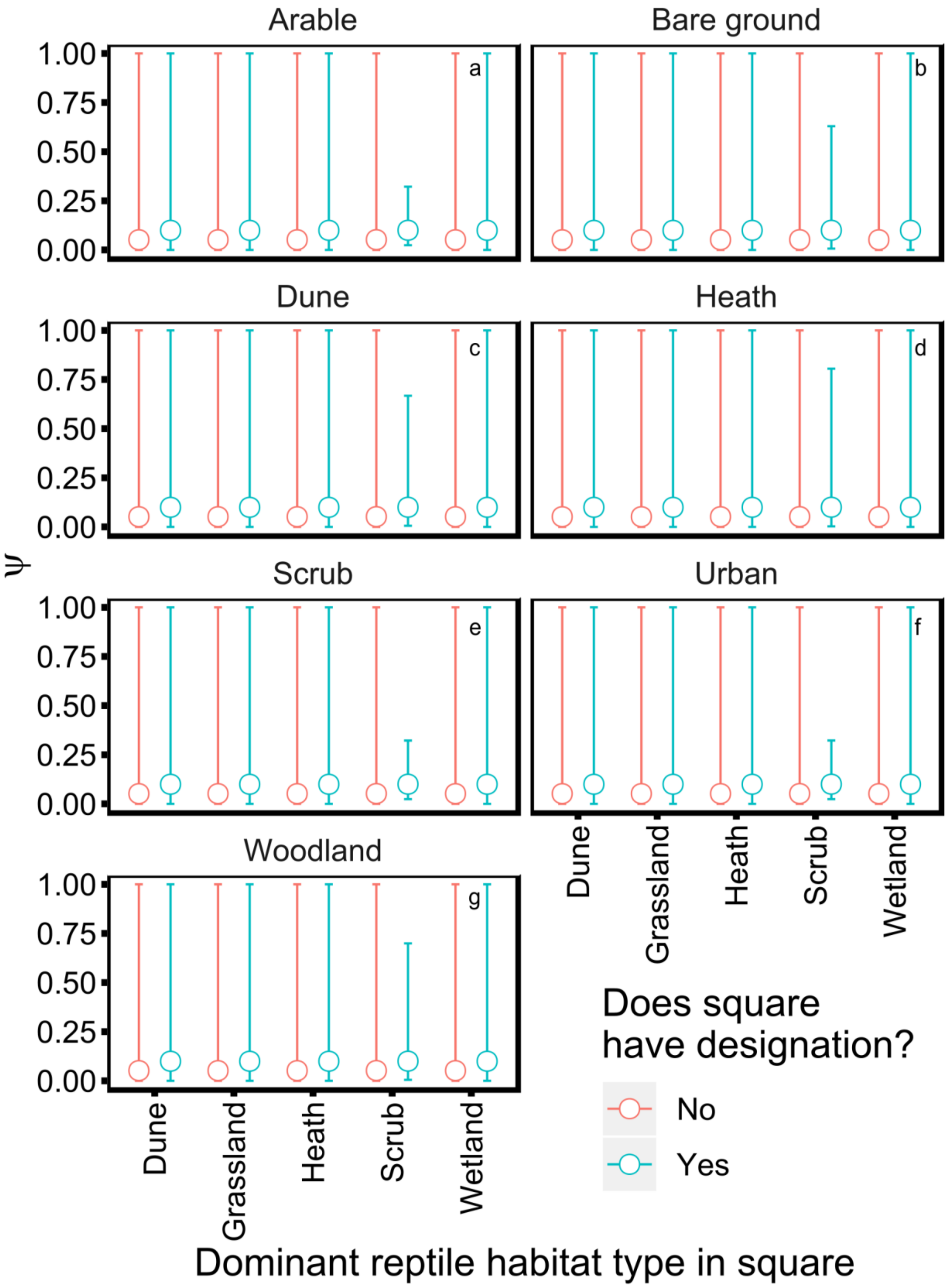

Figure 27 The response of wall lizard (*Podarcis muralis*) occupancy to dominant habitat type in a square relevant to reptiles when the overall dominant habitat type is (a) arable, (b) bare ground, (c) dune, (d) heath, (e) scrub, (f) urban or (g) woodland. Differences between squares with or without site designations are also shown. The number of sites surveyed at each value are shown along the x-axis.

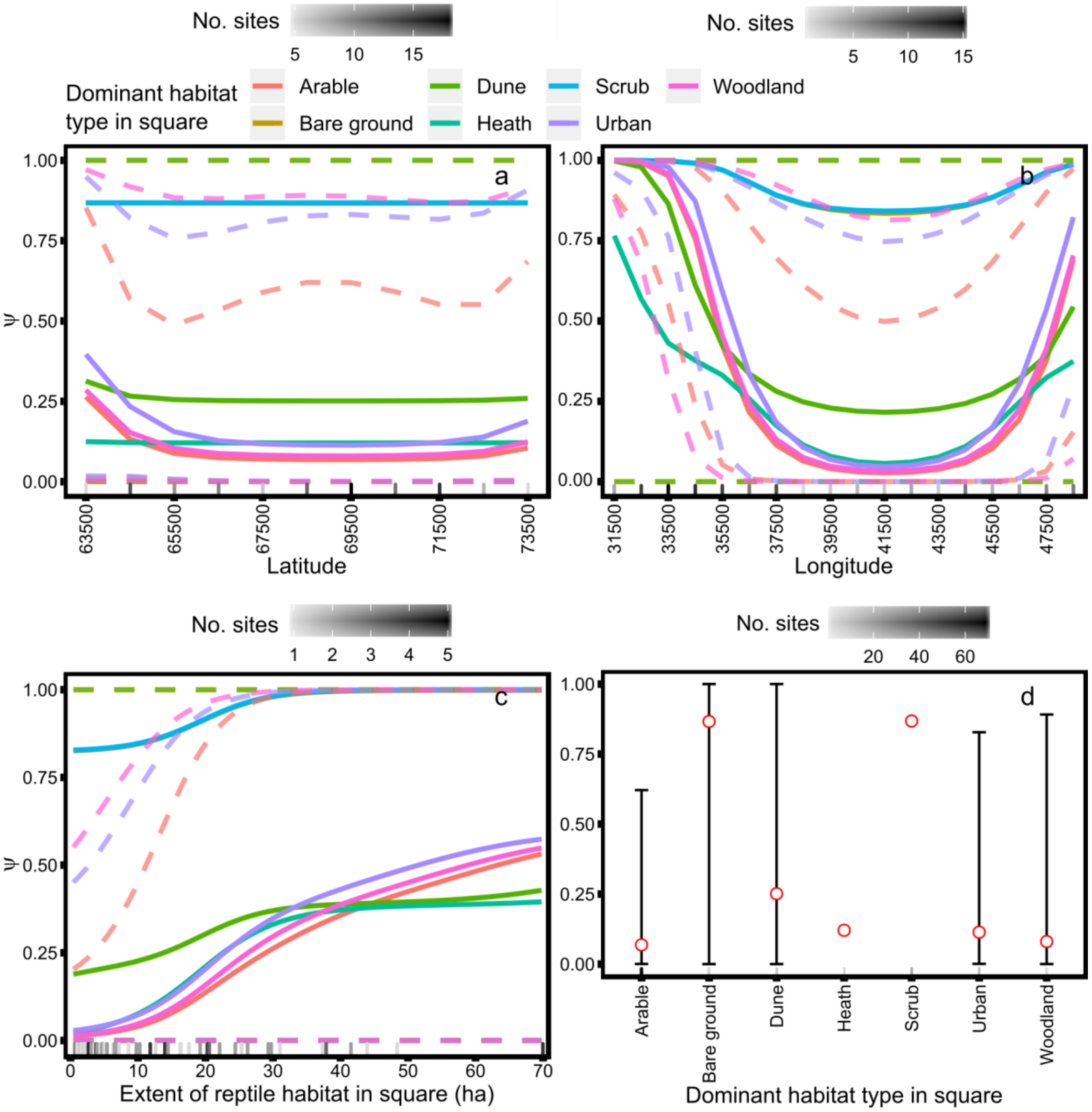

Figure 28 The response of green lizard (*Lacerta bilineata*) occupancy to (a) latitude of a square centroid, (b) longitude of a square centroid, (c) extent of reptile habitat in a square and (d) dominant habitat type in a square. Panels a–c show responses when the dominant habitat type in the square is varied. The number of sites surveyed at each value are shown along the x-axis.

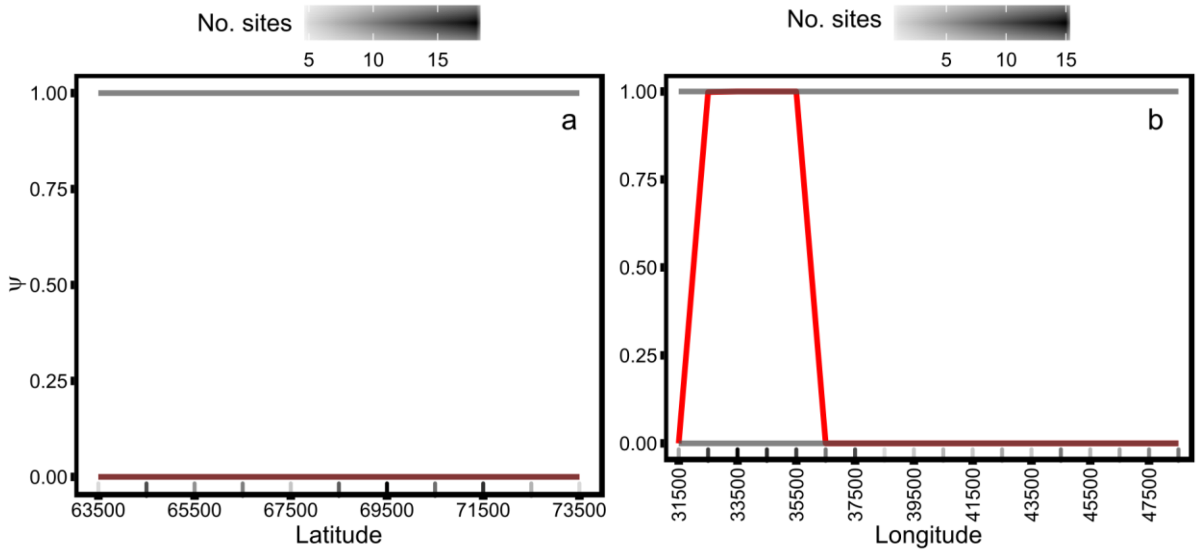

Figure 29 The response of grass snake (*Natrix helvetica*) occupancy to (a) latitude of a square centroid and (b) longitude of a square centroid. The number of sites surveyed at each value are shown along the x-axis.

4.3 Species richness

The number of amphibian species, reptiles and combined for both groups observed in 1-km squares in Jersey is shown in Table 7 and Figure 30–Figure 32. Coastal regions generally showed the highest species richness.

Table 7 Summary of species richness by 1-km squares.

	Species richness (number of squares)								
No. species	**Amphibians**			**Reptiles**			**Total (amphibians and reptiles)**		
	2007–2012	2012–2018	*2007–2018*	2007–2012	2012–2018	*2007–2018*	2007–2012	2012–2018	*2007–2018*
7	–	–	–	–	–	–	–	–	*1*
6	–	–	–	–	–	–	–	1	–
5	–	–	–	–	–	–	–	1	*1*
4	–	–	–	–	–	*1*	6	3	*8*
3	1	2	*2*	2	4	*4*	2	7	*9*
2	9	13	*19*	11	13	*19*	19	15	*22*
1	17	13	*17*	22	16	*24*	20	25	*24*
0	11	9	*9*	15	7	*12*	15	7	*10*

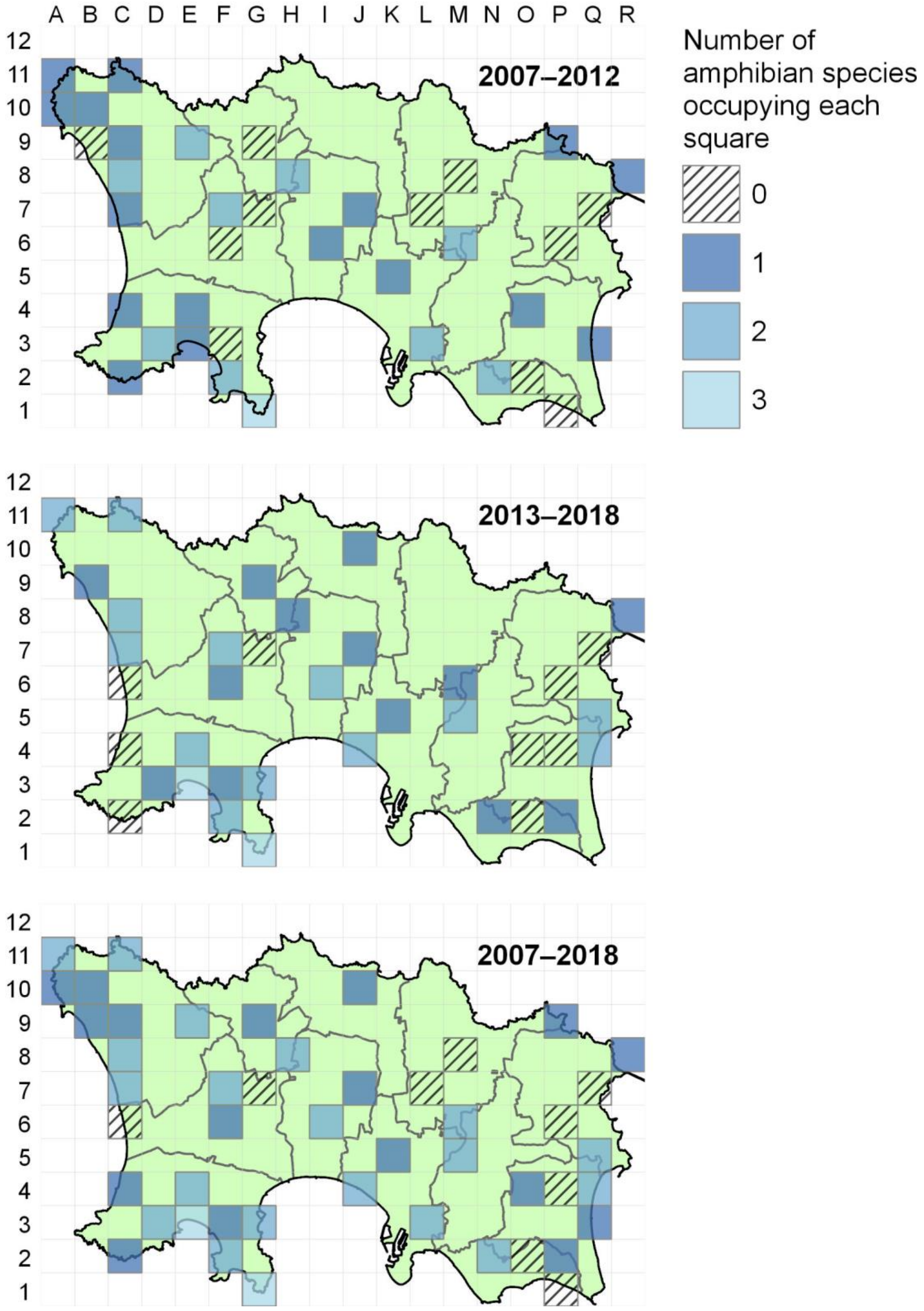

Figure 30 Number of amphibian species observed occupying each 1-km square in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no amphibians were detected are hatched. Grid references are given for orientation.

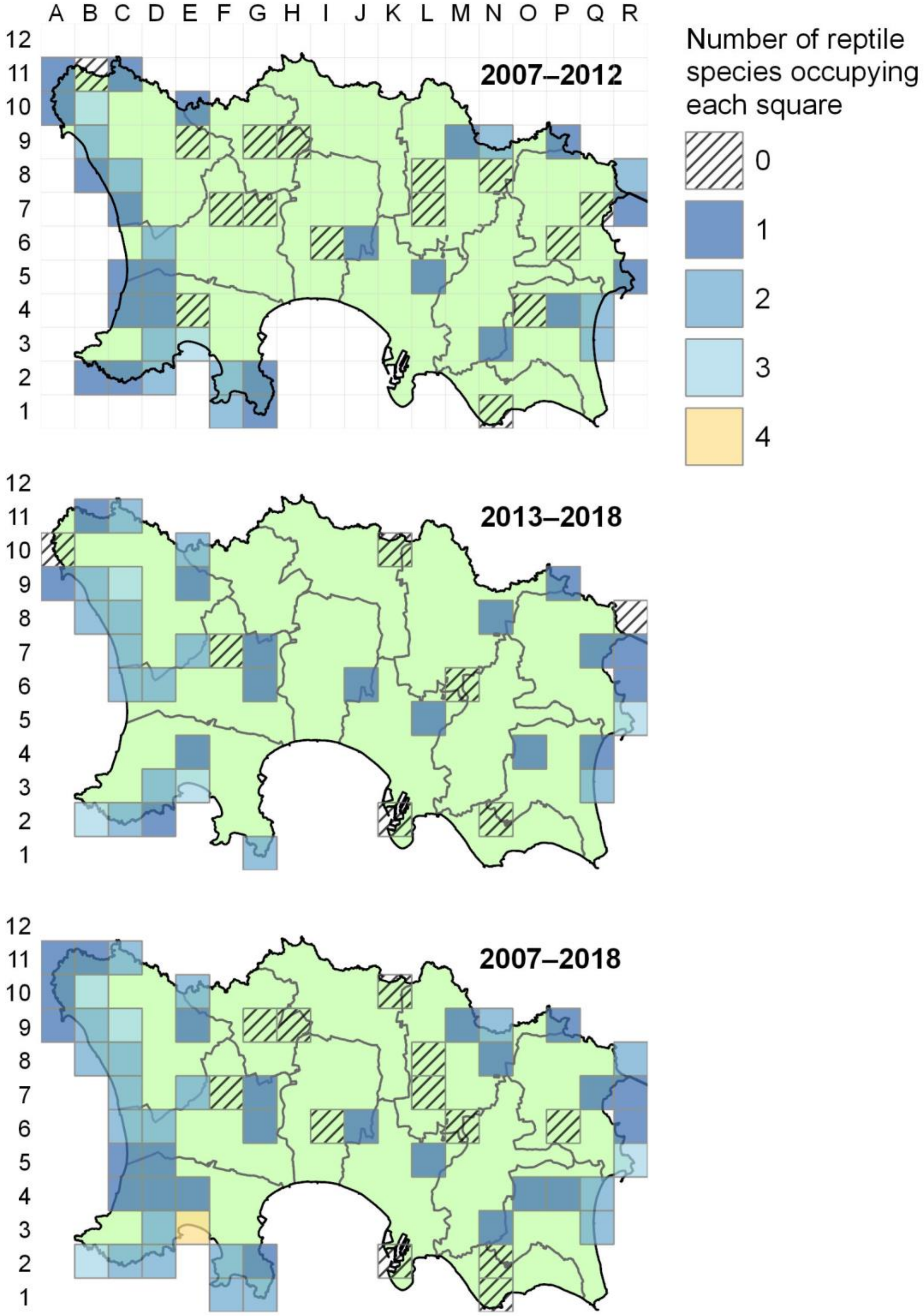

Figure 31 Number of reptile species observed occupying each 1-km square in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no reptiles were detected are hatched. Grid references are given for orientation.

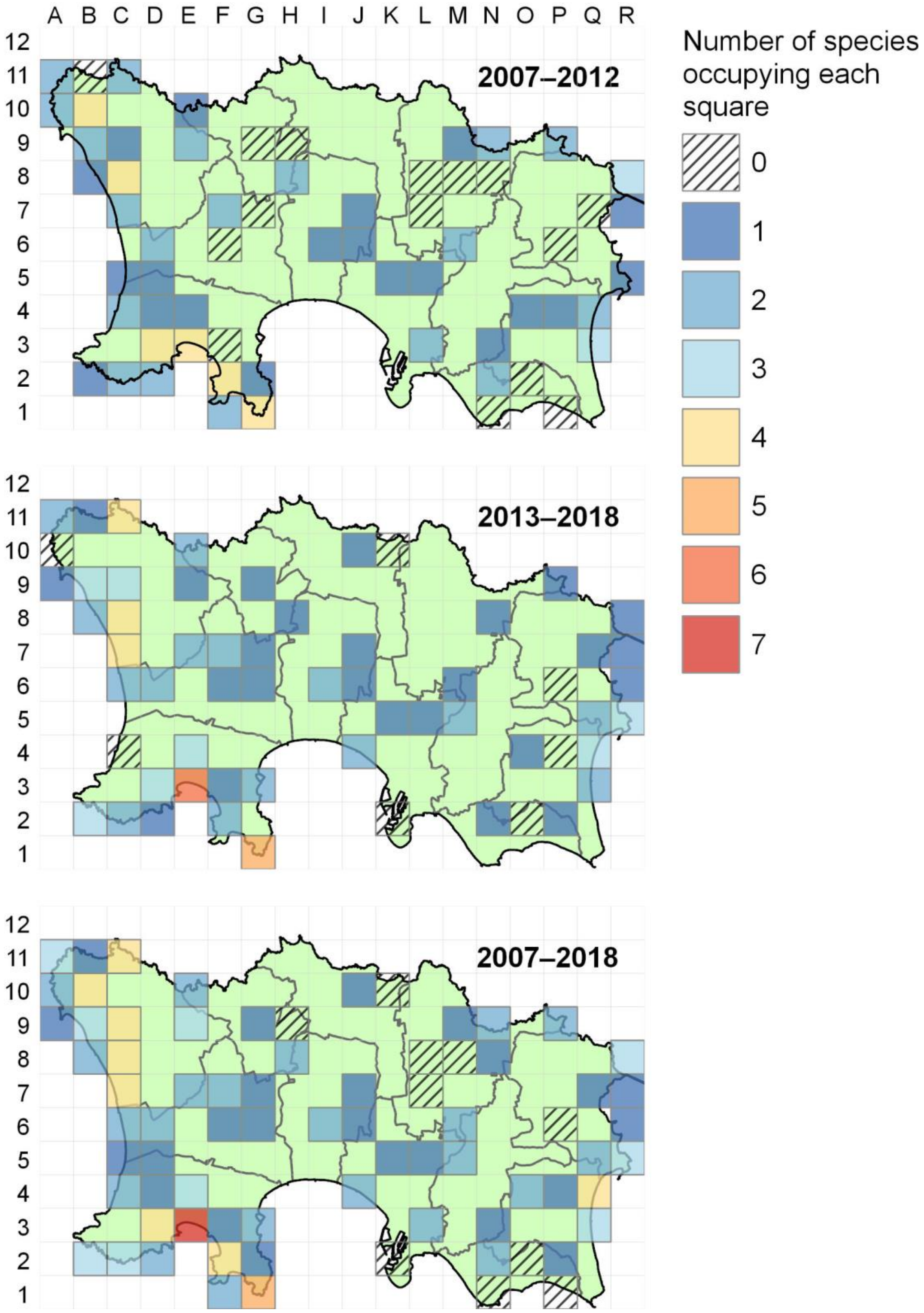

Figure 32 Total number of species (amphibian and reptile) observed occupying each 1-km square in cycle 1 (2007–2012), cycle 2 (2013–2018) and for both cycles combined (2007–2018). Squares that were surveyed but where no species were detected are hatched. Grid references are given for orientation.

4.4 Habitat quality

Amphibians

Habitat Suitability Index (HSI) scores remained fairly constant across the two cycles, with a slight increase in the proportion of ponds with high (> 0.7) HSI values and a similar decrease in the proportion of ponds with low (< 0.3) HSI scores (Table 8).

Reptiles

Comparably little data was available over the two cycles to assess changes in the quality of reptile habitat, though the level of habitat isolation was relatively similar between survey cycles (Table 9).

Table 8 Descriptors of amphibian habitat in Jersey. Ranges are shown in curved brackets. Sample size is shown in square brackets. Values are adjusted for missing data where necessary.

Cycle	Mean HSI score (range)	Ponds with HSI > 0.7 (%)	Ponds with HSI < 0.3 (%)
2007–2012	0.48 (0.14–0.81)	6.98 [n=3]	16.28 [n=7]
2013–2018	0.48 (0.16–0.85)	8.00 [n=4]	14.00 [n=7]
2007–2018	*0.48* *(0.14–0.85)*	*7.53* *[n=7]*	*15.05* *[n=14]*

Table 9 Descriptors of reptile habitat in Jersey. Ranges are shown in curved brackets. Values are adjusted for missing data where necessary and shown in square brackets [ ]. Patch size was not assessed in the first survey cycle.

Cycle	Surveys in which reptile habitat was isolated* (%)	Proportion of surveys of different reptile habitat patch sizes (ha) (%)	
2007–2012	25.00 [27.27]	–	
2013–2018	25.53 [28.57]	<1	28.00
		1–5	40.00
		6–10	16.00
		11–50	12.00
		>50	4.00
2007–2018	*24.32* *[27.84]*	*<1*	*28.00*
		1–5	*40.00*
		6–10	*16.00*
		11–50	*12.00*
		>50	*4.00*

* completely isolated or isolated by sub-optimal habitat

4.5 Sampling effort

Amphibians

Measures of amphibian survey effort were relatively consistent between cycles (Table 10).

Reptiles

Reptile survey effort was also fairly consistent between cycles, with the exception of the number of refugia used in surveys which saw a four-fold increase in the second cycle compared to the first cycle (Table 11). However, for both amphibian and reptile surveys a greater mean number of surveys were conducted per site.

Table 10 Descriptors of amphibian survey effort in Jersey. Ranges are shown in curved brackets. Values are adjusted for missing data where necessary.

Cycle	Survey duration (mins)	Total no. methods used across all site surveys	Number of surveys conducted per site
2007–2012	40.01 (5.00–120.00)	2.14 (1–3)	3.28 (1–7)
2013–2018	33.33 (5.00–240.00)	2.37 (1–3)	4.37 (1–23)
2007–2018	*35.94* *(5.00–240.00)*	*2.26* *(1–3)*	*3.86* *(1–23)*

Table 11 Descriptors of reptile survey effort in Jersey. Ranges are shown in curved brackets. Values are adjusted for missing data where necessary.

Cycle	Mean length (km) of survey route	Number of refugia laid	Percent of key areas surveyed (%)	Survey duration (mins)	Number of surveys conducted per site
2007–2012	1.54 (0.10–5.00)	2.22 (0.00–18.00)	40.14 (1.00–90.00)	61.22 (10.00–210.00)	3.25 (1–15)
2013–2018	1.54 (0.20–4.00)	10.15 (0.00–40.00)	32.69 (1.00–100.00)	64.84 (10.00–170.00)	4.82 (2–11)
2007–2018	*1.54* *(0.10–5.00)*	*5.78* *(0.00–40.00)*	*36.73* *(1.00–100.00)*	*63.24* *(10.00–210.00)*	*3.97* *(1–15)*

4.6 Survey design

4.6.1 Number of surveys

Amphibians

Based on detection values from the null models (Table 5), two surveys would be sufficient to detect toads with up to 90% confidence, but three survey visits would be needed for 95% confidence. Palmate newts would require three, four or five survey visits and agile frogs would need two, two or three. Overall then, if applying the precautionary principle, amphibian surveys should utilise five survey visits.

Using detection estimates from the top model for each species (Table 6) we calculated the number of surveys required to have 80, 90 or 95% confidence of species absence at a given survey site. The data counterintuitively suggested that the number of survey visits required for the toad increases with the number of survey methods and surveyor experience; however, these findings should be treated with caution for the reasons described earlier. More reliably, the number of surveys required decreases with increasing survey start time and survey duration (Figure 34). The number of survey visits required for palmate newts also decreased with survey duration, increasing survey start time and day of the year (Figure 35). Estimates of survey effort for the agile frog lacked confidence limits due to the limited dataset for this species, and the results should be treated with caution because of this. Our findings suggest that the number of survey visits required decreases with an increasing number of survey methods, but increases with increasing surveyor experience and survey duration (Figure 36). With detection covariates at their mean value and applying the precautionary principle for widespread species, toads and palmate newts would require five surveys.

Reptiles

Slow worms would need two, three or four, green lizards would require two, or three visits and wall lizards also two, two or three survey visits. In contrast, grass snakes would require 21, 30 or 39 surveys (

Figure 33). Overall then, if applying the precautionary principle, reptile surveys (excluding grass snakes) based on null models, would require four survey visits.

Using detection estimates from the top model for each species (Table 6) we calculated the number of surveys required to have 80, 90 or 95% confidence of species absence at a given survey site. For reptiles, the number of survey visits required for slow worms initially decreased with an increasing number of refugia, but then increased with high numbers of refugia checks.

This counterintuitive result is likely due to the reasons described earlier when assessing detectability. The number of visits required was also minimised between days 100 and 250, (mid-April to early September) but increased with surveyor experience after two years (Figure 37). Again, this may be due to a limited number of surveyors with more than three years experience resulting in poorly informed detection estimates. Green lizards initially required less surveys with increasing refugia, but with more surveys required and wide confidence limits after approximately 10 refugia due to the reasons described above when evaluating detection covariates. The number of survey visits decreased with improving weather conditions, and with later start times (Figure 38). Finally, the estimated number of surveys required for grass snakes were unreliable due to the extremely low detection of this species, with our results suggesting that more visits were required if more refugia checks were carried out, and that there was only a very limited survey period (around day 150 – late May) when fewer survey visits could be carried out (Figure 39). We instead refer to previous findings for informing grass snake survey design (Ward et al. 2017). We note that the number of survey visits required for wall lizards was not well described due to the unsuitability of NARRS methods for surveying this species. Therefore, we do not discuss them here. With detection covariates at their mean value and using the precautionary principle for widespread species, slow worms would require three surveys whereas green lizards would require six.

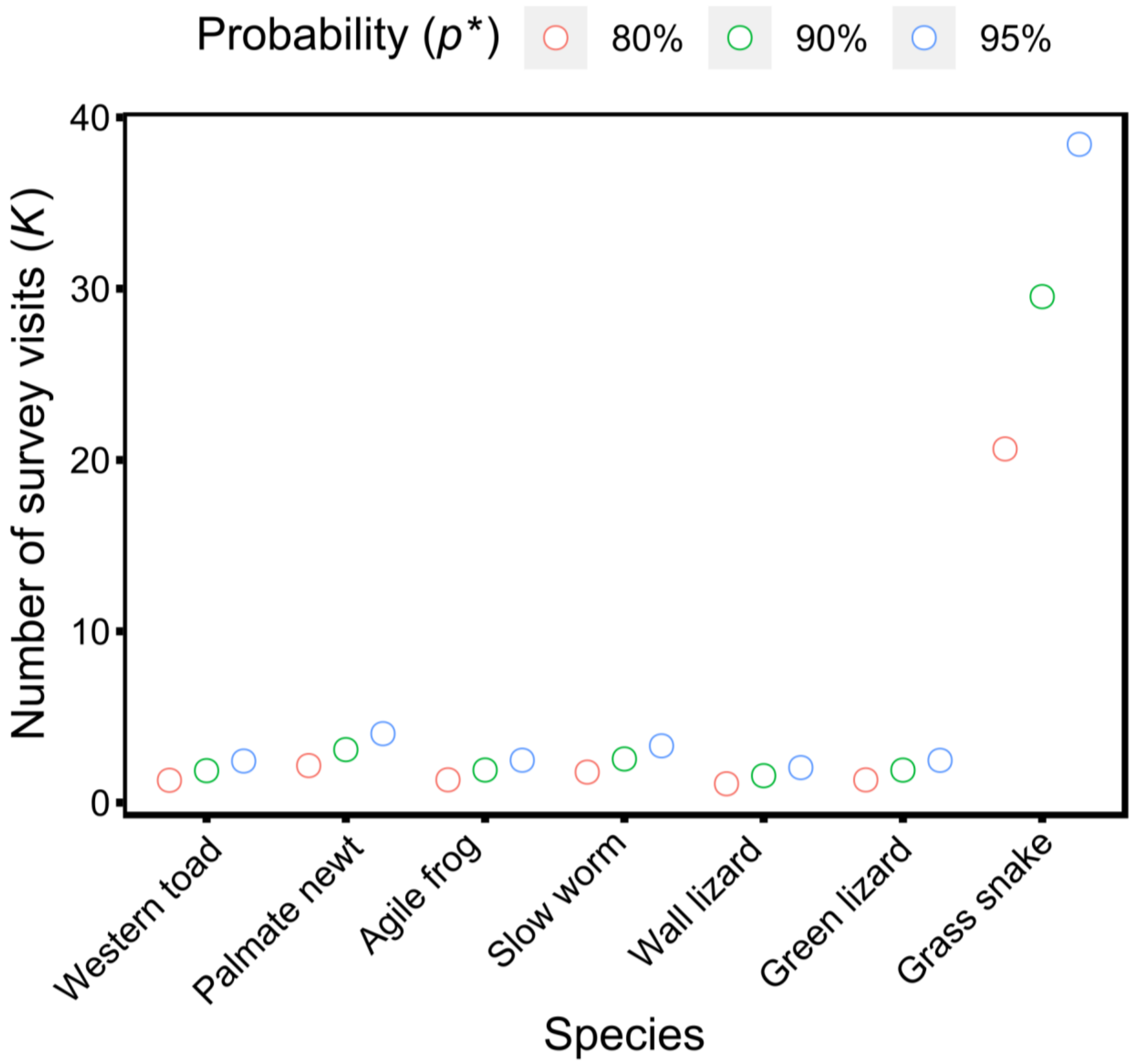

Figure 33 The number of survey visits (K) required to have a given confidence of species absence at a survey site, based on detection rates given by the null models.

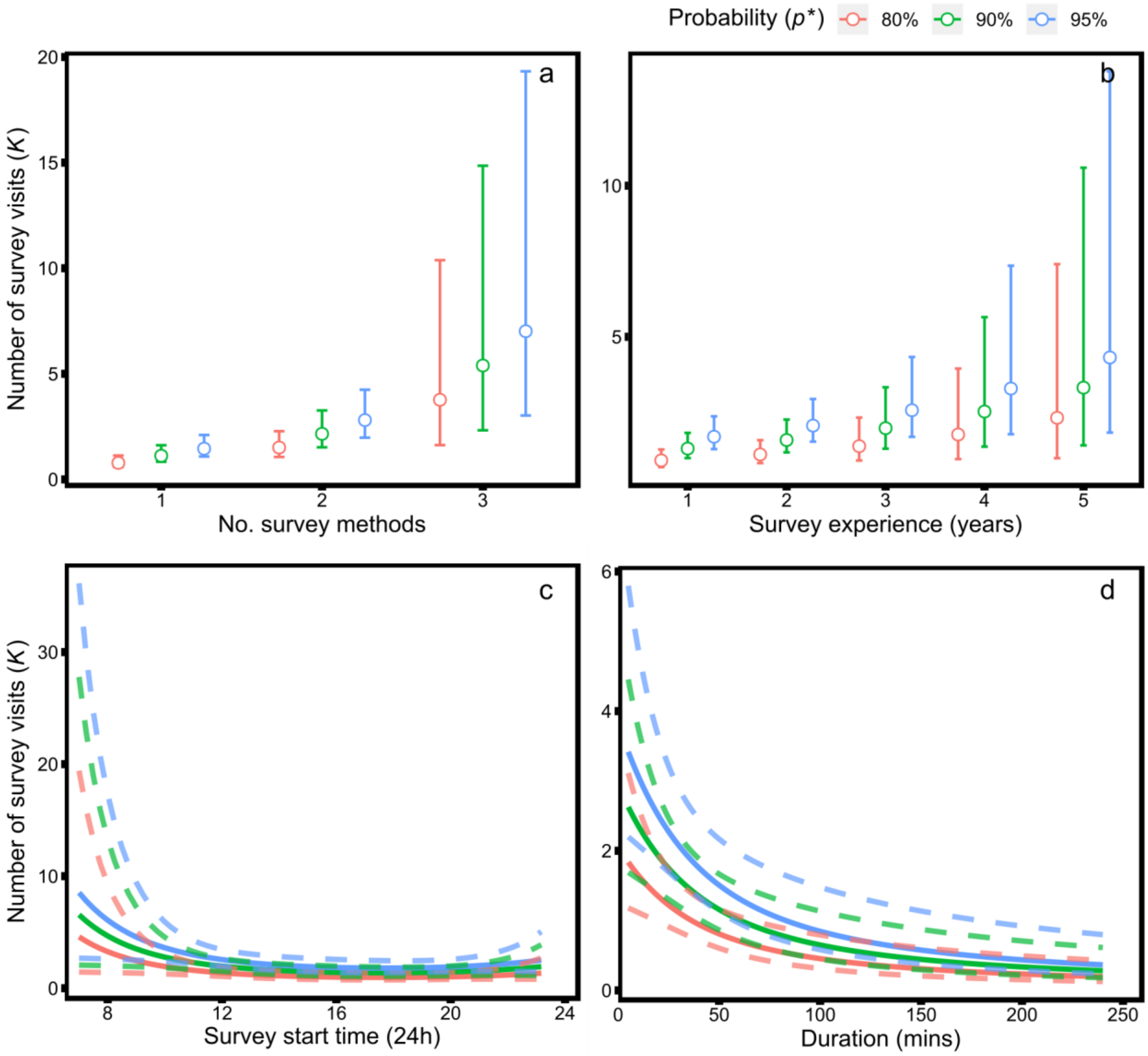

Figure 34 The number of survey visits (K) required to have a given confidence of absence for the western toad (*Bufo spinosus*) based on the following detection covariates: (a) the number of survey methods used, (b) surveyor experience, (c) time of the survey and (d) survey duration.

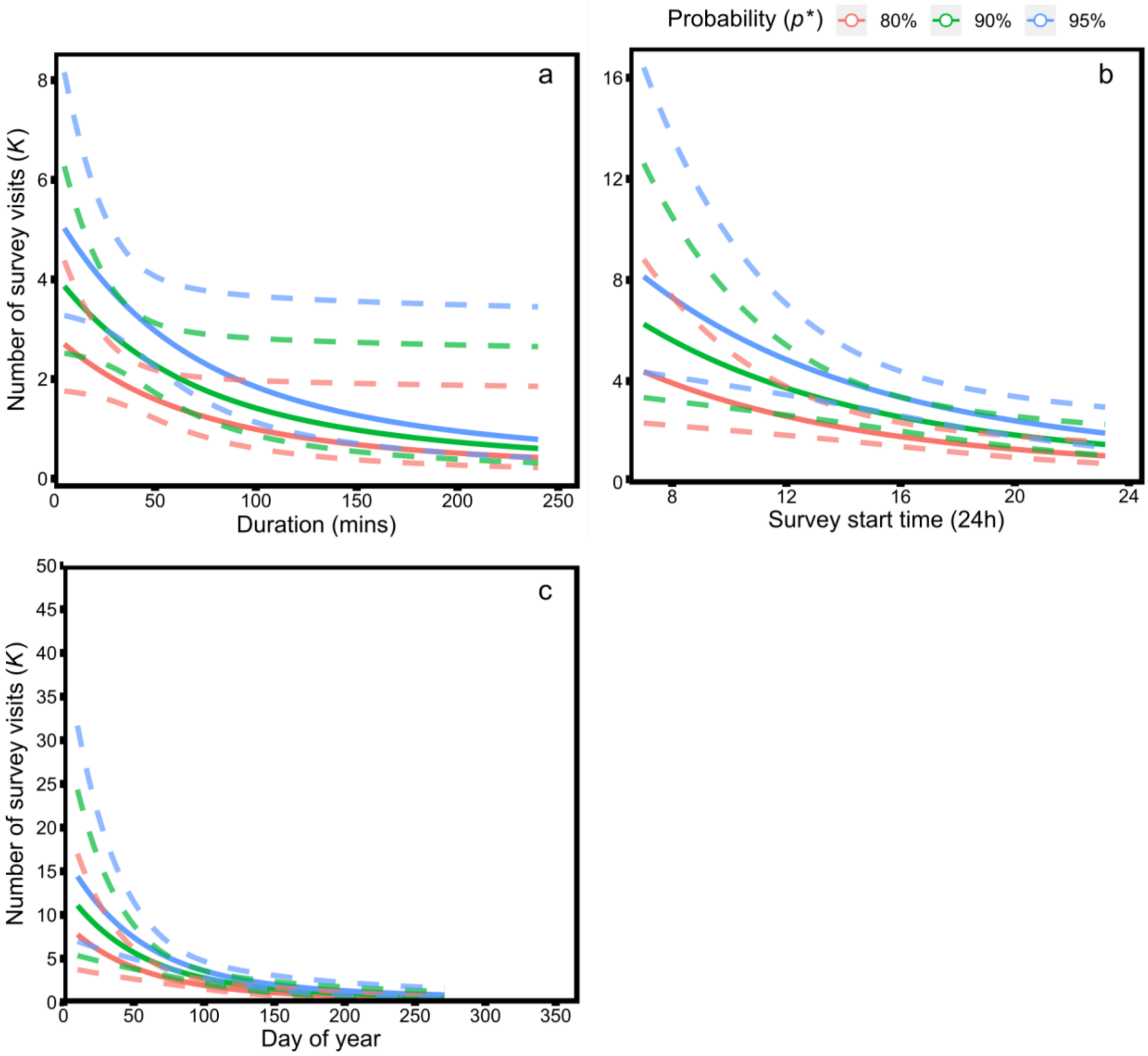

Figure 35 The number of survey visits (K) required to have a given confidence of absence for the palmate newt (*Lissotriton helveticus*) based on the following detection covariates: (a) survey duration, (b) time of the survey and (c) day of the year.

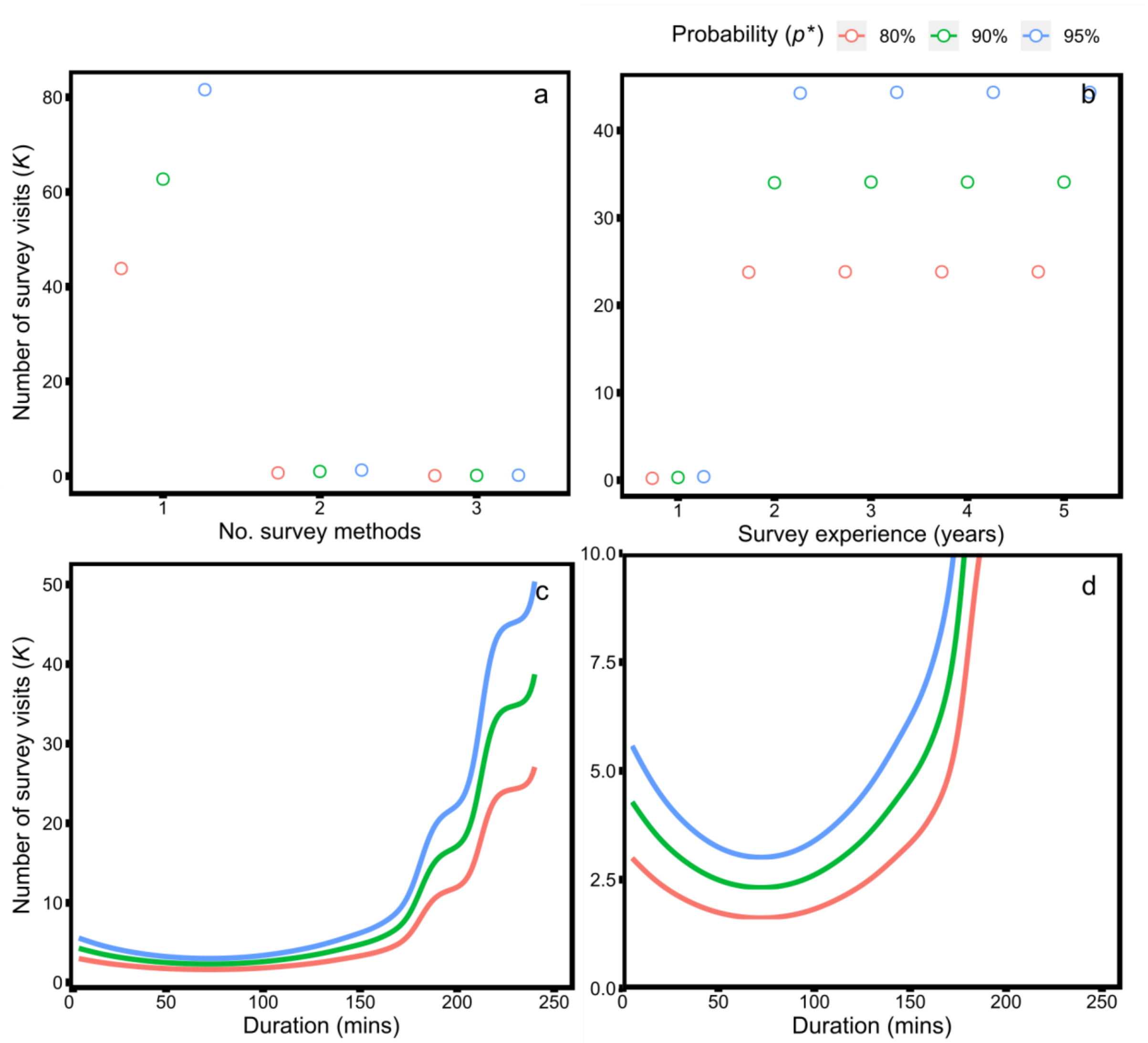

Figure 36 The number of survey visits (K) required to have a given confidence of absence for the agile frog (*Rana dalmatina*) based on the following detection covariates: (a) the number of survey methods, (b) surveyor experience and (c) survey duration. Panel (d) shows survey duration with the y-axis limited to a maximum of 10 survey visits for more detailed interpretation.

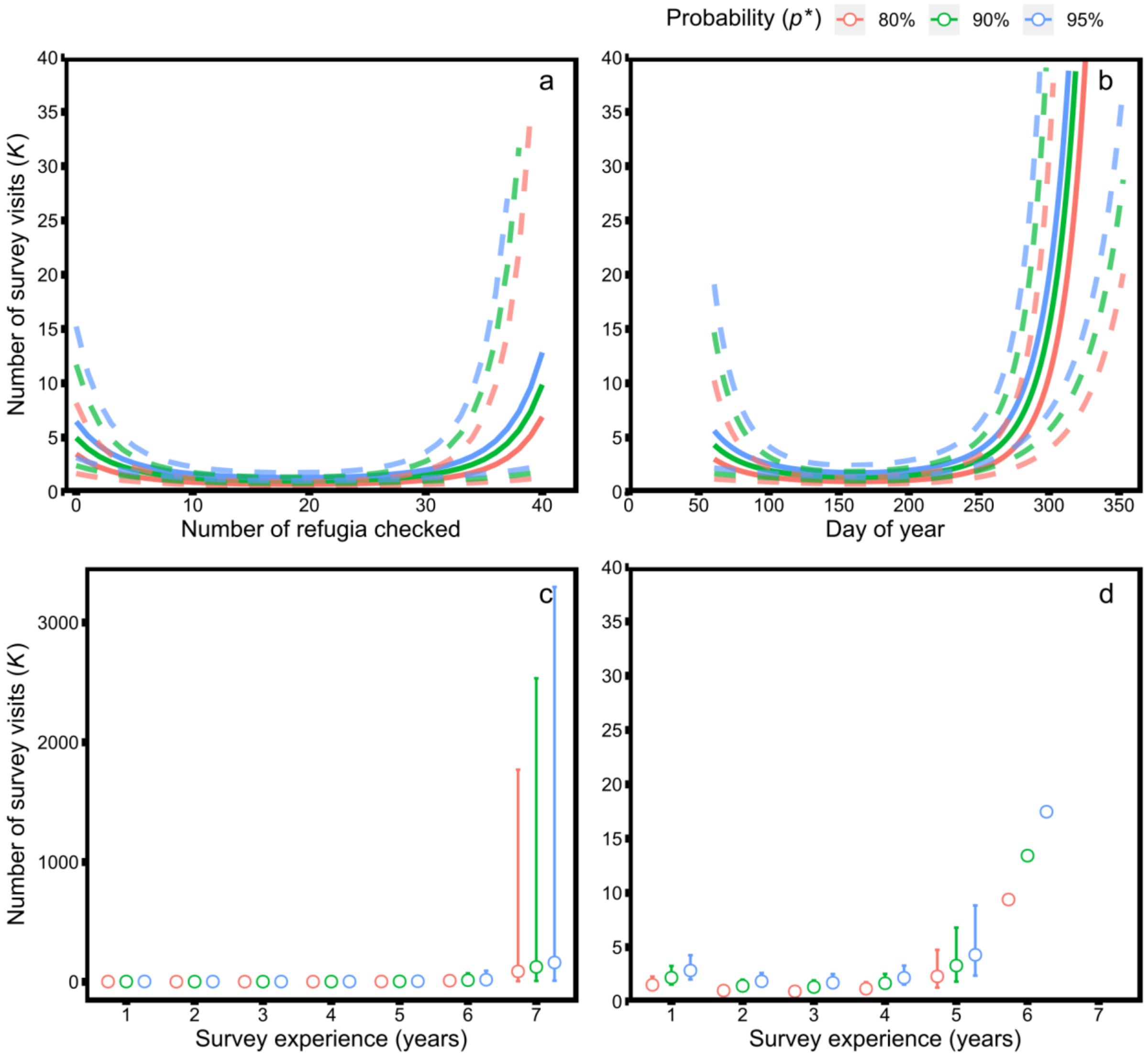

Figure 37 The number of survey visits (*K*) required to have a given confidence of absence for the slow worm (*Anguis fragilis*) based on the following detection covariates: (a) the number of refugia checked, (b) day of the year and (c) surveyor experience. Panel (d) shows surveyor experience with a maximum y-axis limit of 40 survey visits for more detailed interpretation. The y-axis in panels (a) and (b) is also limited to a maximum of 40.

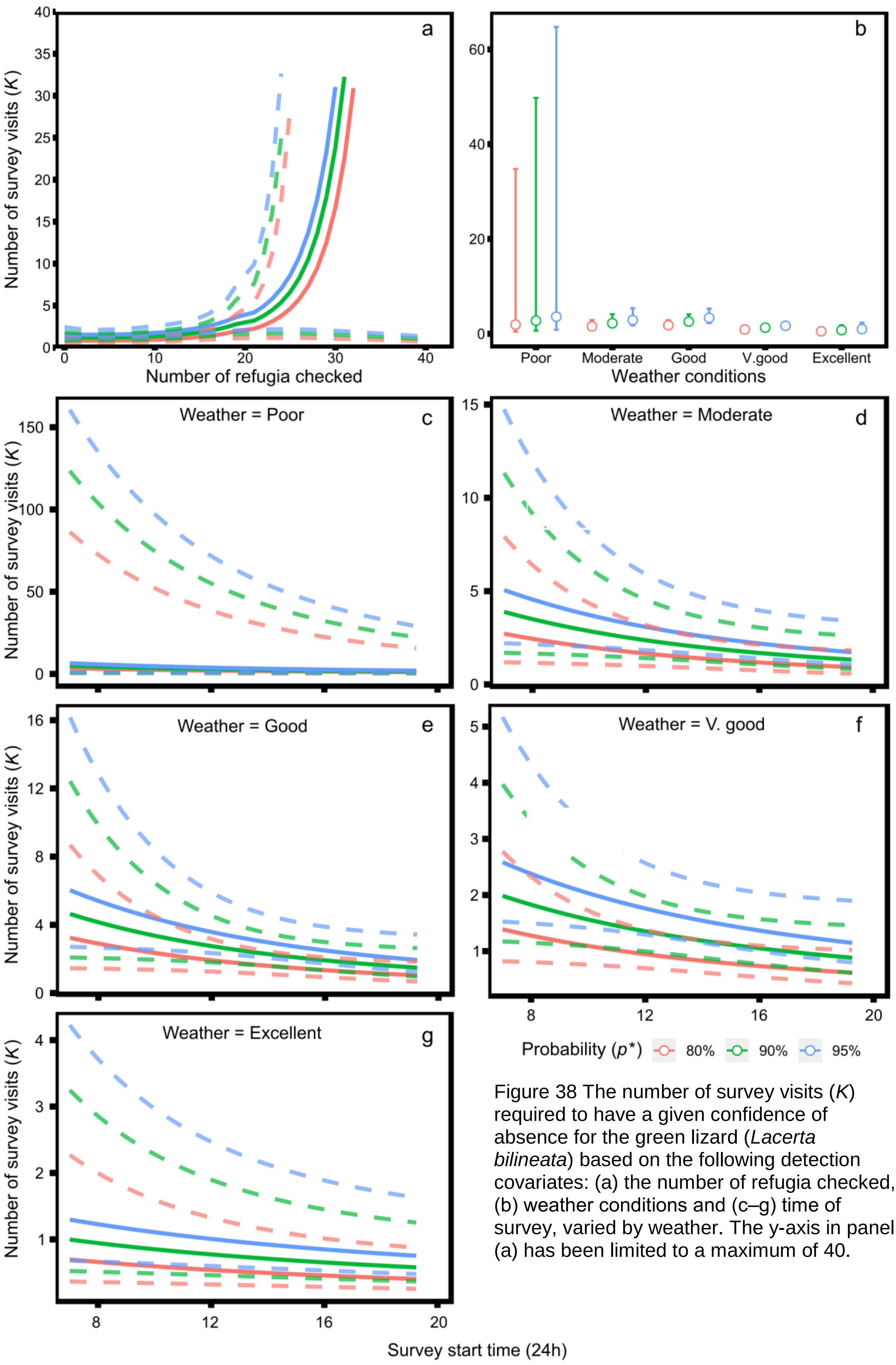

Figure 38 The number of survey visits (K) required to have a given confidence of absence for the green lizard (*Lacerta bilineata*) based on the following detection covariates: (a) the number of refugia checked, (b) weather conditions and (c–g) time of survey, varied by weather. The y-axis in panel (a) has been limited to a maximum of 40.

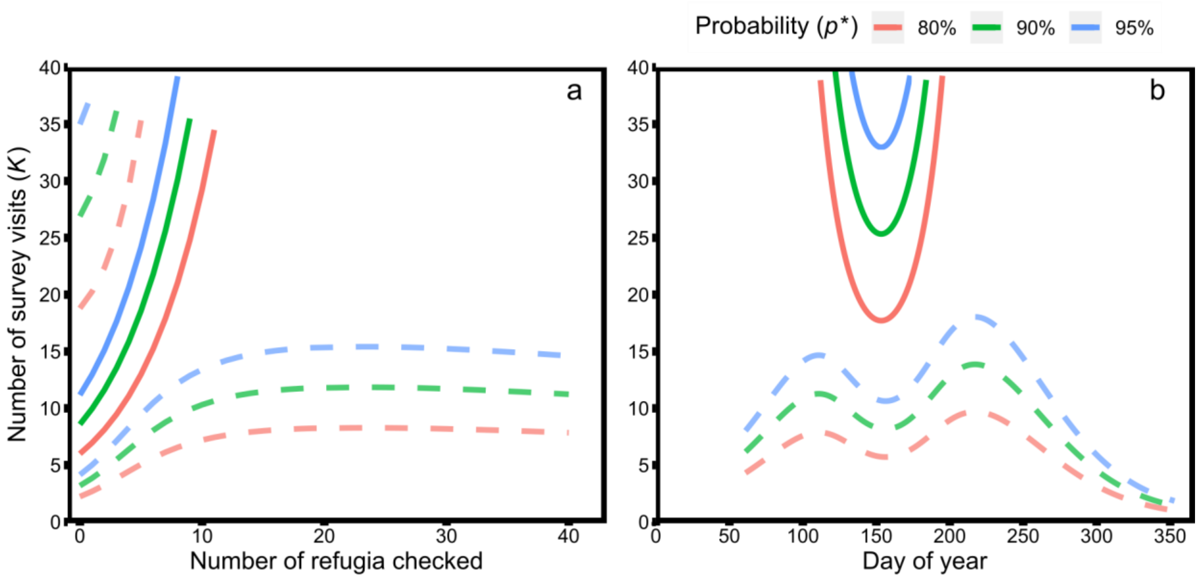

Figure 39 The number of survey visits (K) required to have a given confidence of absence for the grass snake (*Natrix helvetica*) based on the following detection covariates: (a) the number of refugia checked and (b) day of the year. The y-axis in both panels has been limited to a maximum of 40.

4.6.2 Power to detect occupancy changes

The power to detect statistically significant occupancy changes between the two cycles is shown in Table 12. Wald tests indicated that the power to detect changes between the two survey cycles was poor.

Amphibians

Power only exceeded the typical threshold of 0.8 for the toad, assuming a proportional change of 50% has occurred. Power was lowest for the agile frog, which is unsurprising given its limited distribution.

Reptiles

Power only exceeded the typical threshold of 0.8 for the green lizard, assuming a proportional change of 50% has occurred. Power was lowest for the wall lizard. This is unsurprising given that this is a restricted species.

Table 12 Power to detect changes between the first two NARRS survey cycles in Jersey, based on detectability and occupancy estimates from the null model. Proportional changes (R) of 0.15, 0.30 and 0.50 are shown. Instances where power exceeds 0.8 are shown in bold. The number of sites that would have been needed to achieve a power of 0.8 with a given proportional change are shown in brackets. Significance (α) was set to 0.1.

Species	Detectability		Initial occupancy	R		
	2007–2012	2013–2018		0.15	0.30	0.50
Bufo spinosus	0.718	0.708	0.602	0.246 (382)	0.548 (95)	**0.915** (32)
Lissotriton helveticus	0.706	0.454	0.393	0.152 (899)	0.314 (212)	0.622 (69)
Rana dalmatina	0.633	0.715	0.081	0.124 (5894)	0.123 (1385)	0.170 (443)
Anguis fragilis	0.63	0.589	0.239	0.134 (1730)	0.251 (405)	0.485 (131)
Podarcis muralis	0.688	0.845	0.096	0.101 (4902)	0.134 (1135)	0.199 (363)
Lacerta bilineata	0.748	0.673	0.554	0.224 (453)	0.563 (111)	**0.918** (37)
Natrix helvetica	0.126	0.013	0.267	0.393 (555185)	0.389 (114907)	0.364 (29898)

4.6.3 Number of survey sites

We calculated the number of survey sites required to achieve a power of 0.8 using the following settings. The significance level (α) was set to 0.1, and proportional changes (R) of 0.15, 0.30 and 0.50 were assessed.

Amphibians

The number of survey visits (K) was set to five based on our earlier findings for Jersey's widespread species. Detection (p) and occupancy (ψ) probabilities were calculated by model-averaging the top models using the following settings derived from earlier investigations in to detectability and occupancy combined with plans for two new survey schemes (see Ward and Wilkinson 2019). For amphibian detection we set the number of methods to 1, survey duration to 45 minutes, surveyor experience to 1 year, start time to 16:00, and day of year to 75 (16th March). Amphibian occupancy parameters were set to the 2nd survey cycle, survey squares to contain a site designation and the mean values of latitude, longitude, HSI score and number of ponds.

The resulting model-averaged predictions of detectability and occupancy whilst using these settings are shown in Table 13, and were used to assess the number of survey sites required to achieve a power of 0.8. Where occupancy was estimated to be 0.000, we calculated estimates for occupancy equal to 0.01 instead.

The number of survey sites needed to detect occupancy changes are shown in Table 14. Changes of 50% and 30% can be achieved with relatively few sites for the toad. Palmate newts require slightly greater, but still achievable numbers of sites to detect a 50% occupancy change. The number of sites required to detect changes for agile frogs was extremely high as expected.

Reptiles

The number of survey visits (K) was set to six based on our earlier findings for Jersey's widespread species. Detection (p) and occupancy (ψ) probabilities were calculated by model-averaging the top models using the following settings derived from earlier investigations in to detectability and occupancy combined with plans for two new survey schemes (see Ward and Wilkinson 2019). For reptile detection parameters, we set the number of refugia checked to 15, day of the year to 136 (16th May), surveyor experience to 1, weather to 'Very good', start time to 13:00 and duration to 60 minutes. Reptile occupancy parameters were set to the 2nd survey cycle, squares to contain a site designation, the dominant habitat type as 'Arable', the dominant reptile habitat type as ‘Scrub’ and used mean values of latitude, longitude and extent of reptile habitat.

The resulting model-averaged predictions of detectability and occupancy whilst using these settings are shown in Table 13, and were used to assess the number of survey sites required to achieve a power of 0.8. Where occupancy was estimated to be 0.000, we calculated estimates for occupancy equal to 0.01 instead.

The number of survey sites needed to detect occupancy changes are shown in Table 14. Changes of 50% and 30% can be achieved with relatively few sites for the slow worm. The number of sites required to detect occupancy changes for the green lizard is variable due to wide confidence limits in the occupancy estimates. However, the lowest estimate of 29 sites to detect a 50% change is achievable, and the occupancy estimates used in these calculations (Table 13) are likely to be biased low, meaning that the number of sites required to detect changes may be more achievable. For instance, using the mean occupancy rate of 0.522 (Table 5) would mean that 41, 123 or 506 sites would be needed to detect changes of 50, 30 or 15%. The number of sites required to detect changes for grass snakes was extremely high as expected. The number of sites needed to detect any change in wall lizard populations were also fairly high, though due to the occupancy and detectability estimates being derived from the NARRS scheme, we do not consider these to be reliable for future scheme design.

Table 13 Model-averaged estimates of detectability and occupancy from the top models for each species, when applying the settings described above.

Species	Detection				Occupancy		
	mean	SE	95% confidence		mean	SE	95% confidence
Bufo spinosus	0.921	0.035	0.821–0.968		0.674	0.101	0.453–0.841
Lissotriton helveticus	0.494	0.051	0.397–0.592		0.469	0.092	0.298–0.647
Rana dalmatina	0.736	0.116	0.463–0.901		0.000*	–	–
Anguis fragilis	0.761	0.057	0.633–0.854		0.826	0.076	0.625–0.932
Podarcis muralis	0.926	0.087	0.508–0.994		0.100	0.064	0.024–0.322
Lacerta bilineata	0.736	0.066	0.589–0.844		0.069	0.108	0.000*–0.621
Natrix helvetica	0.030	0.031	0.004–0.199		0.000*	0.000	0.000*–1.000

* power calculations carried out using 0.01 instead

Table 14 The number of survey sites required to detect a given proportional change in occupancy at a power of 0.8 and with a significance of 0.1. Changes in detection probability (‘det’) are given horizontally and changes in occupancy probability (‘occ’) are given vertically. Low confidence limits (‘low CL’), mean values and high confidence limits (‘high CL’) are shown. Values ≤ 50 are shown in bold.

			R = 0.15			***R = 0.30***			***R = 0.50***		
			Det low CL	*Det* mean	*Det* high CL	*Det* low CL	*Det* mean	*Det* high CL	*Det* low CL	*Det* mean	*Det* high CL
Bufo spinosus	Occ	low CL	132	132	132	**37**	**37**	**37**	**14**	**14**	**14**
		mean	281	281	282	71	71	71	**25**	**25**	**25**
		high CL	649	649	650	156	156	156	51	51	51
Lissotriton helveticus	Occ	low CL	323	345	408	81	86	101	**28**	**29**	**34**
		mean	625	656	742	150	157	177	**50**	52	58
		high CL	1254	1303	1440	295	306	338	96	99	109
Rana dalmatina	Occ	low CL	-	-	-	-	-	-	-	-	-
		mean	50362	50428	53337	11576	11592	12260	3679	3684	3896
		high CL	-	-	-	-	-	-	-	-	-
Anguis fragilis	Occ	low CL	73	73	74	**23**	**23**	**24**	**9**	**9**	**9**
		mean	143	143	144	**40**	**40**	**40**	**14**	**15**	**15**
		high CL	341	341	343	85	85	85	**29**	**29**	**29**
Podarcis muralis	Occ	low CL	1106	1106	1131	261	261	267	85	85	87
		mean	4611	4611	4691	1066	1066	1084	341	341	346
		high CL	20708	20708	21043	4764	4764	4841	1515	1515	1540
Lacerta bilineata	Occ	low CL	346	346	350	86	86	87	**29**	**29**	**30**
		mean	6895	6897	6932	1591	1591	1599	507	507	510
		high CL	50362	50379	50618	11576	11580	11635	3679	3680	3698
Natrix helvetica	Occ	low CL	428	34030	2089998	105	7825	480141	**35**	2487	152517
		mean	89598	3449851	209046604	20590	792540	48024227	6542	251750	15254756
		high CL	89598	3449851	209046604	20590	792540	48024227	6542	251750	15254756

5. Discussion

5.1 Species occupancy and conservation status

Jersey contains four herpetofauna species which may be considered as being widespread; the western toad, palmate newt, slow worm and green lizard. The previous report (Wilkinson et al. 2014) suggested that changes of eight, nine, 11 or 10 squares would be indicative of real population change for these species respectively. However, comparing cycles based purely on the number of squares occupied is unsuitable as different numbers of squares were surveyed in each. The other three species (agile frog, wall lizard and grass snake) all show a restricted distribution. Furthermore, the grass snake is particularly difficult to detect. Wilkinson et al. (2014) suggested that any change in the number of squares that these species occur in could be an indicator of population change and would require further study.

Based on our estimates, there has been little change in western toad, agile frog, wall lizard and green lizard occupancy rates between the two survey cycles. However, both the palmate newt and slow worm have increased in estimated occupancy by 0.137 and 0.406 respectively. For those species considered rare, agile frogs have been recorded in the same number of squares in both cycles, wall lizards have been recorded in two less squares and the grass snake in one less square. These are equivalent to naïve occupancy changes of 0.000, -0.025 or -0.005, compared to estimated occupancy changes of -0.015, -0.037 and 0.728. Excluding the latter unreliable grass snake estimates, in the context of overall occupancy rates, changes for these rare species have been minimal.

5.1.1 ***Western toad / crapaud*** *(Bufo spinosus)*

Toads continue to be the most widespread and abundant of Jersey's amphibian species (Figure 6). Supplementary data from the Jersey Biodiversity Centre (e.g. Toadwatch records) fill some of the gaps in survey effort, and are especially useful for deriving distribution data from residential ponds that would not typically be surveyed during NARRS. Occupancy models for this species fitted the data poorly, suggesting there are unmodelled influences. This is likely due to the species' use of both urban and semi-natural areas (e.g. garden ponds and coastal heathland). Future monitoring should aim to (i) better understand the factors driving occupancy in these two habitat types, (ii) evaluate water quality of Jersey's ponds and (iii) screen the population for amphibian diseases.

5.1.2 ***Palmate newt*** *(Lissotriton helveticus)*

Palmate newt occupancy has increased between the cycles (Figure 7) and now show a widespread distribution. However, the number of locations is relatively few compared to those recorded for the toad – perhaps because the newts are more particular in their pond selection, as demonstrated by the strong relationship between HSI score and occupancy (Figure 22). The observed increase in occupancy may be attributable to a greater number of night-time torch surveys in the second cycle, which is likely to improve detection. Future monitoring should aim to (i) improve species detection (especially using night time torch surveys and potentially bottle trapping also) in order to gain a better understanding of pond occupancy and habitat preferences for this species in Jersey, (ii) evaluate the influences of water quality and (iii) screen the population for amphibian diseases.

5.1.3 ***Agile frog*** *(Rana dalmatina)*

Agile frogs were recorded in the same three squares in both cycles (Figure 8); however, with additional data, this increases to at least five. Considering the historic decline of this species it is positive to see that its distribution has at least remained stable. Future occupancy rates are likely to increase through translocation and reintroduction efforts under the species recovery programme. The low occupancy rate of this species during NARRS monitoring, combined with there being additional intensive monitoring efforts for the agile frog as part of the recovery programme (Ward and Griffiths 2015) suggests that efforts to monitor this species are best carried out as part of the intensive recovery monitoring process at known sites. However, citizen science monitoring efforts are useful in determining population expansion to surrounding areas, particularly in gardens. Future monitoring should aim to (i) monitor the species at the pond level to detect declines early on, (ii) evaluate the influence of water quality on pond occupancy and (iii) screen the population for amphibian diseases.

5.1.4 ***Slow worm*** *(Anguis fragilis)*

The slow worm showed the greatest increase in naïve occupancy between the two cycles (Figure 9) based on both NARRS and supplementary data, and can be considered as a widespread species. This can be attributed to intensive survey efforts for reptiles (e.g. Ward 2017) and to greater species detection due to an increase in refugia use (Figure 16). Future monitoring should aim to (i) regularly utilise refugia and (ii) further investigate the factors influencing site occupancy by this species.

5.1.5 ***Wall lizard*** *(Podarcis muralis)*

The species remains restricted to coastal areas (Figure 10), though shows an apparent decrease in occupancy in the second cycle based on NARRS efforts. However, additional data from the Jersey Biodiversity Centre shows occupancy to have remained stable. This restricted distribution, combined with uninformative detection and occupancy covariates indicate that efforts to monitor this species should be carried out in a different manner. Therefore, future monitoring should (i) apply survey methods specific to this species, (ii) focus on determining species occupancy status at known and suspected sites and (iii) aim to better understand the factors driving species occupancy and detection.

5.1.6 ***Green lizard*** *(Lacerta bilineata)*

The distribution of the green lizard has remained steady across the two survey cycles, with supplementary data (e.g. Ward 2017) highlighting how widespread the species is in coastal habitats (Figure 11). Weather plays a clear role in detecting this species, which may be considered to be ‘sun-loving’. Future monitoring should aim to (i) improve our knowledge of the species’ distribution further inland and (ii) collect data that will better inform our understanding of the factors influencing species detection and occupancy.

5.1.7 ***Grass snake*** *(Natrix helvetica)*

NARRS was poor at evaluating grass snake occupancy in Jersey, and a decrease in naïve occupancy of one square between cycles (Figure 12) may be cause for alarm. However, the extremely low detection of this species in Jersey suggests that current NARRS survey design is unsuitable for monitoring grass snakes, and requires evaluation. Research carried out as part of a PhD (Ward 2017; Ward et al. 2017) have shown the species to be distributed across the west and southwest coast, but similarly, that detection is low. Future monitoring should aim to (i) carry out species specific efforts at the site-level to monitor population changes using more intensive survey effort than used in NARRS and (ii) improve our knowledge of the species’ distribution across the island.

5.2 Species Richness

Both amphibian and reptile species richness appears to have improved between the two survey cycles, with more squares containing > 1 species. Therefore, overall richness also seems to have improved (Figure 32). This could be an effect of improved species detection for some species (e.g. palmate newt and slow worm). The greatest species richness tends to occur in coastal regions where much of Jersey's semi-natural habitat is concentrated.

5.3 Habitat quality

Measures of habitat quality remained fairly stable across the two cycles, with only a small proportion (7.5%) of ponds overall having 'good' (> 0.7) HSI scores. Seemingly therefore, conservation efforts could be focused on improving pond quality. This may be particularly beneficial for the palmate newt, which showed a strong relationship between occupancy and HSI score. Assessing habitat quality and type are perhaps the most off-putting tasks that volunteers are asked to perform as part of their surveys. Providing greater support and training in how to record these variables as well as making efforts to reduce the workload by carrying out centralised desk-based data collection for some variables (e.g. remote-sensing for evaluating the number of ponds and habitat types) would reduce these pressures.

5.4 Survey design

Due to poor detectability, low occupancy or a combination of both, grass snakes required an excessive number of surveys to be carried out to have confidence of absence using the current survey design. Changes to improve detection would reduce this, but would require separate monitoring efforts to that of other reptile species on the island (Ward et al. 2017). We were only able to generate reliable recommendations for the number of surveys required for Jersey's widespread amphibian and reptile species; specifically, five surveys for amphibians and six for reptiles. This is greater than the four surveys suggested for British amphibians and reptiles (Sewell et al. 2010, 2012, 2013); however, detection of amphibians in Britain was aided through the additional use of bottle traps and greater numbers of surveys were required for the sand lizard (*Lacerta agilis*).

The two NARRS cycles only had sufficient power to detect large (50%) occupancy changes for the toad and green lizard. Achieving the number of sites required for anything else will require greater volunteer recruitment, retention and participation. For reptiles, a move to a smaller grid size (e.g. 500 x 500 m) may make it easier to achieve the larger sample size required and will be more representative of the ranges of Jersey's lizards. However, for the grass snake which can cover large distances, the larger grid size remains appropriate. Future projections using power analysis suggest that it will be challenging to detect more than a 30% change in occupancy for the widespread species, and will be impossible to detect occupancy changes for the agile frog and grass snake. Estimates for the wall lizard are unreliable given that NARRS was not a suitable design for monitoring the species. Future efforts to monitor this species will allow more accurate assessment following a pilot period. Overall, it appears that only relatively large population changes will be detected in any of Jersey's herpetofauna species. Therefore, we recommend the use of the precautionary principle, in that any indications of species declines should be investigated before reaching these thresholds.

5.5 Recommendations

We provide the following recommendations for future monitoring efforts:

1. Develop separate monitoring efforts for widespread (western toad, palmate newt, slow worm, green lizard) and restricted or difficult to monitor (agile frog, wall lizard, grass snake) species.
2. Utilise refugia more regularly and in greater numbers for widespread reptile surveys.
3. Employ site-based population monitoring of restricted and rare species.
4. Increase the number of repeat surveys for widespread amphibians to five.
5. Increase the number of repeat surveys for widespread reptiles to six.
6. Reduce the sampling grid from 1 km to 500 m for all lizard species.
7. Carry out water quality monitoring.
8. Carry out amphibian disease screening.

Further recommendations on future survey scheme design are given in the partner report to this (Ward and Wilkinson 2019).

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