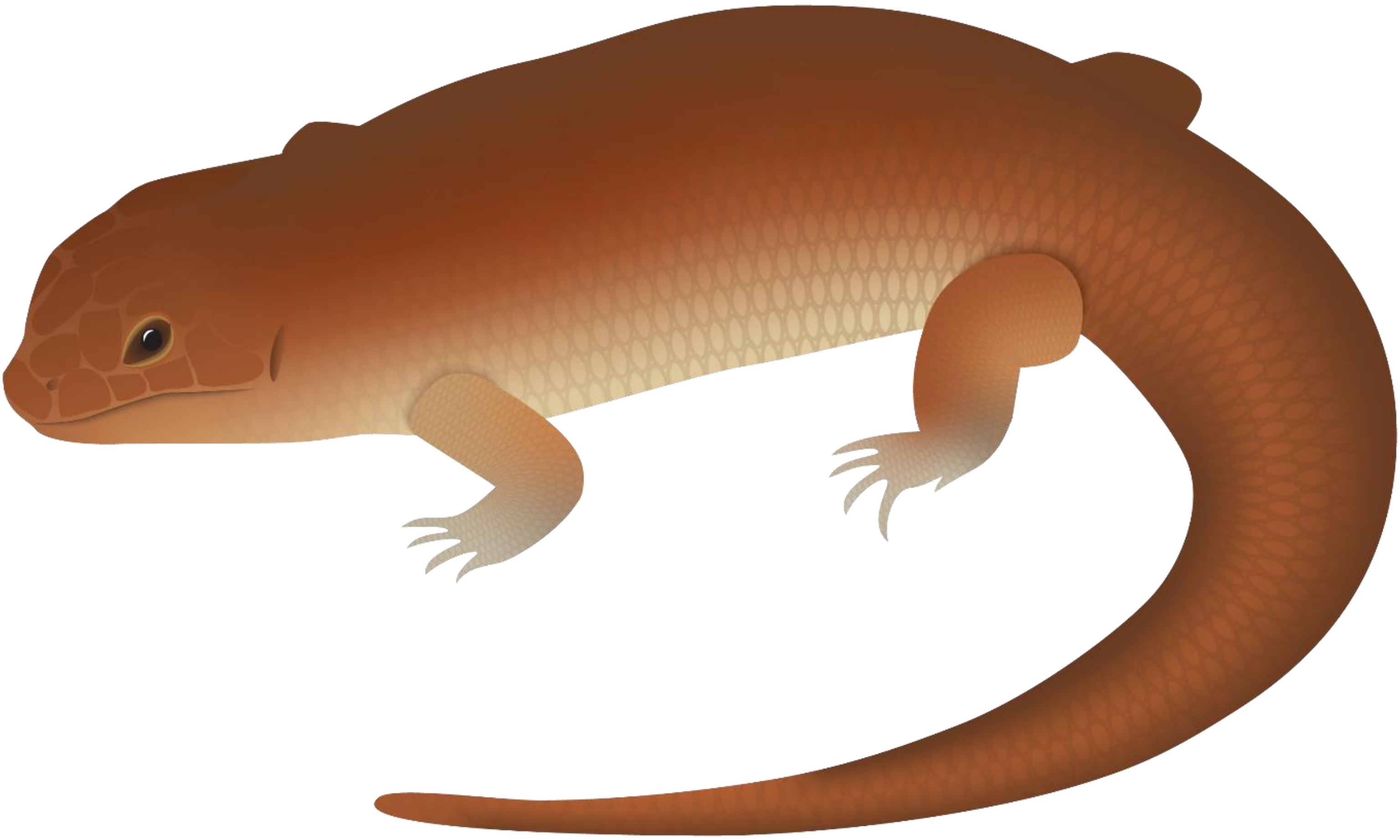
Resilient Landscapes

National Environmental Science Program



A power analysis to inform design of a monitoring program to detect trends in Tjakur̠a

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Cover diagram

Great desert skink icon from the NESP Resilient Landscapes Hub symbol library.

This report is available for download from the Resilient Landscapes Hub website at **nesplandscapes.edu.au.**

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Acknowledgement of Country

The great desert skink is a culturally significant species for Indigenous people across the Australian deserts.

This report is based on data collected on Pintupi Country (Kiwirrkurra), Ngalia-Warlpiri and Luritja Country (Newhaven) and Pitjantjatjara and Yankunytjatjara Country (Yulara and Uluṟu – Kata Tjuṯa National Park).

We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders.

Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

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Acknowledgements

This report is based on data collected by the Kiwirrkurra Rangers from Tjamu Tjamu Aboriginal Corporation and Desert Support Services staff on the Kiwirrkurra IPA, Australian Wildlife Sanctuary staff (and Newhaven Warlpiri Rangers) working at Newhaven Sanctuary, Desert Wildlife Services and Ayers Rock Resort staff working at Yulara and Parks Australia staff working at Uluṟu – Kata Tjuṯa National Park. We specifically acknowledge the long history of data collection by Steve McAlpin across multiple sites.

The survey method for monitoring Great Desert Skinks described in this study is based on identification and interpretation of tracks, scats and burrows. We are grateful to the many expert trackers who have shared their tracking skills, knowledge and stories with us and would like to specifically acknowledge the generous teachings of Alice Nampitjinpa, Christine Michaels, Mitjili Napangangka, Yalti Napangati, Yukultji Napangati, Payu West and Mantua James.

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1. Executive summary

The great desert skink or Tjakuṟa (*Liopholis kintorei*) is a threatened species of lizard that lives in family burrow systems in the central and western deserts of Australia. Some Tjakuṟa populations are monitored annually; however, survey methodologies are inconsistent between land managers, making it difficult to assess overall population trends. A standardised range-wide monitoring program is being designed for Tjakuṟa to track population trends and assess progress against the recovery plan for the species.

In this report, we assessed design considerations for a standardised, range-wide monitoring program for Tjakuṟa. We estimated the average density of active burrows at existing monitoring sites in the Kiwirrkurra Indigenous Protected Area in Western Australia and Yulara, Newhaven Wildlife Sanctuary, and Uluṟu – Kata Tjuṯa National Park in the Northern Territory. We then simulated data that might be collected in future for various combinations of site sizes and numbers of sites. Using the simulated datasets, we estimated the chance (i.e. statisitical power) that monitoring will detect future increases or decreases in Tjakuṟa burrow counts.

From this analysis, we recommend:

- monitoring at least 45 10-ha sites across Tjakuṟa's range – this will improve the spatial coverage of sites and ensure there is a high chance at detecting 20% trends in burrow counts over 10 years
- surveying sites annually to maximise power and embed Tjakuṟa monitoring into the work programs of Indigenous groups and land managers
- surveying a subset of monitoring sites across the species range twice a year, or conducting a separate pilot study, to get baseline estimates of detectability
- where larger long-term monitoring sites already exist, nesting new sites within these sites to maintain data compatibility
- recording site variables, such as broad vegetation type, time since fire, fire frequency and the presence of predators (e.g. tracks, scats or sign), to continue learning about the drivers of burrow counts and responses to management
- if possible, establishing sites in new regions to improve the geographic coverage of monitoring across the Tjakuṟa's range
- better understanding the relationship between burrow counts and population size so that trends in abundance can be inferred.

Standardising the area of sites surveyed will allow for more precise assessments of burrow counts. Monitoring at least 45 sites will ensure trends in counts are confidently detected from future monitoring, and that there is adequate coverage across the species' range. However, the monitoring design decisions discussed here are only one necessary component for successful long-term monitoring. A standardised national monitoring program for Tjakuṟa should also consider how to encourage long-term participation, data curation and management, ongoing funding and legislative support, and capacity for data analysis.

2. Introduction

2.1 Challenges of monitoring design

Monitoring is crucial to conservation because it informs the status and trends of plant and animal populations and evaluates the effectiveness of management interventions (Possingham et al. 2012). To be effective, monitoring should:

- have well-defined objectives (Scheele et al. 2018)
- be designed with adequate statistical power to detect population change (Southwell et al. 2019)
- provide appropriate data consistently through space and time (Likens, 1989)
- be sustained over an appropriate temporal and geographic scale
- produce results that inform management decisions (Lindenmayer and Likens, 2018).

Designing an effective monitoring program requires a hierarchy of complex decisions. Once target species are selected, important decisions must be made about:

- what population metric is measured (i.e. occupancy or abundance)
- the type of sampling methods (e.g. live trapping versus cameras)
- the size of the sampling units (hereafter called sites)
- the number and location of sites
- the frequency of sampling
- who does the monitoring
- what level of expertise is required of people doing the monitoring
- what site variables are recorded to learn about drivers of population trends and management effectiveness (such as time since fire).

It is particularly challenging to decide how much effort to allocate towards sampling across space and time. Detecting population trends with confidence requires sufficient sampling effort, which depends on the sampling method, duration, frequency, location and number of sites. Too little effort can mean that trends are not detected from monitoring data when an actual trend in a population occurs. Too much effort means that population trends could be detected with less survey effort, wasting resources that could otherwise be spent on management. Limited budgets almost always create trade-offs in survey effort. For example, increasing the size of sites or the time spent at sites can compromise the overall number of sites and geographic coverage of a monitoring program.

Data simulation and power analysis are useful tools for assessing trade-offs in survey effort (Rhodes et al. 2006). A power analysis simulates future data that might be collected during monitoring by taking into account natural variation in the data, survey design, and assumptions about population change over time. Statistical models can then be fitted to the simulated datasets, and statistical power can be calculated as the proportion of times the simulated change in the population can be detected. It therefore enables prediction – ahead of time – about the likely effectiveness of monitoring design alternatives.

2.2 The great desert skink

The great desert skink or Tjakuṟa (*Liopholis kintorei*) is a threatened species of lizard that lives in family burrow systems in the central and western deserts of Australia. The species is of cultural significance for Indigenous people, both as an important Tjukurrpa (dreaming) species and as a food resource. Healthy populations of Tjakuṟa reflect the appropriate management of threats such as cat predation and inappropriate fire regimes. Tjakuṟa is therefore an indicator species to monitor throughout arid Australia because of its conservation status, cultural significance, and sensitivity to threats common to other declining species (cat predation and inappropriate fire regimes).

Long-running programs monitor Tjakuṟa in central Australia. In particular, monitoring has been conducted by Kiwirrkurra Rangers from Tjamu Tjamu Aboriginal Corporation and Desert Support Services staff on the Kiwirrkurra Indigenous Protected Area (IPA), Australian Wildlife Sanctuary staff and Newhaven Warlpiri Rangers working at Newhaven Sanctuary, Desert Wildlife Services and Ayers Rock Resort staff working at Yulara, and Parks Australia staff working at Uluṟu – Kata Tjuṯa National Park.

Surveys count the number of active burrows within designated search areas. This is much easier than trying to detect skinks themselves, as active burrows are relatively conspicuous in the landscape and easy to distinguish from diggings and burrows made by other species (primarily because of the distinctive nature of the communal latrine). However, the size of the designated search areas and the way they are searched varies between land management agencies (Table 3-1). Inconsistency in these sampling approaches may limit data compatibility and inferences that can be made about population trends across the entire species range.

2.3 Aim of research

We explored standardised sampling approaches for Tjakuṟa across its entire range. Our primary objective was to recommend a standardised site size and number of sites to survey to confidently detect small-to-medium (≥ 20%) trends in active-burrow counts over 10 years. This trend was chosen because it is roughly equivalent to trends in burrow counts observed over the last decade and because it aligns with the IUCN (International Union for Conservation of Nature) criteria for species of ‘Vulnerable’ status.

To achieve this aim, we simulated future monitoring data based on current estimates of burrow-count density and estimated the statistical power to detect trends for various combinations of site size, number of sites, and magnitudes of change. We briefly discuss other design considerations for a standardised Tjakuṟa monitoring program, such as survey frequency and detectability, and other important ingredients for long-term success, such as how to encourage long-term participation, data curation and management, ongoing funding and legislative support, and capacity for data analysis.

2.4 Defining the monitoring objective

The design of a monitoring program depends critically on the primary objective. The goal of this monitoring program is to track progress against the ***National recovery plan for the great desert skink (*Liopholis kintorei*) 2023–2033*** (Indigenous Desert Alliance 2022); specifically to (i) detect whether there is an ongoing increasing trend in the number of known active burrows across the species range over the next 10 years and (ii) determine whether the estimated number of active burrows across the range exceeds 10,000. Additional monitoring objectives are to incorporate the Traditional Knowledge and tracking skills of Indigenous people in the monitoring methodology and to learn about drivers of population trends.

3. Method

We conducted a power analysis to determine the probability that future monitoring will correctly detect a linear trend (either increasing or decreasing) in active-burrow counts for various combinations of site size, number of sites and effect size (i.e. the magnitude of change). This analysis involves 3 steps: (i) estimating the average density of active burrows, (ii) simulating burrow count datasets that might be collected in future assuming likely trends and (iii) analysing these simulated burrow count datasets – as we would real data – to determine how likely monitoring design alternatives are at detecting the anticipated trends.

3.1 Data collation

We collated active-burrow count data from 31 sites in 4 regions of central Australia: Yulara (11 sites), Newhaven Wildlife Sanctuary (8 sites), Kiwirrkurra IPA (3 sites) and Uluṟu – Kata Tjuṯa National Park (9 sites). The dataset was compiled from 20 years of monitoring (2001–21), with the majority of sites surveyed annually.

The search area and sampling methodology varied between regions. Four-hectare sites were searched at Yulara, 30-ha sites were searched in the Kiwirrkurra IPA, while sites in Uluṟu – Kata Tjuṯa National Park ranged from 13 to 289 ha. At Newhaven, active burrows were recorded within 5-m strips each side of a line transect positioned within a 50-ha site.

We estimated the density of active burrows per region and calculated the average density of active burrows across all sites (Table 3-1). For Newhaven, we only included active burrows detected within the 5-m strip because detectability is likely to decrease with greater distances. We assumed the total area searched was equal to 7 ha (length of transect multiplied by the width within a 50-ha site).

Table 3-1. Number of sites, area of sites and active-burrow density in 4 regions of central Australia.

Region	No. of sites	Area searched (ha)	Active-burrow density (per ha)
Yulara	11	4	0.53
Newhaven	8	5 m either side a transect within a 50-ha site (7 ha in total)	3.04
Kiwirrkurra	3	30	0.42
Uluṟu – Kata Tjuṯa National Park	9	13–289	0.17
		Average density	**1.04**

3.2 Data simulation and power analysis

To simulate burrow-count data that might be collected in future, we assumed that for each site *i* and year *j*, the number of active burrows is described as a Poisson distribution with mean λ_{ij} in Equation 3-1.

Equation 3-1. Poisson distribution describing the number of active burrows.

$$y_{ij} \sim Pois(\lambda_{ij}) \tag{1}$$

We modelled the mean number of active burrows as a log regression as in Equation 3-2.

Equation 3-2. Model of mean number of active burrows.

$$ln(\lambda_{ij}) = \alpha + \beta_1 \mathrm{j} + \varepsilon_i \tag{2}$$

where α is the log-rate intercept, β_1 is a linear trend in active-burrow counts over time and ε_i is a site random effect. We conducted the power analysis using the following steps.

1. We simulated a dataset of active-burrow counts using the model above, with an average starting count of 1.04/ha (from Table 3-1) and choices about site size, number of sites, number of years and a linear trend in the mean burrow count over time. This dataset was assumed as the reference 'truth'.
2. We analysed the simulated dataset using the same model structure as above.
3. We determined whether the estimated trend in burrow activity β_1 from the simulated dataset was statistically significant at a 0.05 significance level.
4. We repeated steps 1–3 for 100 iterations.
5. We estimated the statistical power as the percentage of simulations in which the assumed trend in burrow activity is detected in the reference dataset.
6. We repeated steps 1–5 for combinations of site size (1–50 ha), number of sites (10–50) and for both increasing and decreasing linear trends (10–50% of the mean active-burrow count). We tested these trends because an earlier analysis suggested that active-burrow counts had increased by approximately 30% across all sites over the last two decades (except for in Uluṟu – Kata Tjuṯa National Park).

Simulations were conducted using the software R on the Spartan High-Performance Computing facility at the University of Melbourne. Model fitting was performed using Bayesian markov chain Monte Carlo sampling using the *rjags* package in R.

4. Results

The density of active burrows varied considerably among the different regions surveyed. The lowest density was at Uluṟu – Kata Tjuṯa National Park (0.17/ha), where very large areas were searched. The highest density was at Newhaven, with an estimated density of 3.04/ha within the 5-m transect strip. It is unclear whether this difference reflects true differences in density between regions or is the result of different search strategies. Overall, the average density of active burrows across all sites was 1.04/ha, which is consistent with the literature and expert knowledge.

Given the average burrow density, the results of our power analysis suggest that monitoring has a high chance (> 80% power) at detecting trends in burrow counts over a 10-year time horizon for most scenarios tested (combinations of site size and number of sites). Power increased as the trend in burrow counts increased (i.e. a 50% change was easier to detect than 10% change). Importantly, power was almost always low when sites were only 1 ha in size or when burrow counts increased or decreased by only 10%.

Power was very similar for both increasing and decreasing trends, although comparing Figure 4-1 and Figure 4-2 suggests power was consistently higher for decreasing trends, although the difference was very minor. The reason for this is not clear, although it might be because the starting burrow count was relatively low, which meant that a proportional decrease in power was slightly less than the same increase because it was truncated at zero. This could be explored further by running more simulations with much higher starting burrow densities, although this was beyond the scope here.

Figure 4-1 and Figure 4-2 illustrate the power analysis results for different combinations of site size, number of sites, and effect sizes of trends in active-burrow counts. White shading indicates low power (< 80%) and green shading represents high power (> 80%). Any combination of site area and number of sites with green shading will have a high chance at detecting the assumed trend over a 10-year period.

The results show that 50 or fewer 5-ha sites would not be able to detect increasing trends in burrow counts less than or equal to 20%. However, 30 5-ha sites would be able to detect a 30% increase in burrow counts. Power increases with the increase in the area of an individual site. For instance, 30 10-ha sites could detect up to 20% increases in burrow counts, while only 15 10-ha sites could detect up to 30% increases in burrow counts.

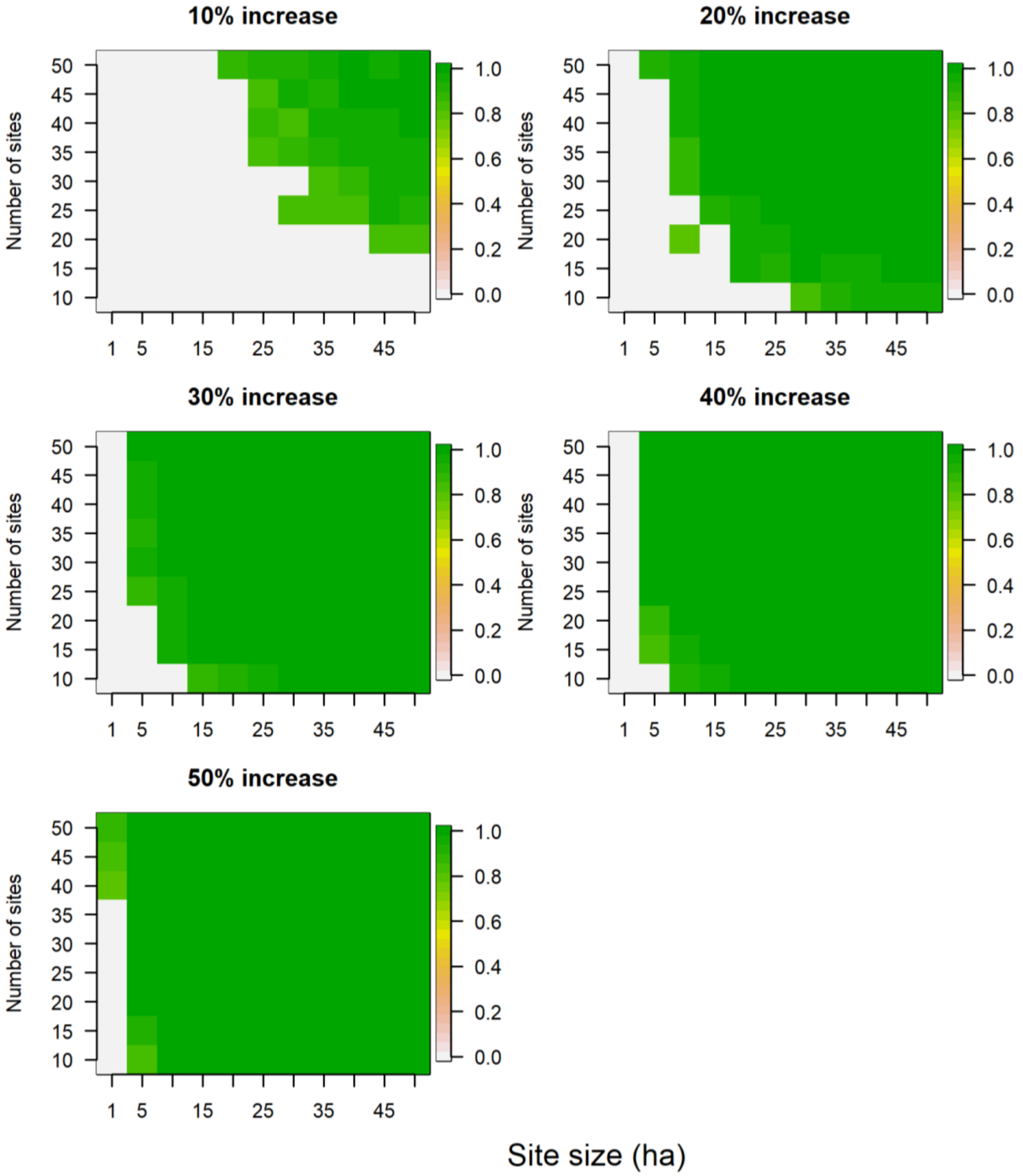

Figure 4-1. Statistical power to detect increasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis). The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.

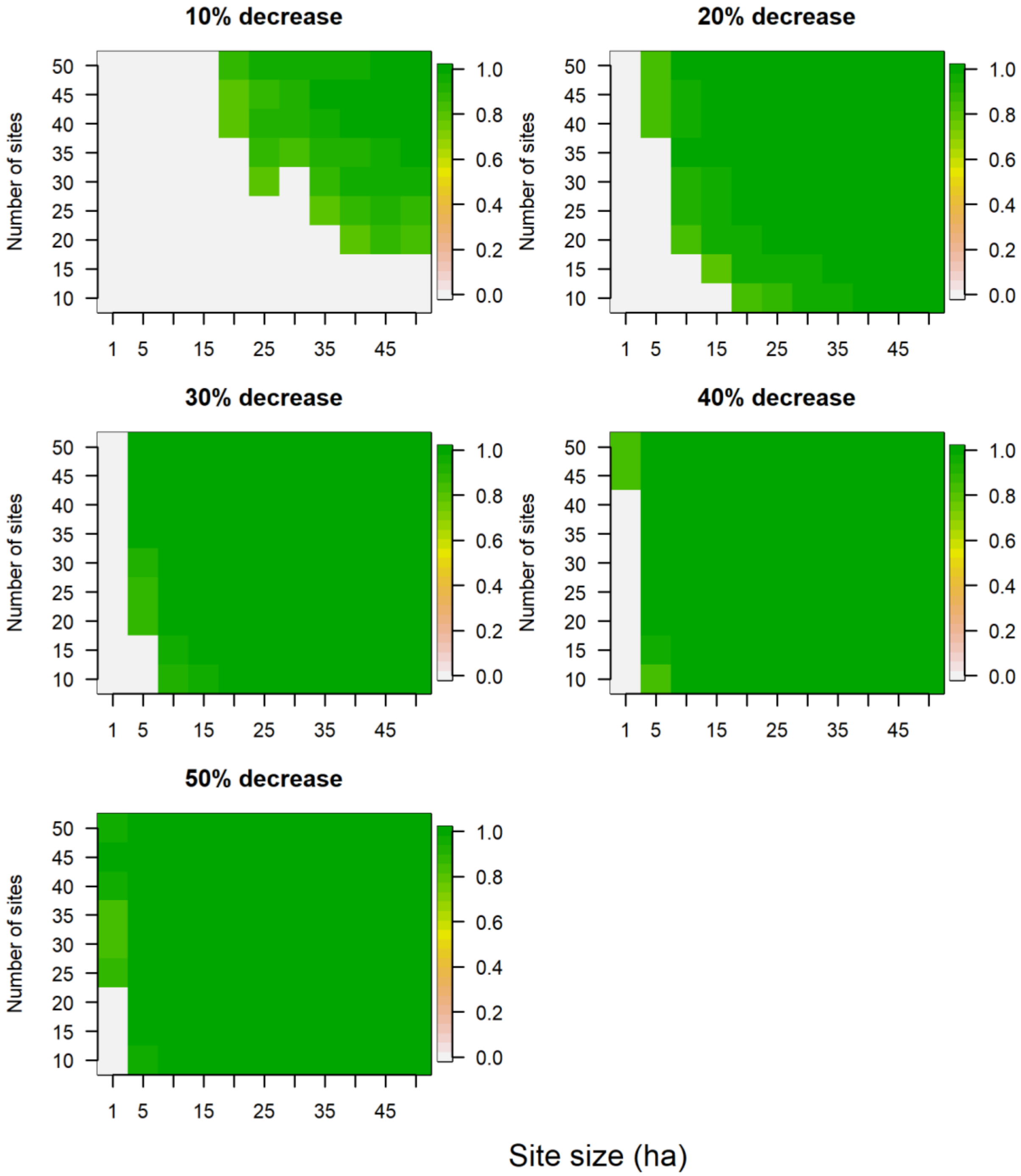

Figure 4-2. Statistical power to detect decreasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis). The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.

5. Discussion

Long-running programs monitor Tjakura in central Australia. These programs all record the number of active burrows, but the size of the designated search areas and the way in which they are searched varies. This can lead to uneven survey effort across sites and limit data compatibility between regions. For example, larger sites may receive less survey effort per unit area than smaller sites. Implementing a standardised survey protocol across the entire species range will ensure consistent survey effort, making it easier to establish new sites and allowing for more efficient and consistent training programs.

5.1 Site size versus number of sites

The area of sites searched varies between regions. In practice, logistics and finances limit the effort that groups can spend monitoring Tjakura each year. This creates a trade-off – either many small sites can be surveyed or fewer large sites (or something in between). Our power analysis suggests that, given the average density of active burrows, high levels of power (> 80% power) can be achieved for most combinations of site size and number of sites, except for when sites drop below 5 ha in size. When this happens, the number of sites needed for power to be high becomes very large and, even then, only large trends can be detected.

We recommend that at least 45 10-ha sites be monitored across Tjakura's range. Figure 5-1 shows a potential array of monitoring locations across 3 states, where each location (yellow and green dots) might include at least 4–6 10-ha sites. This would achieve the minimum number of sites for the national monitoring program, but more sites would be even better. This survey design will have a high chance (> 80%) at detecting 20% trends in burrow counts over 10 years and provide good spatial coverage across the Tjakura's range. An alternative is to monitor fewer 5-ha sites, which will have high power to detect 30% trends in burrow counts; however, this strategy is unlikely to detect smaller trends (i.e. 20% trends). Analysis of the existing burrow count dataset (excluding sites in Uluru – Kata Tjuta National Park) suggests that burrow counts have increased by 30% over the last 2 decades. Surveying 10-ha sites should, therefore, have sufficient power to detect smaller changes in burrow counts than what has been observed recently.

Choosing one design over another will likely be determined by logistics and the willingness of people to search large versus smaller sites. The 'best' combination of site size and number of sites will also be determined by the costs and benefits of travelling between sites during a day of surveying. People may be less willing to survey one large site in a single day or, alternatively, many small sites if the distance between sites is large. If we assume that groups of 4 people can search a maximum of 20 ha per day, perhaps 2 10-ha sites could be surveyed with one break in a single day or 3 5-ha sites with 2 breaks in between. If Tjakura surveys are run over 3–5 days, this might result in 6–10 10-ha sites or 9–15 5-ha sites searched by each group annually.

There are additional benefits to maximising the number of sites and minimising site area.

- Sites can be stratified across a greater range of covariates (e.g. time since fire, predator baiting intensities). This can improve learning about the response of burrow counts to these factors, especially management interventions.
- Small-scale monitoring programs may document localised changes due to localised threatening processes but not those that are not representative of the broader population. Maximising the number of sites will therefore increase geographic coverage across Tjakur̲a's range, giving a more representative picture of its status.
- Willingness to maintain high levels of survey effort might be higher when smaller areas are searched with breaks in between, rather than large areas being searched in a single effort, although we acknowledge that too many breaks between many small sites might also affect motivation.

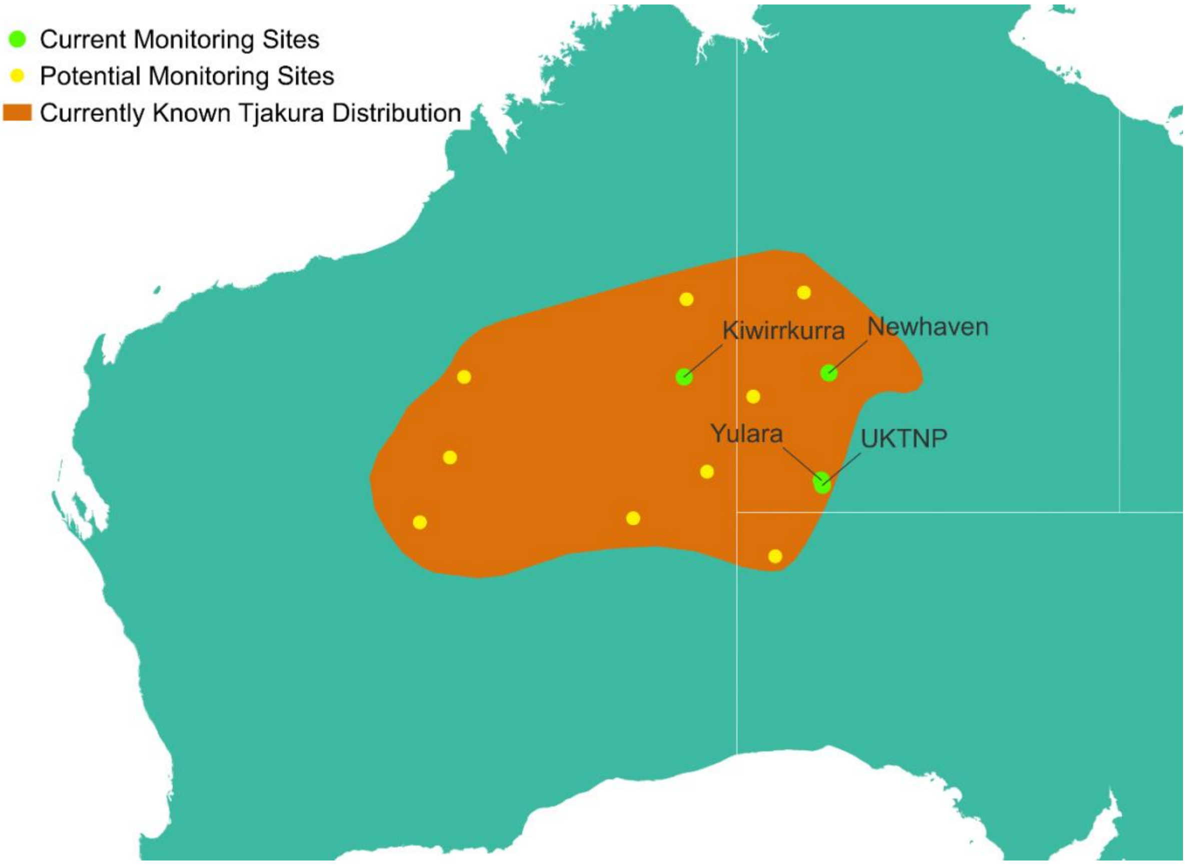

Figure 5-1: Map showing the currently known distribution of Tjakur̲a in Australia (2023), showing a potential spread of monitoring locations across 3 states. Ideally, a national monitoring program would comprise a minimum of 4–6 10-ha burrow monitoring sites at (at least) this number of locations to achieve the required number of 45 sites.

5.2 Survey frequency

The most appropriate survey frequency depends on the status and generation length of the target species. Surveys can also be synchronised with natural peaks and troughs in populations where possible. This is particularly challenging in arid Australia because 'boom–bust' cycles are irregular and difficult to anticipate. Existing Tjakur̲a sites have been surveyed annually, and we recommend this continue in the future, rather than dropping back to surveying every 2 or 3 years. Annual surveys have higher power to detect trends, are easier to coordinate, and are more likely to embed Tjakur̲a monitoring in organisations' work plans. Another option is rotational sampling, where a subset of sites is surveyed each year, ensuring all sites are visited at least once over a 3-year period. This would allow many sites to be surveyed, increasing the strength of inferences that can be made while overcoming logistical constraints. However, rotational sampling requires a higher level of coordination across regions and groups compared to annual surveys, increasing the risk of program failure.

5.3 Detectability

The rate of false positives and false negatives will influence the number of active burrows recorded at sites. False positives can be reduced through regular training to minimise the misidentification of active burrows. False negatives will occur if active burrows are missed during searches. Failing to account for false negatives can bias burrow counts and inference about population trends. For example, if burrows become more difficult to detect as time since a fire increases, monitoring data at unburnt sites might give the false impression that burrow counts are declining when in fact they are stable. Given detectability of active burrows is not known, we recommend that a subset of sites be searched twice per year (with the smallest possible time interval between visits) so that detectability can be quantified. Alternatively, a pilot trial could be conducted independently to quantify detectability for different weather conditions, vegetation types, and levels of observer experience.

An alternative approach to dealing with detectability would be to conduct distance sampling at sites instead of exhaustive searches. Distance sampling records the perpendicular distance of detected burrows to a line transect. This is similar to the search strategy currently implemented at Newhaven. The decline in detectability with distance from the transect can then be modelled, giving unbiased estimates of density across the transect belt. The downside of this approach, however, is that surveys become much more time consuming and may not be best suited to how Indigenous rangers prefer to search the landscape.

5.4 Site variables (other factors)

We recommend measuring site variables during monitoring so that management can be evaluated. This information indicates whether management is effective, identifies when changes are needed, and helps set management triggers. Site variables for Tjakur̲a include variables such as:

- broad vegetation type
- proportion of vegetation cover or normalised difference vegetation index (NDVI)
- dominant species of vegetation
- time since fire
- fire frequency.

Threatening processes for Tjakur̲a should also be recorded, such as:

- presence (or sign) of feral animals (especially cats and foxes) and the location
- timing, extent and intensity of predator control.

Trends in burrow count data could then be analysed using the regression model in Equation 3-1 and Equation 3-2 but with the addition of the site-level covariates listed above.

5.5 Data compatibility

All effective ecological monitoring programs have consistent long-term datasets. Breaches of consistency can lead to irreparable breaks in a time series and cause monitoring programs to fail. If site size for Tjakur̲a is standardised across regions, historic and future datasets will need to be compatible. If sites are made smaller, new sites should be positioned within existing ones so that historic burrow-count data can be recovered and used in future analyses. It is therefore important to record the GPS coordinates of active burrows so their location can be compared with boundaries of old and new sites. Monitoring has to start from scratch if new count data cannot be combined with historical data. That should be avoided if possible.

5.6 Other factors for successful monitoring

This report primarily considers how to design surveys to detect national trends in Tjakur̲a – specifically, site size and number of sites. However, other attributes are equally necessary for the success of long-term monitoring. Monitoring of Tjakur̲a will also require good levels of structure and governance, effective data management and reporting, and appropriate funding and legislative support. Meaningful partnerships with communities and other stakeholders are essential. This means involving them in identifying objectives, developing field protocols, and establishing an appropriate governance structure. High-quality curation of the datasets is also often overlooked but is needed to ensure that errors are corrected and robust analyses can subsequently be completed. A comprehensive approach that considers all these elements is necessary for long-term monitoring of Tjakur̲a to succeed.

5.7 Alternative monitoring objectives

We assumed the goal of monitoring was to detect trends in Tjakur̲a active-burrow counts across the entire species range over 10 years. An alternative objective might be to detect trends with high levels of power within specific management areas (e.g. park, sanctuary, IPA). We could estimate the number of 10-ha sites needed for high power for each management area separately using the densities presented in Table 3-1. We do this in Appendix 1 for the management areas with the highest and lowest recorded density of burrow counts (Newhaven Wildlife Sanctuary and Ulur̲u – Kata Tjut̲a National Park, respectively). This shows how the number of sites needed to achieve high levels of power changes with starting density. We did not repeat this for all management areas because it was not explicitly part of the fundamental monitoring objective.

We simulated Tjakuṟa active-burrow counts over the next 10 years assuming a linear trend in the mean count and that counts are described by a Poisson distribution. Arid regions have high levels of natural variability and burrow counts will vary widely from year to year or in response to infrequent rainfall events. For simplicity, we fitted linear trends to our simulated data; however, our approach could be expanded to model more complicated changes in burrow counts over time, such as non-linear trends. There also might be an upper limit in burrow-count density, making the larger trends considered here unlikely (i.e. 50% increase).

Other sampling methods may be deployed in combination with the approach discussed here to address other survey objectives. For example, the occupancy extent of Tjakuṟa is poorly understood. Rather than search sites for active burrows, rapid searches for evidence of sign (tracks, burrows, scats) could be conducted in 2-ha sites to determine presence/absence and range edges. Alternatively, management actions could be experimentally manipulated at select sites if relationships between management and burrow counts are highly uncertain. For example, a selection of sites could be purposely burnt to accelerate learning about the relationship between Tjakuṟa and time since fire. However, such strategies are only beneficial if the response of Tjakuṟa to management is highly uncertain.

6. Conclusions and recommendations

The recommended survey design for monitoring Tjakura includes the following principles.

- Minimise the area of a site and maximise the total number of sites. This will increase geographic coverage across the species range and capture site variables that influence burrow counts.
- Survey at least 45 10-ha sites annually to have a high chance of detecting 20% trends in burrow counts over 10 years while ensuring good coverage across the Tjakura's range.
- The optimal method depends on logistics, such as the area participants are willing to survey and the cost of travelling between sites.
- Survey sites annually to maximise power and embed Tjakura monitoring into the work programs of Indigenous groups and conservation land managers.
- Survey a subset of sites twice per year or in a separate pilot study to establish baseline estimates of detectability.
- If the area of existing sites is reduced, then nest new boundaries within the original sites to maintain data compatibility.
- Record site variables to learn about the drivers of burrow counts and their response to management. These variables might include broad vegetation type, proportion of vegetation cover, dominant species of vegetation, time-since-fire and the presence-absence of predator sign.
- If possible, establish monitoring sites in new regions to improve the geographic coverage of monitoring across Tjakura's range.
- Better understand the relationship between number of active burrows and population size so that trends in abundance can be inferred.

7. References

Indigenous Desert Alliance (2022) *Looking after Tjakura, Tjalapa, Mulyamiji, Warrana, Nampu. National recovery plan for the great desert skink (*Liopholis kintorei*)*.

Legge S, Lindenmayer D, Robinson N, Scheele B, Southwell D and Wintle B (eds) (2018) *Monitoring threatened species and ecological communities,* CSIRO Publishing, Melbourne.

Likens GE (1989) *Long-term studies in ecology: approaches and alternatives,* Springer-Verlag, New York.

Lindenmayer DB and Likens GE (2018) *Effective ecological monitoring,* CSIRO Publishing, Melbourne.

Muscarella R, Galante PJ, Soley-Guardia M, Boria RA, Kass JM, Uriarte M and Anderson RP (2014) 'ENMeval: an R package for conducting spatially independent evaluations and estimating optimal model complexity for MAXENT ecological niche models', *Methods in Ecology and Evolution,* 5:1198–1205, doi:10.1111/2041-210X.12261.

Naimi B, Hamm NAS, Groen TA, Skidmore AK and Toxopeus AG (2014) 'Where is positional uncertainty a problem for species distribution modelling?', *Ecography,* 37:191–203, doi:10.1111/j.1600-0587.2013.00205.x.

Newman P, Raymond B, VanDerWal J, Belbin L and Stevenson M (2020) *ALA4R: Atlas of Living Australia (ALA) data and resources in R*.

Possingham HP, Wintle BA, Fuller RA and Joseph LN (2012) 'The conservation return on investment from ecological monitoring', in Lindemayer DB and Gibbons P (eds) *Making biodiversity monitoring happen in Australia*, CSIRO Publishing, Melbourne.

Scheele BC, Legge S, Armstrong DP, Copley P, Robinson N, Southwell D, Westgate MJ and Lindenmayer DB (2018) 'How to improve threatened species management: an Australian perspective', *Journal of Environmental Management,* 223:668–675, doi:10.1016/j.jenvman.2018.06.084.

Scheele BC, Legge S, Blanchard W, Garnett S, Geyle H, Gillespie G, Harrison P, Lindenmayer D, Lintermans M, Robinson N and Woinarski J (2019) 'Continental-scale assessment reveals inadequate monitoring for threatened vertebrates in a megadiverse country', *Biological Conservation,* 235:273–278, doi:10.1016/j.biocon.2019.04.023.

Southwell D, Einoder L, Lahoz-Monfort J, Gillespie G, Fisher A and Wintle B (2019) 'Spatially explicit power analysis for detecting occupancy trends in multiple species in dynamic landscapes', *Ecological Applications*, 29(6):e01950, doi:10.1002/eap.1950.

8. Appendix 1. Supplementary data

Here, we re-ran the power analysis simulations using active-burrow count densities from Uluṟu – Kata Tjuṯa National Park, where densities were lowest, and Newhaven Wildlife Sanctuary, where densities were highest.

Uluṟu – Kata Tjuṯa National Park – decreasing trends

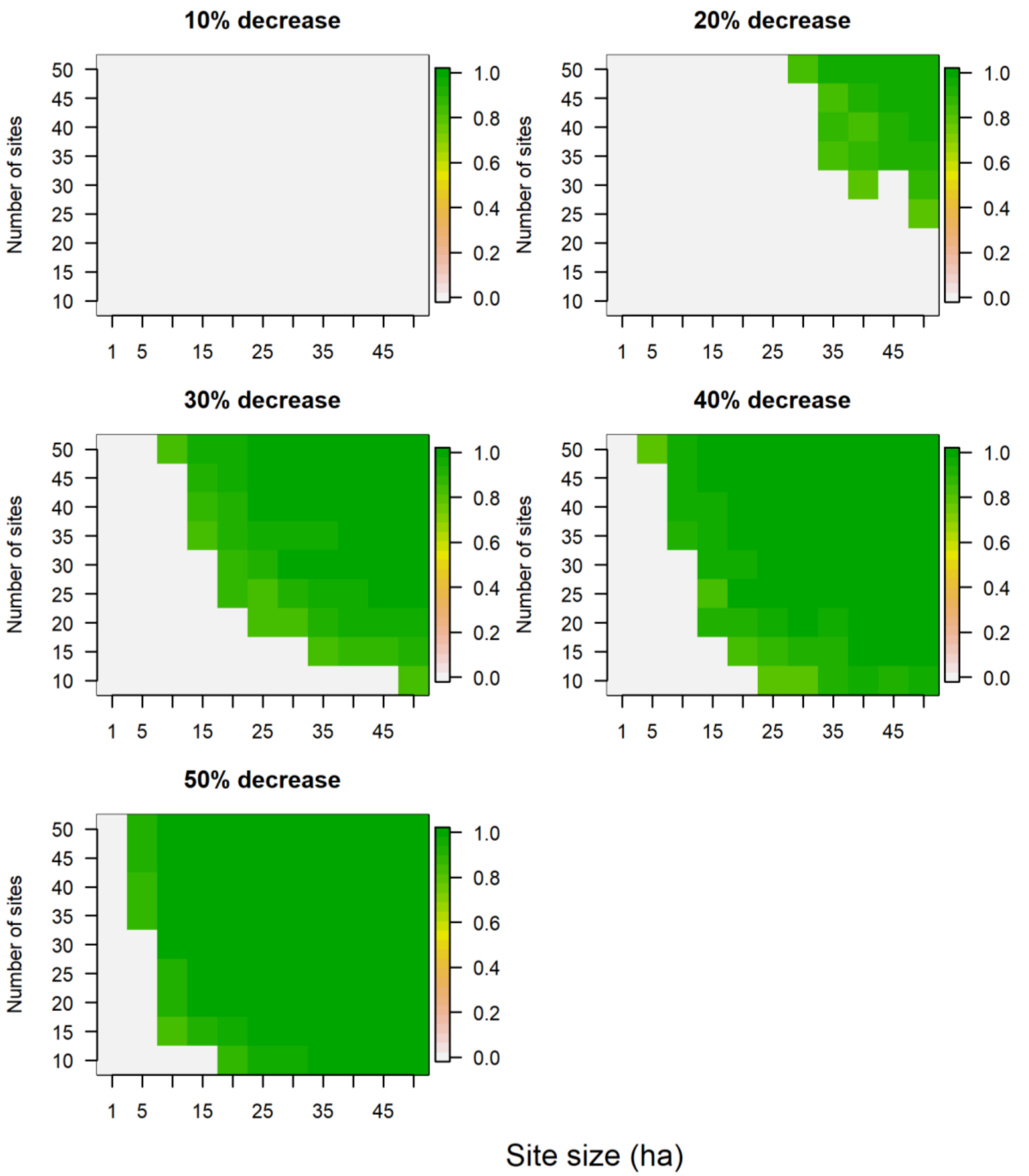

Figure 8-1. Statistical power to detect decreasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis) given burrow densities recorded at Uluṟu. The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.

Uluṟu – Kata Tjuṯa National Park **– increasing trends**

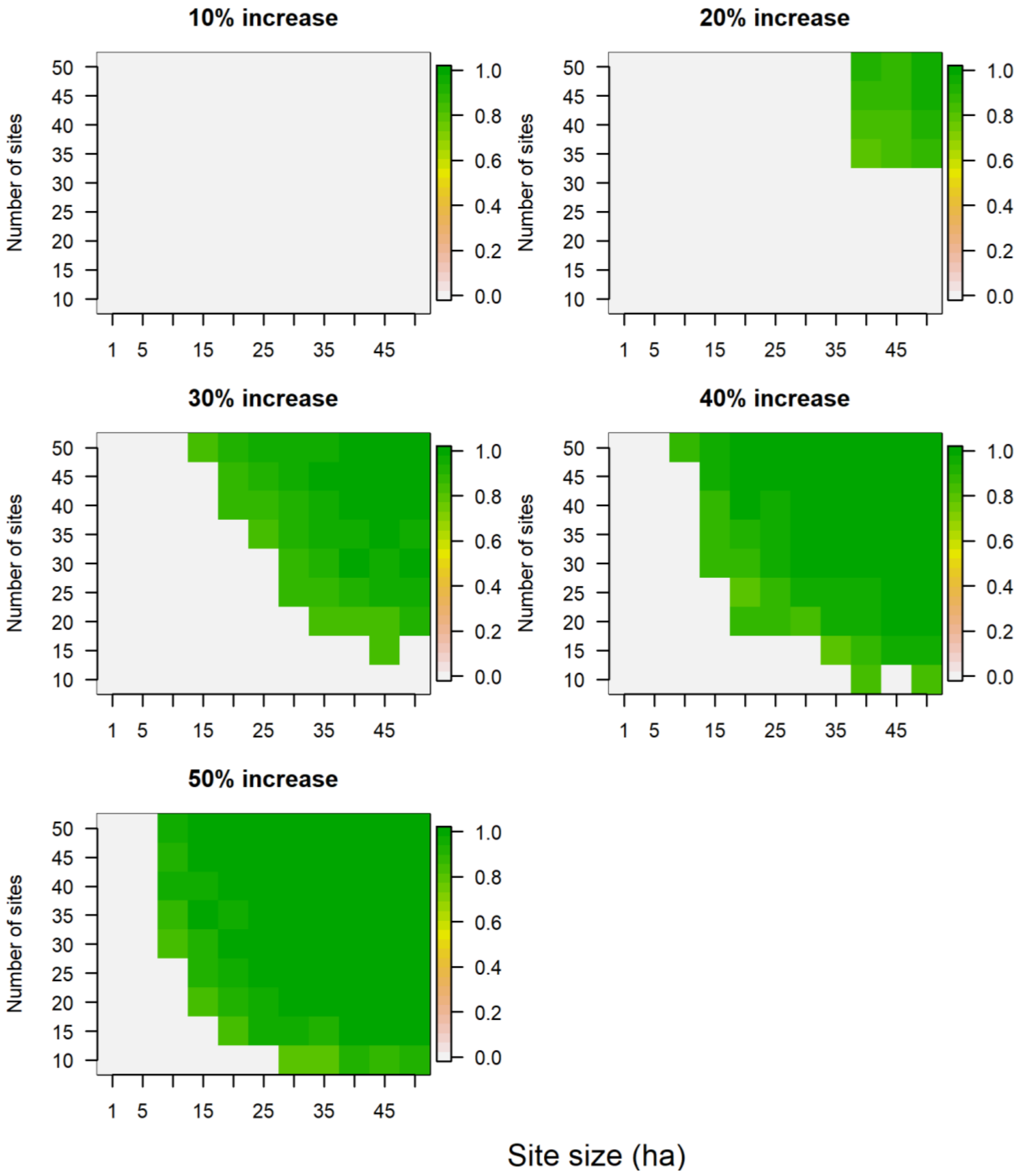

Figure 8-2. Statistical power to detect increasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis) given burrow densities recorded at Uluṟu. The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.

Newhaven Wildlife Sanctuary – decreasing trends

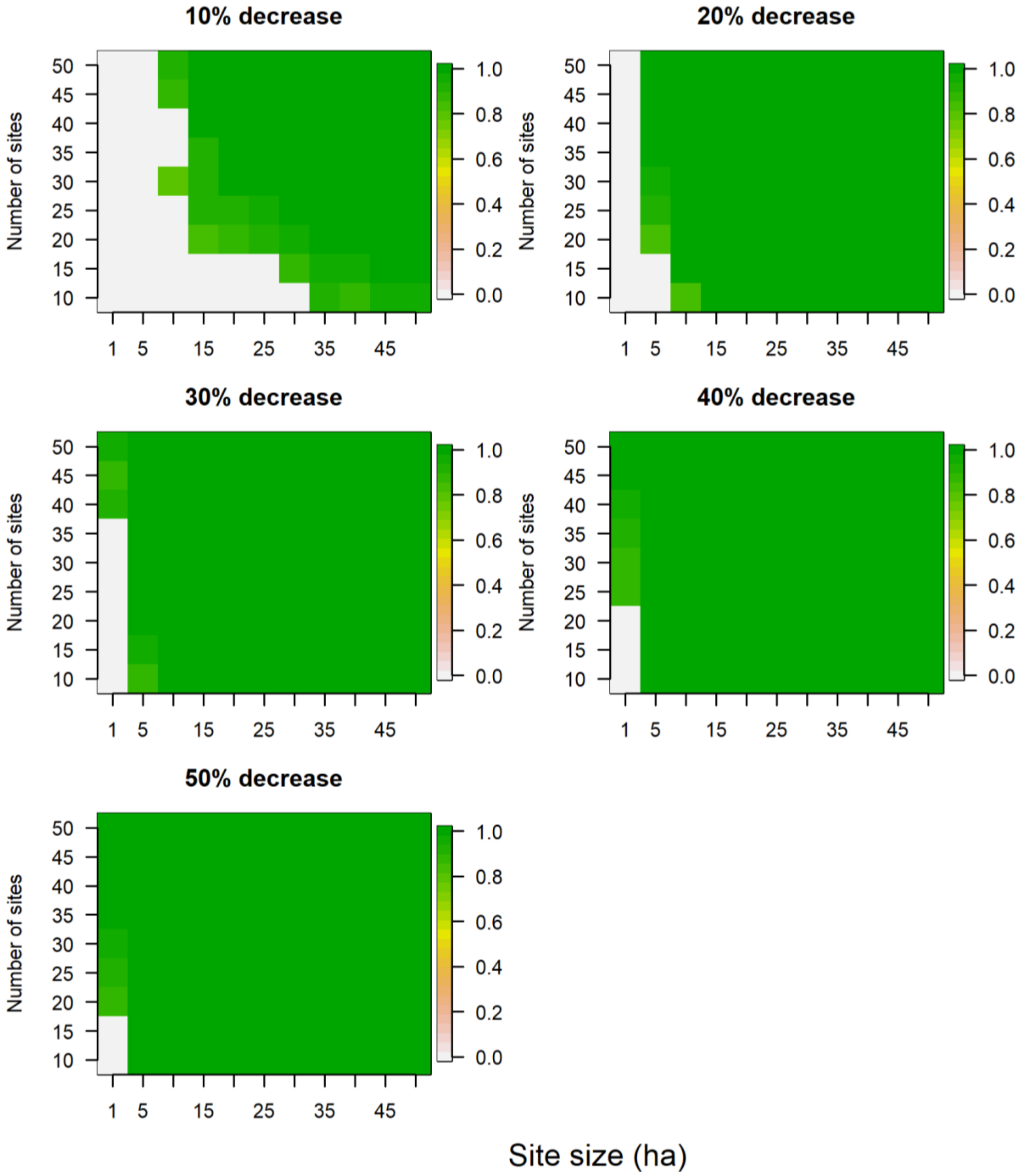

Figure 8-3. Statistical power to detect decreasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis) given burrow densities recorded at Newhaven. The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.

Newhaven Wildlife Sanctuary – increasing trends

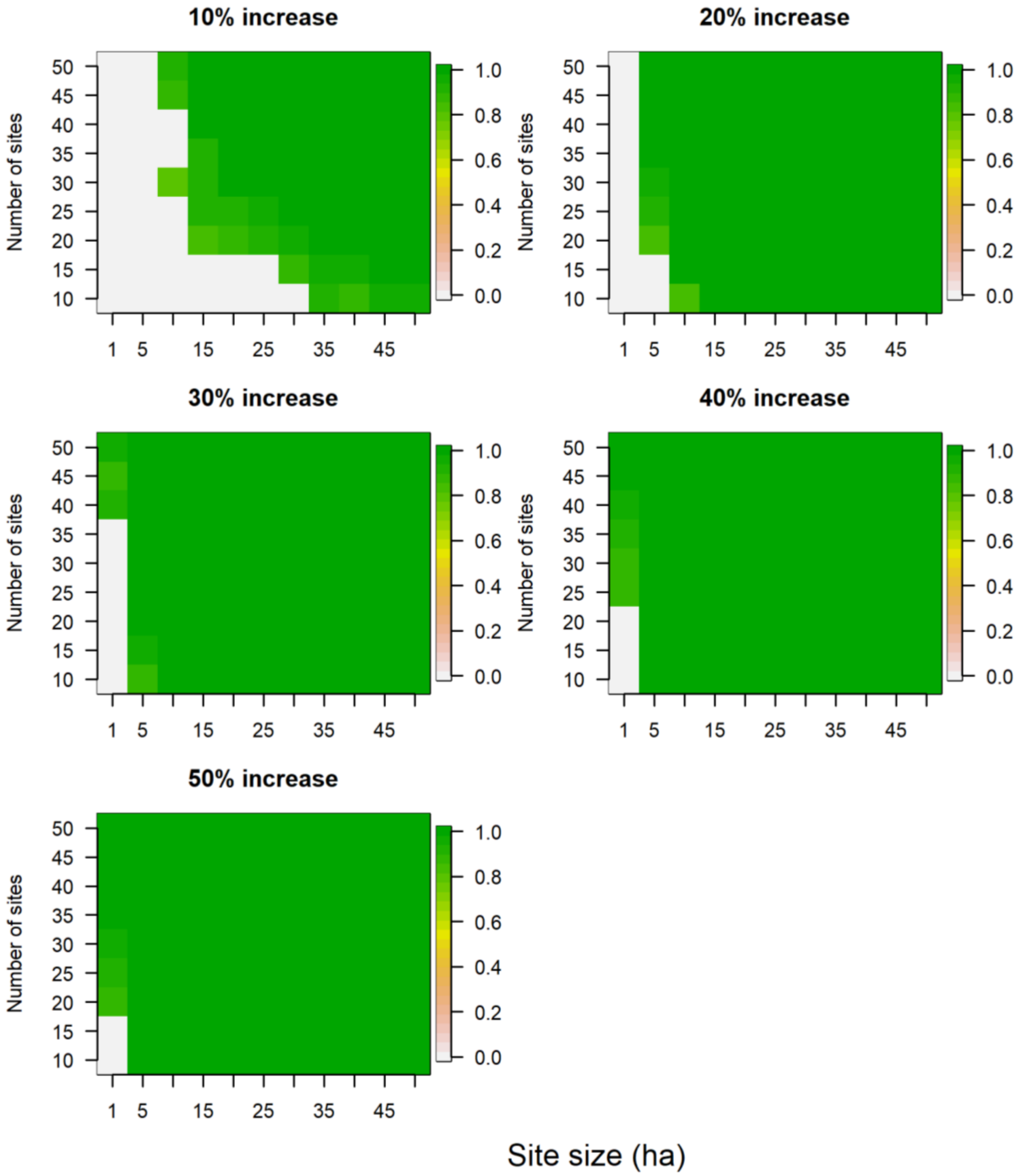

Figure 8-4. Statistical power to detect decreasing trends (10–50%) in burrow activity over the next 10 years for combinations of site size (x-axis) and number of sites (y-axis) given burrow densities recorded at Newhaven. The green shading shows combinations where power exceeded 80%. Combinations with power less than 80% have been shaded white.