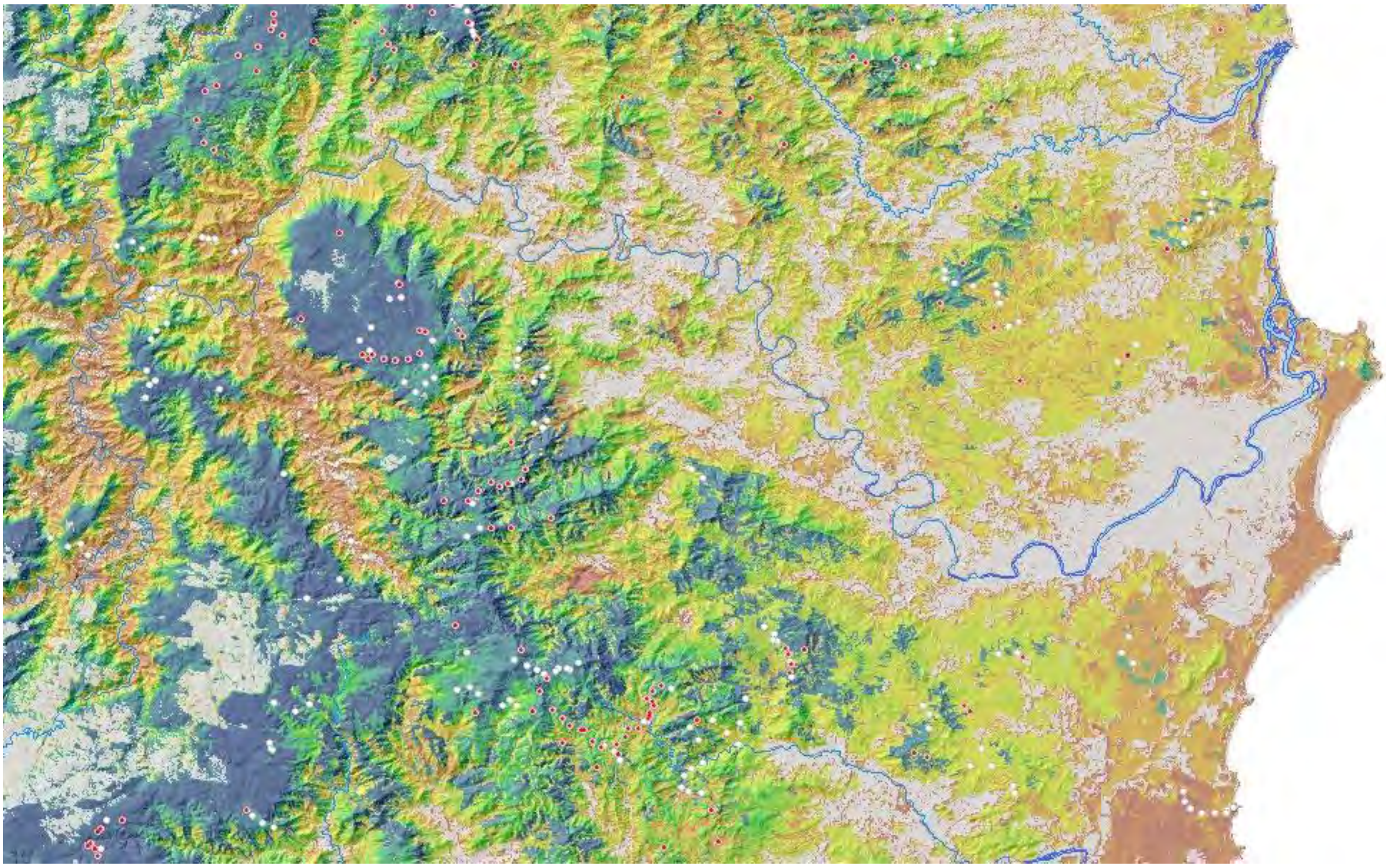

NSW Forest Monitoring and Improvement Program
Final Report

Project 2: Baselines, drivers and trends for species occupancy and distribution

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NSW Forest Monitoring and Improvement Program

Project 2: Baselines, drivers and trends for species occupancy and distribution

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Executive Summary

In the late 1990s, the NSW Government made significant changes to the management of public forest lands in eastern NSW to improve long-term sustainable management and conservation outcomes for forests, including its biodiversity. These changes included the conversion of large areas of state forest to national park for conservation and the formal adoption of new harvesting rules in state forests to limit harvesting and better protect important habitat for threatened flora and fauna. Comprehensive flora and fauna surveys – for example, the Comprehensive Regional Assessments – were undertaken at this time to provide the scientific evidence to guide decision making.

In 2019, the NSW Government established the NSW Forest Monitoring and Improvement Program (the Program) to provide the necessary information to strategically manage outcomes for NSW forests. Under this Program, the NSW Government has also established a specific program to monitor and evaluate the effectiveness of the Coastal Integrated Forest Operations Approvals (Coastal IFOA).

New cross-tenure species monitoring programs are now being piloted under both programs. These provide the first landscape-wide opportunity to evaluate the effectiveness of these significant changes to forest management for conservation.

Using historical data to establish NSW's first landscape-scale baselines for flora and fauna

The Program's cross-agency steering committee, independently chaired by the Natural Resources Commission (NRC), has overseen several projects to build the information base to inform forest management. The current project – *Baselines, drivers and trends for species occupancy and distribution* – resurrected data to establish baselines, drivers of change, and trends in flora and fauna species occupancy and distributions.

The project goals were complex and ambitious, and so a transdisciplinary team was assembled from universities, NSW agencies and the private sector. The team developed a framework for the project by collating and synthesising a range of data and spatial, temporal and analytical techniques (including historical baseline data collation, species occupancy and environmental niche modelling, forecasting, survey gap analysis and power analysis) to establish baselines and context for the new cross-tenure species monitoring programs. This provides a benchmark for the future monitoring program results to be compared and evaluated against.

In doing so, this project recovered disparate historical data sets from comprehensive surveys undertaken in the 1990s, and managed significant data gaps to report on the baseline status for hundreds of vertebrate fauna species and thousands of vascular plant species across four Regional Forest Agreement regions (Upper North East, Lower North East, Southern, Eden).

A significant dataset was collated and analysed

Our work addressed:

- 520 native fauna species (mammals, birds, reptiles and amphibians) and 11 species of introduced mammals
- over 2,800 native vascular plant species, and over 300 introduced plant species.

Species distribution models of various types were developed for:

- nearly 450 fauna species, collected at over 5,700 systematically surveyed sites
- over 170 flora species, collected at nearly 5,250 survey sites.

Many additional non-systematic survey records from the study region were used in environmental niche modelling for fauna and flora species (1991–1998). These baseline models predicted species' habitat suitability during the 1990s. Preliminary projections of landscape capacity and habitat suitability (up to 2070) were developed to demonstrate the likely response to climate change of about 150 species of fauna and flora, respectively.

Occupancy models established, but trend analysis limited by available data

Species occupancy modelling (SOM) provided the most useful metrics for reporting on the status and trends of fauna species, including measures of detectability and occupancy. SOM was undertaken for 28 priority fauna species in the North East RFA region and for 16 of these priority species in the combined Southern and Eden regions, using data from systematic repeat surveys in the 1990s. For example:

- Koala (*Phascolarctos cinereus*) – Koala detectability in the 1990s was low using the listening, call playback and spotlighting methods available at the time (less than 10% probability of detection during a single survey visit). This resulted in an imprecise median occupancy estimate (27% ± 17%) across all public forest lands in North East region. An analysis of recent trends in Koala occupancy in hinterland forests of north-eastern NSW, where surveys targeted their habitat and were based on recordings of Koala calls, provided greater precision and higher estimates of occupancy (averaging 68% ± 7%). This recent trend shows a stable meta-population over the last 5 years, including after fires burnt 30% of Koala habitat in 2019. Based on these data, only 61 sites would need to be monitored (using seven nights of acoustic monitoring) per year in Koala habitat to detect a 30% change in occupancy within 10 years, using these methods.
- Greater Glider (*Petauroides volans*) – Both detectability and occupancy for this species in the 1990s using nocturnal spotlighting surveys were relatively high: detectability ranged from 51% to 75% likelihood of detection after one survey visit and median occupancy between 52% and 62%, depending on the region. Using this baseline information, to detect a 30% change in Greater Glider occupancy over 10 years, at least 200 monitoring sites (visited twice during the same survey period) would be required. Important drivers for Greater Glider occupancy included cooler temperatures at higher elevation, forest type, time since fire and land tenure.

Camera traps were not used in the systematic fauna surveys of eastern NSW forests in the 1990s. However, the project had WildCount camera data from 2012–2016 re-analysed for 155 sites in national parks and nature reserves in the study region.

In decreasing order of occupancy of mammal species, the Feral Cat (*Felis catus*) and Red Fox (*Vulpes vulpes*) were ranked fourth and fifth, respectively, in Southern–Eden forests, and fifth and tenth, respectively, in North East forests. The threat posed by invasive predators to native fauna should be a key focus of future forest monitoring.

The requirement for fauna survey methods to include repeat visits to sites restricted the number of species for which occupancy modelling could be undertaken, because not all methods in the 1990s systematic surveys included repeat visits. However, environmental niche models were useful for modelling historical status and habitat suitability of fauna when the data were inadequate for occupancy modelling. The project produced fit-for-purpose models of habitat suitability for about 340 fauna species. Environmental niche models were also developed for 174 priority flora species. All but one of these models was a good fit to the input data, but only 123 species models were a satisfactory or better fit to known species distributions. This was partly due to the lack of baseline data from the private forest estate and partly to the lack of covariate environmental layers (e.g. soils, topography) accurate at sufficiently fine scale.

Unfortunately, the scarcity of long-term species monitoring programs and regional-scale research programs limited the extent to which species trends could be determined since the 1990s baseline period. However, the proposed monitoring program under the FMIP will provide the necessary data to enable trend analysis for key forest-dependent species into the future.

Climate change and fire will be key drivers of change and a threat to forest-dependent biodiversity

Climatic drivers, particularly several temperature, precipitation and related variables, were important covariates in species occupancy and environmental niche models for most flora and fauna species investigated. For instance, the project identified many potentially climate-sensitive, widespread flora species spanning a range of life-forms (e.g. *Acacia dealbata*, *Alpinina caerulea*, *Asperula scoparia*, *Eucalyptus campanulata*, *E. sieberi*, *Persoonia stradbrokensis*, *Platylobium formosum*, *Platysace ericoides*, *Poa meionectes* and *Sorghum leiocladum*). The species most sensitive to climate change should form a focus of future biodiversity monitoring.

Fire variables were included in most flora and fauna species models to determine if species were associated with either an absence of fire or frequent fire. Maxent flora models incorporated a binary variable (fire recorded or not since 1950). Generalised additive modelling of flora species occurrence incorporated a three-level factor (no fire vs infrequent fire vs frequent fire), and species occupancy modelling of fauna species incorporated two quantitative covariates, Years since Fire and Number of Fires. The project identified hundreds of fire-responsive flora species, including widespread species associated with long-unburnt sites (e.g. *Acacia dealbata*, *A. melanoxylon*, *Acmena smithii*, *Breynia oblongifolia*, *Corymbia intermedia*, *Dichondra repens*, *Eucalyptus tereticornis*, *E. viminalis*, *Oplismenus imbecillis*, *Poa sieberiana* and *Trochocarpa laurina*). At the other extreme, widespread species associated with recent fire included *Allocasuarina littoralis*, *Angophora floribunda*, *Billardiera scandens*, *Eucalyptus agglomerata*, *E. campanulata*, *E. saligna*, *E. sieberi*, *Gonocarpus teucrioides*, *Leucopogon lanceolatus*, *Lomandra multiflora* subsp. *multiflora*, *Persoonia linearis* and *Poa labillardierei* var. *labillardierei*. Fire-responsive species should also form a focus for future biodiversity monitoring.

Fire was a primary driver or correlate for one quarter of all fauna and had a minor association with a further 11% of species modelled. The results of species occupancy modelling for 28 priority fauna species showed that Years since Fire (YSF) was a significant variable associated with the distribution of five species in northern NSW forests: Australian King Parrot (*Alisterus scapularis*), Common Brushtail Possum (*Trichosurus vulpecula*) and Southern Boobook (*Ninox boobook*) exhibited a positive relationship between occupancy and YSF when plotted (i.e. higher occupancy in forests unburnt for more than 20 years), whereas Greater Glider and Varied Sittella (*Daphoenositta chrysoptera*) exhbiited a negative relationship when plotted (i.e. higher occupancy in forests burnt in the preceding 10 years).

The Number of Fires (or CountFire, CF) between 1962 and 1991 was a significant variable associated with the distribution of 10 species: in northern forests, Australian King Parrot, Common Ringtail Possum (*Pseudocheirus peregrinus*), Long-nosed Bandicoot (*Perameles nasuta*) and Noisy Miner (*Manorina melanocephala*) exhibited a positive relationship with CF when plotted, whereas Koala and Varied Sittella exhibited a negative relationship with CF when plotted. In southern forests, Bell Miner (*M. melanophrys*), Brown Treecreeper (*Climacteris picumnus*), Masked Owl (*Tyto* *novaehollandiae*) and Sugar Glider (*Petaurus breviceps*) all exhibited a negative relationship with CF when plotted.

Climate change is expected to exacerbate the freqiuency and severity of fire, which is a major determinant of flora and fauna species occurrence and driver of change. The combined effects of climate change and fire represent the most significant threat to the biodiversity of eastern NSW forests. Concurrently, the biota of eastern NSW eucalypt forests is inextricably dependent on periodic fire. Identifying appropriate fire regimes and managing the shifting mosaic of fires across the forest estate to conserve biodiversity remains a major challenge. Climate projections suggest that potential occupancy of 54 of 78 threatened fauna species and of seven species, in particular (i.e. Rufous Bettong *Aepyprymnus rufescens*, Rufous Scrub-bird *Atrichornis rufescens*, Stuttering Frog *Mixophyes balbus*, Barking Owl *Nixox connivens*, Powerful Owl *Ninox strenua*, Greater Glider *Petauroides volans* and Sooty Owl *Tyto tenebricosa*) will decline by 2070.

For 81 climate-sensitive flora species, the global climate model, MIROC3.2 (version RCM1), in the NARCliM suite predicted that 59% of species will have less medium to high-suitability habitat by 2070 due to climate change, whereas 37% will have more. Given that MIROC3.2 predicts a warmer wetter future climate, and that three other equally likely climate futures are predicted to be hotter or drier or both, this level of predicted change in habitat suitability of climate-sensitive flora species in eastern NSW forests is likely a best-case scenario, at least with regard to increased extremes of heat and drought.

Species differed in their associations with mapped old-growth forest

Modelling showed that the extent of 'Candidate Old Growth' (COG) Forest was significantly associated with the occurrence of priority flora and fauna species in the 1990s. COG mapping was developed as part of the Comprehensive Regional Assessment (CRA) process, which also instigated many of the fauna surveys that informed the occupancy models. Timber harvesting has been permanently excluded from these mapped areas since the early 2000s under revised forestry rule sets. In the absence of a robust historical harvesting layer, the COG spatial layer was used as a surrogate for the reciprocal of harvesting disturbance and to mask out areas that are known to not have had harvesting since the early 2000s.

It is important to note there are significant and known inaccuracies with the COG layer: it includes areas of forest that do not meet the definition of old-growth forest and areas where timber harvesting occurred prior to the early 2000s. Its main value was to indicate areas in the mid 1990s where at least 10% of the forest canopy included senescent trees and less than 10% was even-aged regrowth. As such, caution is necessary in interpreting results when using this dataset especially as a surrogate for historical harvest disturbance. It should also be acknowledged that harvesting practices have changed since the 1990s and areas of additional exclusions have generally increased since that time.

We found few plant species in eastern NSW forests were positively associated with COG and, by inference, few plant species to have been adversely impacted by native timber harvesting up to 2000, although many species were recorded too infrequently for rigorous analysis. Nine rainforest and wet sclerophyll forest species, including three epiphytes, were identified as likely to be sensitive to timber harvesting, despite the absence of harvesting within identified rainforest areas. Most epiphytes can be expected to decline in harvested wet sclerophyll forest due to the loss of large habitat trees; the following species is an example:

- Orange-blossom Orchid (*Sarcochilus falcatus*) – Naïve occupancy of the Orange-blossom Orchid, a semi-pendent epiphyte that inhabits rainforest and wet sclerophyll forest, was low in the northern RFA regions (1.4–6.4%), and even lower in the southern regions. In the baseline period, predicted occupancy in the Lower North East was 92% greater in eucalypt-dominated plots mapped as COG than across all sclerophyll forest plots in the region, and was significantly greater in northern NSW forests not burnt for more than 30 years than in sites burnt within the previous 30 years. Despite the species' high detectability, its low frequency of occurrence meant that a monitoring program capable of detecting a 30% decline in occupancy over 10 years would require 1,785 survey plots. Environmental niche modelling highlighted the species' occurrence in high-rainfall, well-insolated, high-productivity forests with a marked seasonal temperature differential, as well as its association with candidate old-growth forest.

Species occupancy modelling showed that COG was associated with the distribution of seven priority fauna species. In the northern forests, four priority species were positively associated with COG: Glossy Black Cockatoo (*Calyptorhynchus lathami*), Leaden Flycatcher (*Myiagra rubecula*), Mountain Brushtail Possum (*Trichosurus caninus*) and Varied Sittella; and two species were negatively associated with COG in the north: Koala and Powerful Owl. One species was negatively associated with COG in southern forests: Yellow-bellied Glider (*Petaurus australis*). The counter-intuitive results for the hollow-dependent Yellow-bellied Glider and Powerful Owl may be partly due to the large home-ranges of these two species, such that required nesting and denning hollows may be available within unlogged riparian reserves retained within harvested landscapes.

Few trends in fauna occupancy were available for assessment

Since 2000, trends in fauna occupancy or activity that could be modelled, were split between species that remained stable or increased and species that declined, at different times and in different locations. For example, between 1988 and 2011 in the forests south of Eden, the Powerful Owl and Sooty Owl recovered significantly to more than 0.5 occupancy 20 years after several major disturbances (intensive timber harvesting during the 1970s and wildfire in 1980) from a near-zero base in 1988 when monitoring surveys began. During the same period, the Greater Glider declined significantly and did not recover in the survey period. The extent of unlogged forest and lack of recent fire at Eden were the most important influences accounting for species occupancy and rates of recovery or decline following logging and wildfire for most of the nine fauna species studied.

The results of these long-term trend analyses are consistent with the literature that hollow-dependent fauna species are sensitive to timber harvesting, underlining support for appropriate environmental protections and mitigations.

The foundation is laid despite the challenges

Throughout this project, considerable challenges were faced, including the lack of repeat visits in most fauna surveys and a tenure bias toward public rather than private forest; the poor quality of environmental covariate data in the 1990s, especially disturbance history and threats; and the difficulties of accessing and massaging historical survey data into a usable form.

The complexity and ambition of the project also presented a number of issues, including synthesising disparate expertise (e.g. occupancy modelling and environmental niche modelling and projections) for such a large number of species; modelling across both space and time; inconsistent survey data by species; and uncertainty in relation to climate projections. The lack of systematic regional surveys since the 1990s resulted in a lack of suitable trend data for almost all species.

The project identified a number of important opportunities, including modelling species occupancy for many common fauna species using the data resurrected by this project. Ideally, this modelling should use upgraded and newly developed environmental covariate layers, which address significant disturbances (e.g. fire and logging), additional threats (e.g. invasive species) and anticipated climate extremes.

There is also a significant opportunity for new species monitoring programs to use the 1990s baseline data to report against the status of species before the advent of major climate change and before the 2019–20 ('black summer') bushfires. This would provide the opportunity to fulfil the intentions from the 1990s regional forest agreements to assess and evaluate forestry impacts on species in NSW forests over the past 25 years.

Recommendations

Future monitoring should use, where possible, a broader set of fauna survey methods than camera traps, song meters and ultrasonics (which do not detect all priority species, notably most reptiles, many high priority mammals, and some diurnal raptors), and repeat surveys should be conducted over several days during each sampling period. Additional survey methods will be costly but could target specific species and in selected areas (e.g. spotlighting for Greater Glider). It will be impractical to monitor priority fauna species if their detectability or occupancy is too low, regardless of survey method. Further, power analysis and survey gap analysis should inform the selection of species for monitoring and optimised design of the monitoring networks.

We also recommend that new fauna survey technologies should be further developed (e.g. call recognisers, image recognition) and calibrations made between these new methods and those used in the 1990s. New covariate layers are needed for fauna and flora modelling, including better disturbance histories (extent and severity of logging and fire), the density of large old hollow-bearing trees, and the occurrence or density of invasive species (e.g. introduced predators, herbivores, pathogens and domestic livestock grazing).

We strongly recommend that forest monitoring begins as soon as possible, especially of priority species and including those most at risk from climate change and fire regime changes, as identified above. Adequate and ongoing resourcing of forest monitoring is needed to provide continuous data streams and best-practice data management, analysis and reporting mechanisms. The number of historical species models (SOM and, for plants, ENM) should be expanded to include common species that may already be declining, or could decline in future, due to climate change and other threats. This modelling effort should include an expanded set of climate projections.

Finally, the designs of the Forest Monitoring and Improvement Program and the Coastal IFOA monitoring program should be integrated. The Coastal IFOA program can be designed to serve both surveillance monitoring purposes and to answer questions about the impact of land management using an adaptive management framework.

Project Summary

At the request of the NSW Premier, the Natural Resources Commission (NRC) is overseeing the design, implementation, review and continuous improvement of the NSW Forest Monitoring and Improvement Program (FMIP) with a cross-agency and expert steering committee. The geographical scope of the FMIP is to support the ecologically sustainable management of the more than 20 million ha of all NSW forests on public and private land, including forests in national parks, state forests, plantation forests, private native forestry, and forests on private and Crown land (NRC 2019).

As part of the FMIP, the NRC is also overseeing a monitoring program to ensure the ongoing effectiveness of the Coastal Integrated Forestry Operations Approvals (IFOA) in achieving its objectives and outcomes. The geographical scope of the Coastal IFOA is confined to state forest and other Crown-timbered land in the North East (Upper North East and Lower North East), Southern and Eden Regional Forest Agreement (RFA) regions. The overall objective of the FMIP is to improve the evidence base for decision making for forest management across all tenures. This will be done by linking monitoring, evaluation, research and reporting to decision making for policy and on-ground management of NSW forests.

As part of the process, the NRC sought existing information about species baselines, drivers of change, and trends in species occupancy and distributions so that monitoring program results can be compared and evaluated. Historical benchmarks for species occupancy, particularly those developed in relation to landscape characteristics and disturbance history, will provide a useful point of reference for assessing the results of contemporary species monitoring programs. The program commissioned UNE and a team of experienced forest ecologists and data analysts to interrogate the most comprehensive datasets available for NSW forests, which include several large state-owned datasets covering the four NSW RFA regions for fauna (> 5,000 sites) and flora (> 5,000 sites) that were collected in 1990–1998 (fauna) and 1987–2000 (flora) to provide this '1990s' baseline information.

Cross-tenure conceptual framework

A conceptual framework is provided that summarises certain key properties, disturbances and dynamics that structure eucalypt-dominated forested ecosystems and communities in eastern NSW. Forest floristic types are primarily determined by abiotic environmental factors, principally precipitation, temperature, soil type and topography (e.g. aspect). Six forest structural states are proposed that represent the main forest condition classes in forest landscapes in eastern NSW, each of which supports a characteristic assemblage of fauna and flora species. The frequency and severity of fire and harvesting and time since the last disturbance event are the main factors responsible for transitioning one forest structural class to another. However, many other factors, both biotic (e.g. predation by cats and foxes) and abiotic (e.g. the increasing number of heatwaves associated with climate change, and the destructive influence of severe drought followed by high-intensity fire), are known to significantly affect fauna and flora species assemblages, with or without changes in forest structural states. The main environmental variables accounting for the distribution of fauna and flora species at regional scale are discussed. Data layers that encapsulate these drivers have been sourced and have been used to model species occupancy, distribution, trends in occupancy (where available) and abundance (see below); and potentially predict changes in species occurrence due to climate change or altered management. However, data layers for some drivers were not available in the 1990s, for example, the abundance of foxes and cats, and their development is flagged as a priority for future monitoring.

Baseline datasets available for analysis

A major part of the project has been the significant effort required to acquire, collate and interrogate the fauna baseline information, the associated metadata and survey methodologies, for species and survey sites in the north-east and south-east forests. Multiple datasets, each at regional scales, were available for analysis. In total, this amounted to 5,719 sites where 520 native fauna species were recorded using systematic methods. In addition, flora data were available for 2,808 native and 327 introduced plant species recorded at 5,248 sites in forested areas across all four RFA regions, a significant proportion of which were either spatially coincident with, or in close proximity to, fauna survey sites.

Fauna priority species list

A list of 140 priority fauna species (53 mammals, 37 birds, 32 reptiles and 18 frogs) was proposed for particular investigation for establishing 1990s fauna baselines in this project, and potentially to be closely tracked in future fauna monitoring programs. This list was derived using multiple criteria, including a consideration of the species' ecological characteristics, sensitivity to disturbance and other factors, legislative status, state conservation priorities, regional distribution and abundance, and whether the species can be detected reliably using a range of proposed survey methods. Most species did not meet all of these criteria but were included because they either scored highly on certain criteria or they were relatively common examples within species functional groups. Species relevant to one or more of the four RFA regions are listed. Many of the species scored poorly in terms of their likelihood of detection using remote cameras, song meters and bat detectors, suggesting that a wider range of survey methods may be required if they are to be monitored (though cost-effectiveness is an important consideration here).

Flora priority species list

A list of 192 flora priority taxa (191 species including two subspecies) were identified on the basis of modelled sensitivity to harvesting, fire, and changing climate, their likely susceptibility to pathogens, and, in the case of introduced species, their potential importance as environmental weeds. Vascular plant species are less subject to errors in species detection during plot-based surveys than is the case for fauna where species detectability is usually a significant problem. Consequently, 'naïve' species occupancy or plant species cover-abundance scores are normally used in analysis of flora datasets. Also, flora data are typically analysed as species assemblages or plant communities rather than as individual species. A combination of these two approaches was used to analyse flora data in this project, but given the project brief, we have only reported the results of the species analyses.

Survey methods summary

The report summarises the range of survey methods that were used to collect the fauna and flora species information that is provided in each dataset. While there was a broad consistency in the survey methods used for each dataset, there were differences in the sampling effort that was expended for some methods and, in particular, whether repeat visits were made to each site. Such variations in methods were considered when modelling species occupancy and for comparisons with future monitoring with potentially different methods. However, many species were recorded too infrequently for analysis, in part because some survey methods performed poorly in detecting species due to the way in which they were implemented (i.e. lack of repeat visits) rather than to any fundamental deficiencies in the survey methods themselves.

Naïve occupancy and survey methods comparisons

Naïve occupancy estimates (i.e. proportion of total sites surveyed where a species was recorded) are presented for about 500 fauna species that were recorded during systematic survey counts in all four RFA regions. Similar data are presented for about 2,820 (native and introduced) plant species. Of particular note is the relatively large number of fauna priority species that were not reliably detected using any of the 'standard survey and monitoring methods' that are proposed for use in the planned FMIP and Coastal IFOA biodiversity monitoring programs. This includes most of the reptiles on the list and several of the highest priority mammal and bird species (e.g. Platypus *Ornithorhynchus anatinus*, Brush-tailed Phascogale *Phascogale tapoatafa*, Squirrel Glider *Petaurus norfolcensis*, Greater Glider *Petauroides volans*, Mountain Brushtail Possum *Trichosurus caninus*, Common Ringtail Possum *Pseudocheirus peregrinus*, Feathertail Glider *Acrobates pygmaeus*, Eastern Pygmy Possum *Cercartetus nanus*, Gould's Long-eared Bat *Nyctophilus gouldii*, Lesser Long-eared Bat *Nyctophilus geoffroyi*, Golden-tipped Bat *Phoniscus papuensis*, Hastings River Mouse *Pseudomys oralis*, Grey Goshawk *Accipiter novaehollandiae* and Square-tailed Kite *Lophoictinia isura*). While important, the fauna results need to be interpreted carefully due to the effects of imperfect detection on presumed absence.

Covariates available for analysis

A large number of potential covariates was informed by our forest conceptual model and many of these covariates were available for use in species modelling. These covariates were sourced largely from DPIE, as listed in SEED (https://datasets.seed.nsw.gov.au/dataset/svtm-modelling-grid-collection). Some covariates (e.g. tenure) had to be compiled from other sources (i.e. 1991 State Forests of NSW mapping). Standard sets of covariates were used to develop species models.

Survey gap analysis

The Survey Gap Analysis Tool was applied to evaluate the regional representation of sites that were surveyed for fauna and flora during the 1990s baseline period throughout all four RFA regions. This analysis showed that the environmental space present in national parks and state forests has been better sampled than private native forests (PNF) and Crown forest lands (CFL). PNF and CFL are likely to include environmental space that is very poorly sampled (under-represented) in the large corporate data sets under analysis for species occupancy in this project.

Modelling approaches

Naïve occupancy is usually a significant underestimate of faunal species occupancy because it takes no account of species detectability during surveys. Occupancy modelling is a statistical method that improves species occupancy estimates by taking imperfect detection into account where repeat visits surveys to a site using the same survey method enable this to be done. Since such data were not always available, environmental niche modelling was also undertaken to describe habitat suitability for each species, although this does not lead to improved estimates of species occupancy. Each method has its advantages and limitations. Occupancy modelling of 1990s data can account for the effect of different fauna survey methods, allowing for comparisons with future occupancy estimates that may be based on new survey methods, whereas environmental niche modelling is well suited for incorporating climate variables that can be projected into the future.

Fauna species occupancy models

Occupancy modelling was undertaken for 28 priority fauna species in North East (i.e. Upper North East and Lower North East) region using data from systematic repeat surveys in the 1990s (Table A).

Table A. Baseline results from species occupancy modelling of priority fauna in northern (N) and southern (S) NSW forests

Fauna surveys were conducted from 1991–1998 (1990s) or from 2000–2018 (2000s), and systematic survey methods are described later in the report (Section 6.1.1): NOCPB = nocturnal listening, call-playback and/or spotlighting. Opport = opportunistic records. Covariates (described in detail in Section 6.1.4): AI = Annual Insolation; AR = Annual Rainfall; AWC = Available Water Capacity; COG = Candidate Old Growth Forest; CTI = Wetness Index; DFS = Distance from Stream; DPR = Driest Period Rainfall; DSGF = Dry Sclerophyll Grassy Forest; DSSF = Dry Sclerophyll Shrubby Forest; DSSGF = Dry Sclerophyll Shrub–Grass Forest; ECL = Extent of Cleared Land; Evap = Mean Annual Evapotranspiration; FC = Fire Count; Fert = Soil Fertility; GW = Grassy Woodland; MAT = Mean Annual Temperature; NDVI = Normalised Difference Vegetation Index; NP = National Parks; NRF = Non-Rainforest Vegetation; PP = Private Property; RF = Rainforest; RS = Rainfall Seasonality; SF = State Forests; TR = Topographic Roughness; TS = Temperature Seasonality; WSGF = Wet Sclerophyll Grassy Forest; WSSF = Wet Sclerophyll Shrubby Forest; YSF = Years Since Last Fire. The ^{Q} superscript indicates a significant quadratic relationship

Common name	Region	Survey method, period	Detectability	Occupancy	Positive covariates	Negative covariates
Australian King-Parrot	N	Diurnal Bird, 1990s	0.47	0.81	FC^{Q}, NDVI^{Q}, RS^{Q}, YSF	Evap^{Q}
	S	Diurnal Bird & Opport, 1990s	0.12	0.71	Evap, NDVI	DFS, YSF^{Q}
Bell Miner	N	Diurnal Bird, 1990s	0.75	0.28	CTI^{Q}, NDVI^{Q}, TR, TS^{Q}	AR, COG, DFS, MAT^{Q}, SF
	S	Diurnal Bird & Opport, 1990s	0.41	0.001	–	AR^{Q}, FC^{Q}, TS^{Q}, WSSF
Barking Owl	N	NOCPB, 1990s	0.02	0.004	Evap^{Q}, MAT	NDVI
Brown Treecreeper	N	Diurnal Bird, 1990s	0.47	0.004	Evap, TS, DFS^{Q} DSSF, MAT^{Q}	AR
	S	Diurnal Bird & Opport, 1990s	0.24	0.02	–	AI^{Q}, AR, FC^{Q}
Common Brushtail Possum	S	NOCPB & Spotlighting, 1990s	0.33	0.28	–	–
Common Ringtail Possum	N	NOCPB, 1990s	0.43	0.12	AI^{Q}, FC^{Q}, NP, TS^{Q}	AWC^{Q}, CTI^{Q}, MAT^{Q}, TR
Eastern False Pipistrelle	N	Ultrasonics, 2000s	0.55	0.13	–	MAT
	S	Harp Trap, 1990s	0.38	0.85	DPR, RF, Evap	AI, MAT
East-coast Freetail Bat	N	Ultrasonics, 2000s	0.45	0.18	MAT	–
Glossy Black-Cockatoo	S	Diurnal Bird & Opport, 1990s	0.30	0.03	MAT	DPR^{Q}, NDVI^{Q}, NP, WSGF
Golden-tipped Bat *	N	Harp Trap, 1990s	0.22	0.26	–	–
Greater Glider	N	NOCPB, 1990s	0.75	0.52	AWC^{Q}, Evap^{Q}, MAT^{Q}, NRF, SF, YSF^{Q}	AR, DPR, NDVI^{Q}, TR^{Q}
	S	NOCPB & Spotlighting, 1990s	0.51	0.62	AI, AR^{Q}, CTI, DPR^{Q}, RS^{Q}	MAT^{Q}, TS^{Q}
Grey-crowned Babbler	N	Diurnal Bird, 1990s	0.54	0.003	AI^{Q}, MAT	NDVI^{Q}, NP
Koala	N	NOCPB, 1990s	0.09	0.27	DPR^{Q}, Evap^{Q}, MAT, NDVI, WSSF	COG, FC, RS
Leaden Flycatcher	N	Diurnal Bird, 1990s	0.30	0.54	AI, COG^{Q}, MAT^{Q}, NRF, TR	CTI, NDVI, NP
	S	Diurnal Bird & Opport, 1990s	0.01	0.57	–	DPR
Long-nosed Bandicoot	N	NOCPB, 1990s	0.10	0.62	Evap, DFS, FC^{Q}, NDVI, RF, TS	AR^{Q}, MAT^{Q}
Masked Owl	N	NOCPB, 1990s	0.11	0.25	DPR^{Q}, WSGF	Evap^{Q}, NDVI
	S	NOCPB & Spotlighting, 1990s	0.44	0.07	MAT^{Q}, FC^{Q}, NP	DPR^{Q}

Common name	Region	Survey method, period	Detectability	Occupancy	Positive covariates	Negative covariates
Mountain Brushtail Possum	N	NOCPB, 1990s	0.26	0.27	COG, CTI, NDVI^{Q}, RF, RS	Evap, SF
Noisy Miner	N	Diurnal Bird, 1990s	0.48	0.04	Evap, FC^{Q}, MAT, TS^{Q}	NDVI^{Q}, NP
Powerful Owl	N	NOCPB, 1990s	0.16	0.56	COG^{Q}, Evap, DFS	AI^{Q}, AR^{Q}, AWC^{Q}, CTI^{Q}, MAT, PP, TR, TS^{Q}
	S	NOCPB & Spotlighting, 1990s	0.11	0.58	–	AR^{Q}
Satin Flycatcher	N	Diurnal Bird, 1990s	0.41	0.09	NRF, RS^{Q}, TS	CTI^{Q}, MAT
	S	Diurnal Bird & Opport, 1990s	0.35	0.37	DPR, MAT^{Q}	CTI^{Q}, AR^{Q}, TR^{Q}
Sooty Owl	N	NOCPB, 1990s	0.13	0.68	AWC^{Q}, NDVI	AR^{Q}, DFS, DSSGF, MAT^{Q}, RS^{Q}, TR^{Q}
	S	NOCPB & Spotlighting, 1990s	0.01	0.13	–	TS
Southern Boobook	N	NOCPB, 1990s	0.26	0.60	AI^{Q}, DSSF, Evap^{Q}, MAT^{Q}, NDVI, WSGF	AR^{Q}, DPR, TR^{Q}, YSF^{Q}
	S	NOCPB & Spotlighting, 1990s	0.51	0.80	DPR, RS, TS	NDVI^{Q}, NP
Sugar Glider	N	NOCPB, 1990s	0.30	0.71	Evap	DFS, NDVI^{Q}, RF, RS, TR
	S	NOCPB & Spotlighting, 1990s	0.77	0.99	CTI, MAT, RS^{Q}	AI^{Q}, AR^{Q}, AWC, DFS, FC, TS^{Q}
Yellow-bellied Glider	N	NOCPB, 1990s	0.34	0.39	Evap^{Q}, DPR^{Q}, NDVI, SF	AI^{Q}, AR, DFS, GW, MAT^{Q}
	S	NOCPB & Spotlighting, 1990s	0.73	0.17	AWC, DSGF, MAT^{Q}, RS^{Q}, TS^{Q}	AI^{Q}, COG
Yellow-bellied Sheathtail Bat	N	Ultrasonics, 2000s	0.58	0.05	ECL, MAT, Fert	AR, TR

* Covariate information not available

Occupancy modelling was also undertaken separately for 16 of these 28 priority species in the combined southern region (Southern and Eden). All other priority species had no or too few surveys with repeat visits to model.

Results from individual species occupancy modelling included estimates for species detection probability based on the survey methods used, probability of occupancy after accounting for detection, influential covariates (Table A) and maps of predicted occupancy (Appendix 7). Plausible estimates of detection and occupancy were modelled for most of these species as reflected by the precision of the estimate, but spatial predictions of occupancy were considered unreliable for six species. As an example, using dataset-specific detection probability for Greater Glider, median occupancy probability across the range of conditions surveyed for the species was 0.52 ± 0.05 in northern NSW forests, indicating that the species could be expected to occur on approximately 52% of surveyed sites. Occupancy was higher or lower in specific areas depending on the conditions in those forests. This median estimate provides a 1990s baseline for Greater Glider occupancy across the sites surveyed in the forests of the combined northern RFA regions.

Detection probability can be used with power curves to estimate the number of sites required for robust monitoring if the survey method is proposed for use in the future. Estimates of occupancy (and their error) account for imperfect detection and so provide the baseline estimate for forests in the 1990s that can be used to provide context for future monitoring.

Environmental niche models (ENMs) for fauna

Fauna environmental niche models (ENMs) were fitted with Maxent to 444 of the 470 fauna taxa that were recorded in various databases as occurring in the four RFA regions that were the focus of this project during the 1990s. The remaining 26 taxa could not be modelled due to very low numbers of occurrence records remaining after the spatial and temporal filters specified for the project were applied. The quality of the successfully fitted models ranged from excellent (i.e. Test Area Under the receiver operating Curve, or Test AUC = 0.99) to poor (Test AUC = 0.59).

Our expert team reviewed 441 of the Maxent fauna models to determine if they were a good fit to contemporary understanding of the range and habitat suitability of each species in the study region. Some 77% of models were judged satisfactory or better, with reptile models judged more harshly (71% of models judged satisfactory or better) than mammal models (85%). Bird (76%) and amphibian (77%) models were rated in between.

Environmental niche models (ENMs) for flora

ENMs in Maxent were produced for 174 species of the 192 priority flora taxa, the remaining taxa having too few records to model. All but one of the 174 species generated statistically robust models (Test AUC > 0.75), but only 123 species models (71%) reflected the respective species' distributions based on all *Australian Living Atlas* (ALA) occurrences, due to the baseline spatio-temporal filter applied to records. As an example of a satisfactory Maxent flora model, the model for Blackbutt (*Eucalyptus pilularis*) used 886 sites selected from the 452 sites from systematic surveys and 832 ALA points. The model was statistically robust (Test AUC = 0.902 ± 0.010, mean ± s.d.), highlighting the coastal distribution of *E. pilularis* in NSW and being a fair representation of all known occurrences of the species as well as of the input points used in the modelling.

Projecting fauna and flora models into future climates

Environmental niche modelling is well-suited to the projection of the modelled distributions of fauna and flora species into future climates, and, in conjunction with Rapid Evaluation of Metapopulation

Persistence (REMP) modelling, the application of additional spatial constraints (e.g. minimum patch size, habitat connectivity, dispersal capacity) can help to estimate species persistence in the landscape and potential future occupancy. Climate projections of 81 climate-sensitive priority flora species and seven priority fauna species are presented in this report, to demonstrate the potential of species projection modelling to guide the continuing design of the FMIP and Coastal IFOA monitoring programs. The outcomes of the modelling of the seven fauna species were similar to the results for a larger group of 78 fauna species. The modelling suggested that most native fauna and flora species will be disadvantaged under climate change and a minority advantaged. We recommend that climate projection modelling be ramped up to guide survey design, with a focus on those zones where the most susceptible species will come under stress and where it will be most important to safeguard climate refugia and their concentrations of climate-sensitive species in future.

Trend analyses

Example trends are presented to illustrate different approaches for monitoring trends over time and the dynamic nature of trends as populations recover from major disturbance events such as fire and timber harvesting. Occupancy modelling of trend data was found to be a powerful approach to account for imperfect detection, which is a common problem with fauna survey data. Occupancy monitoring typically relies on sampling many sites (50–100 per region) to capture changes at a meta-population or regional scale. This approach is well-suited to methods that include repeat visits to sites over a short period of time, such as camera trapping, passive acoustics and ultrasonic monitoring.

The trend analyses highlighted that use of a single year as a baseline is fraught; rather, averaging over a number of years is likely to better represent a range of conditions. ‘Baseline’ occupancy estimates presented in this report combine multiple datasets from forest surveys in the 1990s and so satisfy these criteria and could be used for a number of species as a broad baseline to provide context for future monitoring. Overall, the great variety in trends of different species illustrate the importance of capturing data on individual species and the inadequacy of using simpler surrogates, such as indices, to describe such varied trends.

Recommendations

Recommendations are made to assist aspects of the design and implementation of the new forest biodiversity monitoring programs in NSW. These include a discussion of the ways in which species occupancy estimates can be used to evaluate the results obtained in future monitoring programs, and suggestions to improve the capacity of monitoring programs to obtain meaningful results for a range of conservation-priority species:

- *The objectives and complementarity of the FMIP and Coastal IFOA monitoring program designs* should be clarified. Both monitoring programs are intended for surveillance of significant trends in species relative abundance and distribution in NSW forests. However, the Coastal IFOA species monitoring program provides an opportunity to go beyond surveillance monitoring by incorporating management questions into the design. These could be achieved using a variety of approaches, including a paired compartment design in which species monitoring sites are located within areas subject to harvesting that are contrasted with nearby areas that are not (e.g. within adjacent national park). The Coastal IFOA species monitoring program also provides an opportunity to include survey methods that are more appropriate for priority species of forestry interest that are not well surveyed using the standard methods that are likely to be applied in the FMIP species monitoring program.

- *Appropriate expertise is required to model occupancy*, spatial predictions of occupancy and its trends. This project has also highlighted the value of expertise in forest ecology and fauna species when undertaking and interpreting such modelling.
- *Occupancy estimates for fauna species* from this project can be used in two ways: first, a mean occupancy estimate provides an overview of species occupancy probabilities for average conditions at sites surveyed in the 1990s. These data provide an important context for comparisons with future monitoring results, given the comprehensive 1990s database that has been compiled and analysed for this project, and which accounts for detection probability of different survey techniques. Second, a spatial surface of occupancy for each priority species with sufficient data in the 1990s provides an additional point of reference for future monitoring. Future occupancy surfaces can be subtracted from the 1990 surface to identify where decreases or increases in occupancy have occurred.
- Use of both detection and occupancy estimates were formalised in *power analyses*, and these should be used as a guide for designing future monitoring programs.
- For those species in which 1990s surveys lacked repeat visits, *ENMs provide spatial representations* of potentially suitable habitat based on records collated from the 1990s. However, it was clear, upon examination of the filtered data for both fauna and flora that the '1990s baseline' and the geographical focus on eastern NSW forests did not do justice to our full knowledge of the occurrence for some species, resulting in suboptimal models. We recommend that these models be rerun to utilise all the current occurrence information available, with an updated array of new explanatory covariates. ENMs can also be used to identify putative areas of refugia from disturbances, including climate change. From the perspective of the forest monitoring program, ENMs combined with REMP can help to identify both refugia and areas where populations are likely to be exposed to stress due to disturbances such as fire, timber harvesting, invasive species and climate change. A third way in which ENMs can be expanded to inform a forest monitoring program is to stack the habitat suitability maps for all taxa. The resulting maps provide for visualisation of the regions where populations of multiple species may be subject to stress: these maps can be referred to in the monitoring planning process to help improve the efficiency of program design.
- *Survey gap analysis* shows that more confidence can be placed in the species occupancy estimates for national parks and state forests in this project than those for private native forests and Crown forest lands, because far fewer survey sites were located in these last two land tenure categories. This deficit should be rectified in the proposed FMIP.
- *Climate projections* revealed the potential of climate change to drastically reduce the capacity of NSW forests to support valued fauna and flora. Modelling of 78 fauna species, including seven priority species, and of 81 climate-sensitive priority flora species indicated that most species will suffer a reduction in landscape capacity or habitat suitability by 2070 simply due to changing climate. It is strongly recommended that any future design, monitoring and analysis includes a significant climate projection component.
- The accuracy and resolution of the existing suite of *covariates can be improved* using conventional approaches and new remote-sensing equipment, including airborne and

satellite-derived information. There is also a need to continually improve the statistical basis for spatial modelling. The potential to enhance current covariates and develop related and new environmental covariates is large.

Project outputs and products

The project produced the following outputs and resources, which may be of interest to researchers, managers and administrators:

Fauna

- List of 140 priority species of mammal, bird, reptile and amphibian for monitoring future fauna occupancy in eastern NSW forests (Table 1)
- List of naïve occupancies of 494 species of mammal, bird, reptile and amphibian in eastern NSW forests based on various field survey techniques employed by systematic fauna surveys undertaken between 1991 and 1998 (Table 22)
- Survey gap analysis of 1990s systematic fauna survey sites (Tables 18 & 19, Figure 12)
- Survey gap analysis of 2012–16 WildCount forest survey sites (Tables 18 & 21, Figure 12)
- Species occupancy models for 18 mammal and bird species in northern NSW forests based on data collected from 1991–98 (Table 25, Appendix 7a)
- Species occupancy models for 16 mammal and bird species in southern NSW forests based on 1991–98 records (Table 25, Appendix 7b)
- Species occupancy models for four bat species in northern NSW forests from 2003–18 (Table 25, Appendix 7c)
- Environmental niche models in Maxent for 442 mammal, bird, reptile and amphibian species from 1991–98 (Table 26, Appendix 10)
- Climate projections of landscape capacity for seven mammal, bird and frog species in the years 2030 and 2070 based on 2000 baseline environmental niche models (Table 34, Appendix 8)
- Seventeen trend analyses of selected mammal, bird and frog species at various times from 1988–2019 in various parts of the eastern NSW forests (Table 36, Section 7.4)
- Species occupancies of 24 mammal, bird and reptile species in northern NSW forests from 2012–16, based on re-analysis of WildCount data from the NSW national park estate (Table 38, Appendix 9)
- Species occupancies of 16 mammal and bird species in southern NSW forests during the period 2012–16, based on re-analysis of WildCount data from the NSW national park estate (Table 38, Appendix 9).

Flora

- List of 191 priority species of vascular plant for monitoring future flora occupancy in eastern NSW forests (Table 3)

- List of naïve occupancies of 2,808 native and 11 introduced flora species based on systematic surveys undertaken in eastern NSW forests between 1987 and 2000 (Appendices 5a & 5b)
- Survey gap analysis of 1987–2000 systematic flora survey sites (Tables 18 & 20, Figure 12)
- Results of generalised additive modelling of sensitivity of 2,808 native species to the candidate old growth forest layer and fire variables in each RFA region in eastern NSW forests between 1987 and 2000 (Table 24, Appendix 6a)
- Results of median and percentile climate analysis of 993 native species to determine potential sensitivity to climate change (Table 3, Appendices 6b & 6c)
- Maxent models of habitat suitability of eastern NSW forests in 1987–2000 for 174 priority flora species (Table 31, Appendix 11a)
- Climate projections of habitat suitability of eastern NSW forests in 2030 and 2070 for 81 native species based on 2000 baseline models in Maxent (Table 35, Appendix 11b).

Other data

An extensive set of electronic resources, input data and outputs of the project have also been collated and forwarded to the NRC.

Maps of the covariate layers used in species modelling are provided in hard copy in Appendix 12.

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List of Appendices

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The list of Appendices is as follows:

Appendix 1. Fauna taxonomy and nomenclatural alignment, 1990–recent

Appendix 2. Flora taxonomy and nomencatural alignment, 1990–recent

Appendix 3. Baseline survey methods (EIS, NEFBS, CRA)
- Appendix 3a. CRA survey methods
- Appendix 3b. EIS survey methods
- Appendix 3c. NEFBS survey methods

Appendix 4. Investigation of impacts of spatio-temporal filtering on Environmental Niche Models

Appendix 5. Flora naïve occupancy
- Appendix 5a. Native flora naïve occupancy
- Appendix 5b. Introduced flora naïve occupancy

Appendix 6. Flora disturbance factors and climate sensitivity
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Appendix 7. Species Occupancy Models (SOM)
- Appendix 7a. Baseline (1990s) UNE–LNE (Northern RFA) SOM
- Appendix 7b. Baseline (1990s) Southern and Eden RFA regions (Southern RFA) SOM
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Appendix 8. Summary reports for Persistence in the Landscape Project (PLP) Maxent fauna models

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Appendix 10. Summary reports for Maxent fauna models

Appendix 11. Summary reports for Maxent flora models
- Appendix 11a. Baseline (1990s) flora model reports
- Appendix 11b. Flora climate projections (NARCliM)

Appendix 12. Maps of the covariate layers used in species modelling
- Appendix 12a. DPIE Baseline covariate maps (1 arc-second ~30 m)
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List of Species Products

The project produced many outputs and species models using a range of analytical and modelling methods. The species models, products and reports are summarised here, and the locations where the various outputs can be found are indicated.

Fauna

Output or modelling approach	No. of species considered	No. of species for which outputs were produced	Location of information
Priority fauna list (multi-criteria assessment)	All terrestrial vertebrate species in E NSW forests	140 species	Table 1
Naïve occupancy by RFA region and survey method	494 mammal, bird, reptile & amphibian species (497 taxa) based on systematic surveys between 1991 and 1998	494 species	Table 22
Species occupancy models	50 mammal & bird species based on 1991–98 records in N NSW	18 mammal & bird species models	Table 25, Appendix 7a
Ditto	50 mammal, bird and frog species based on 1991–98 records in S NSW	16 mammal & bird species models	Table 25, Appendix 7b
Ditto	4 bat species based on 2003–18 records in N NSW	4 models	Table 25, Appendix 7c
Environmental niche models – Maxent	468 mammal, bird, reptile & amphibian species (470 taxa) based on 1991–98 records in E NSW	442 models	Table 26, Appendix 10
Environmental niche models – Boosted Regression Tree	427 mammal, bird, reptile & amphibian models based on 1991–98 records in E NSW	Models for 252 species (281 species × survey-method models)	Table 29 (reports not publicly available)
Climate projection models – Maxent with NARCliM climate covariates	7 mammal, bird & frog models based on NSW records up to 2020	7 models	Table 34, Appendix 8
Trend analyses – mostly Dynamic occupancy modelling but some activity and count time-series analyses	17 mammal, bird & frog accounts based on 1988–2019 records in various parts of E NSW	17 mammal, bird & frog accounts	Table 36, Section 7.4
Species occupancy models – re-analysis of WildCount data	39 mammal, bird & reptile species based on 2012–16 records in N NSW	Results for 23 mammal, bird & reptile species	Table 38, Appendix 9
Ditto	39 mammal, bird & reptile species based on 2012–16 records in S NSW	Results for 16 mammal & bird species	Table 38, Appendix 9

Flora

Output or modelling approach	No. of species considered	No. of species with satisfactory outputs	Location of information
Priority flora list	2,808 native species (2814 taxa) & 327 introduced species (332 taxa)	191 species selected	Table 3
Naïve occupancy (sample frequency)	2,808 native species (2814 taxa)	2,808 species	Appendix 5a
Naïve occupancy (sample frequency)	11 introduced species (12 taxa)	11 species	Appendix 5b
Generalised additive models – sensitivity to candidate old growth	2,808 native species (2814 taxa)	26 species selected	Tables 3 & 24, Appendix 6a
Generalised additive models – sensitivity to fire variables	2,808 native species (2814 taxa)	40 species selected	Tables 3 & 24, Appendix 6a
Median and percentile analysis of species climate records to determine sensitivity to climate change	933 species (with > 25 occurrences)	90 species selected	Table 3, Appendices 6b & 6c
Environmental niche models – Maxent	191 species (192 taxa)	174 species models	Table 31, Appendix 11a
Climate projections from 2000 to 2030 and 2070 in Maxent	81 native species	81 species model projections	Table 35, Appendix 11b

1. Introduction

National parks and nature reserves are the principal means of ensuring the conservation of biodiversity in NSW, but other land tenures, in particular the publicly owned state forests of NSW, also make a significant contribution. However, there are no comprehensive measures in place to track the contributions to nature conservation and the effectiveness of land management activities in most NSW conservation reserves and state forests, and how these public lands compare to each other and to other land tenures. Designating lands as protected areas does not ensure that biodiversity will be adequately conserved for the future. Many threats, known and unknown, continue to operate within, and around, protected areas. A framework is needed for identifying the most important biodiversity 'assets' and 'threats' that may be operating within protected areas and on other land tenures so that their status can be measured and reported on, and management effectiveness can be assessed and improved.

The context for national and international reporting about changes in the condition and extent of Australia's forests, including their use for multiple benefits and contributions to biodiversity conservation, is grounded in the Rio Convention on Biological Diversity that was developed during the 1992 Earth Summit. The ensuing Montreal Process Agreement that was signed in 1995 (Santiago Declaration) by 12 countries, including Australia, described a basis for consistent reporting on the State of Australia's forests. This required measurement and reporting on seven criteria (including Criterion 1: Conservation of Biodiversity) and 44 indicators (including nine relating specifically to biodiversity). To date, the information required to report against these biodiversity indicators has been lacking from all jurisdictions, such that reporting on important indicators of Ecologically Sustainable Forest Management (ESFM), such as Indicator 1.2c *'Representative species from a range of habitats monitored at scales relevant to regional forest management'*, have not been possible or limited only to isolated, local case studies (https://www.agriculture.gov.au/abares/forestsaustralia/sofr/sofr-2018/criterion1).

The context for region and state reporting are the bilateral agreements (Regional Forest Agreements) between the Australian Government and four state governments. These long-term agreements are intended to provide for the sustainable management and conservation of Australia's forests and their biodiversity. The NSW Government and the Australian Government have recently revised and renewed until 2039 the three regional agreements in NSW (Eden, Southern and North East Regional Forest Agreements; previously four, as the Upper North East [UNE] RFA and the Lower North East [LNE] RFA have been combined). These renewals require a strengthened commitment to ecologically sustainable forest management in each region, including more comprehensive outcomes-focused reporting and improved accountability. The location of the regional agreements, and the focus of this report, is shown in Figure 1.

The NSW Natural Resources Commission (NRC) has been tasked by the Premier to independently oversee and advise on the implementation of a state-wide monitoring, evaluation, reporting and improvement program for NSW forests. The Forest Monitoring and Improvement Program (FMIP) has the objective of linking monitoring, evaluation, research and reporting to decision making for policy and on-ground management of NSW forests. It is intended to improve the evidence base for decision making for forest management across tenures, and to strengthen the NSW Government's ability to strategically and adaptively manage forests over time, including state forests, national parks, private native forests and Crown forested land.

The 'state-wide' forest monitoring program established within the FMIP framework will include a status and trend monitoring program for focal or priority species. A complementary, more targeted, forest fauna and flora monitoring program will also be implemented concurrently on state forest under the NSW Coastal Integrated Forestry Operations Approvals (Coastal IFOA) agreement that will establish a 'question-based', trend monitoring program to strengthen the evidence base for improved, ecologically sustainable forest management practices. Data from both forest monitoring programs will contribute to the 5-yearly review and reporting obligations of NSW to the Australian Government under the revised Regional Forest Agreements. The data will also support other state and national forest/environmental reporting obligations, including the NSW State of the Environment report, the Australian State of the Environment report and, crucially, the Australian State of the Forests (SOF) report.

A permanent, cross-tenure, network of plots (sites) at which a range of attributes is recorded (vegetation, water, soil, remotely-sensed data, and fauna) will form the basis for the FMIP program monitoring assessments. These permanent monitoring sites, to be established from 2021, will be drawn from a representative sample of up to 1,000 sites that are stratified by tenure (national park, state forest, private native forest, other Crown land), regional forest agreement area (Upper North East, Lower North East, Southern, Eden), IBRA region (10 categories), vegetation classes (50 Keith classes), and distributed across areas with forest cover having > 20% foliage projective cover at > 2 m above ground. The locations for these permanent monitoring sites have yet to be finalised.

As part of the process, the FMIP requires existing information to identify expectations about species baselines, drivers of change, and trends in species occupancy and distributions so that monitoring program results can be compared and evaluated. A collaboration of experienced forest ecologists and data analysts has been funded to interrogate several large state-owned data sets for fauna (> 2,000 sites) and flora (> 5,000 sites) that were collected in 1991–1998 and 1987–2000, respectively, to provide this '1990s baseline' information.

This report proposes a conceptual framework that summarises existing knowledge and beliefs about the key properties, disturbances and dynamics that structure forested ecosystems and communities in NSW and influence the occupancy and distribution of species. It provides a list of priority fauna and flora species that should be the subject of particular investigations for species modelling purposes and also closely tracked in future monitoring programs. The report collates and tabulates the list of baseline (1990s) datasets and covariates available for species occupancy modelling, along with a summary of the survey methods that were used to collect this information. Survey methods vary in cost and efficacy in detecting particular species, and future monitoring programs will have to weigh up the costs and benefits of employing different methods.

Naïve occupancy estimates are presented for approximately 500 fauna species and for more than 2,800 plant species. These data indicate the baseline frequency of occurrence of plant and animal species in eastern NSW forests in the 1990s (i.e. how widespread or rare a species was at that time), unadjusted for each species' detectability. Naïve occupancy is used in this report to identify the best survey-method datasets for modelling the occupancy of a given fauna species: the survey method yielding the greatest naïve occupancy for a species was the dataset used for occupancy modelling of that species. Naïve occupancy should be treated cautiously because it does not account for imperfect detection, which is a well-known problem in fauna surveys, although it is of lesser importance in flora surveys. Occupancy modelling is a statistical method that takes imperfect detection into account where repeat surveys enable this to be done. In this report, the results of species occupancy modelling for 28 priority fauna species are presented along with the results for 446 fauna species using two other statistical approaches (Maxent and Boosted Regression Trees) to predict the distribution of potentially suitable habitat for these species (termed environmental niche modelling). A similar approach using Maxent was also undertaken to model the distribution of 174 priority flora species to predict habitat suitability across the nominated RFA regions during the 1990s. Trends in species occupancy since the 1990s are presented for a range of priority fauna species, based on the results of several local-area research projects. The drivers of change of the trends in these species as well as the impact of timber harvesting and fire on priority flora species, and on fauna and flora more generally, are reviewed and discussed. Long-term climate projections of the distribution of potentially suitable habitat are presented for 81 flora species regarded as climate-sensitive. Recommendations are made to assist aspects of the design and implementation of the new forest biodiversity monitoring program in NSW.

Figure 1. The four RFA regions in eastern NSW

Upper North East and Lower North East are now combined in one region (North East)

2. Objectives and scope

2.1 Aims and objectives of FIMP Project 2: Baselines, drivers and trends for species occupancy and distribution

At the request of the NSW Premier, the Natural Resources Commission (NRC) is overseeing the design, implementation, review and continuous improvement of the state-wide Forest Monitoring and Improvement Program (FMIP). As part of the FMIP, the NRC is also overseeing a monitoring program to ensure the ongoing effectiveness of the Coastal Integrated Forestry Operations Approvals in achieving its objectives and outcomes. The geographical scope of the FMIP is to support the ecologically sustainable management of the more than 20 million ha of all NSW forests on public and private land, including forests in national parks, state forests, plantation forests, private native forestry, and forests on private and Crown land (NRC 2019). The geographical scope of the Coastal IFOA is confined to state forest and other Crown-timbered land in the North East (UNE and LNE), Southern and Eden Regional Forest Agreement (RFA) regions.

As part of the FMIP, the project team led by Dr Rod Kavanagh, Dr Michael Drielsma, Dr Brad Law and Professor Nick Reid (through the University of New England) was commissioned to deliver baselines, drivers and trends for fauna and flora species occupancy and distribution under the two distinct monitoring programs:

- Forest Monitoring and Improvement Program
- Coastal IFOA monitoring of landscape-scale trends.

The project commenced on 29 July 2020 and contractually concluded on 30 June 2021. The objectives of the project were to deliver for forest under all tenures in the North East (UNE and LNE), Southern and Eden RFA regions:

1. A cross-tenure **conceptual framework** of drivers and threats to forest biodiversity.
2. A list of **key species** (and rationale) for consideration in the project.
3. Metrics **including landscape-scale metrics** that describe historic and current state of species occupancy and distribution.
4. Maps of **species distributions** and tables of **naïve species occupancies** in the 1990s in each RFA region.
5. **Species occupancy models** incorporating species detectability and key spatial data layers – **baseline** (1990s) and **trends** (subsequent decades) in species occupancy if repeat sampling data were available.
6. Species detectabilities using **different survey methods.**
7. **Power** of each sampling method to detect changes in species occupancy as a function of number of sites surveyed.
8. **Environmental niche models** (using species incidence data) in relation to available spatial data, including climate and the biophysical environment.
9. **Recommendations** about competing approaches for determining species baselines, the role of habitat surrogates, and the key drivers affecting species occupancy and occurrence.

The full set of contracted deliverables is shown in Box 1 (over page).

Box 1. The contracted set of deliverables for the Forest Monitoring and Improvement Program Baseline Project 2: Baselines, drivers and trends for species occupancy and distribution

1. Collate species data. Locate data sets, and make sure the data are in correct format for occupancy analysis. Also, review, summarise and tabulate the methods used to originally collect the data.
2. Collate key spatial data layers. Obtain copies of these spatial layers for subsequent analyses. Also, summarise and tabulate the methods used to collect this information, the resolution at which they apply, and a description of the categories in each spatial layer.
3. Cross-tenure conceptual framework. Develop models of drivers and threats to forest biodiversity. Identification of key species for consideration in the project. Determine metrics for monitoring of key species indicators and proposed landscape-scale metrics that best describe historic and current state of species occupancy and distribution within RFA regions. Identify existing data sets that are available for analysis. Review species baselines, drivers and trends in species occupancy and distribution that may already be available.
4. Plot/tabulate species distributions. Calculate naive species occupancy rates in each RFA region. Identify any major associations between species and habitat/environmental variables or management treatments.
5. Species occupancy modelling. Incorporate species detectability and model species occupancy in relation to several key spatial data layers. Estimate trends in species occupancy if repeat sampling data are available across more than 10 years. Calculate species detectability using different survey methods.
6. Power calculations relevant to future monitoring. Calculate power to detect changes in species occupancy for each sampling method as a function of number of sites surveyed. Prepare power curves for individual projects.
7. Environmental Niche Modelling. Model species distribution (using naïve occupancy and relative abundance) in relation to the full range of available spatial data, including climate and habitat connectivity. Role of regional species probability surfaces in determining trends in species abundance/occupancy and distribution.
8. Evaluate competing approaches for determining species baselines. Role of habitat surrogates.
9. Identify key drivers affecting species occupancy and distribution.
10. Final report. Baseline occupancy values for a range of species from 20–30 years ago. Indicators most useful for monitoring; expected range for species abundance or frequency of occurrence; threats and likely major impacts to long-term conservation of key focal species; recommended framework for monitoring the proposed indicators (species and habitat); power to detect species as a function of the number of sites surveyed; and trends in occupancy for long-term projects.

3. Cross-tenure conceptual framework

3.1 Literature review

Australia's extinction crisis is among the worst in the world, with terrestrial mammals being the most affected (Chapman 2009; Woinarski *et al.* 2015). Cats (*Felis catus*) and foxes (*Vulpes vulpes*) are the main drivers of this process, but habitat loss, inappropriate fire regimes, introduced herbivores, hunting, and climate change are important contributing threatening factors (Martin *et al.* 2012; Woinarski *et al.* 2015; Legge *et al.* 2018; Radford *et al.* 2018). Species that are extinct in the wild in NSW include, for example, the Numbat (*Myrmecobius fasciatus*), Greater Bilby (*Macrotis lagotis*), Bridled Nail-tail Wallaby (*Onychogalea fraenata*) and Brush-tailed Bettong (*Bettongia penicillata*), all of which are highly susceptible to predation by introduced cats and foxes and which have now been successfully reintroduced to some areas of NSW after these predators have been removed and excluded (Legge *et al.* 2018; Radford *et al.* 2018).

Forested ecosystems have not yet suffered species extinctions to the same degree as arid and semi-arid or woodland environments in Australia (Martin *et al.* 2012; Woinarski *et al.* 2015), but there are concerns that logging practices combined with other factors, in particular climate change (Mac Nally *et al.* 2009), may change this situation. Prolonged drought, heatwaves, and extensive wildfires (all exacerbated by climate change) constitute significant threats to biodiversity (Lunney *et al.* 2017). For example, the 2019–2020 (black summer) bushfires were more extensive and severe than previous wildfires, burning 49% of the native forests in NSW nature conservation reserves and 47% of the native forests in NSW state forests (Boer *et al.* 2020; Davey and Sarre 2020; DPIE 2020a; Collins *et al.* 2021), resulting in a potentially devastating impact on the state's biodiversity (Ward *et al.* 2020; Wintle *et al.* 2020). A key question remains whether areas excluded from harvesting for environmental reasons, in combination with the national park estate, are sufficient to protect forest biodiversity in NSW.

The NSW Forest Monitoring and Improvement Program framework requires land managers to review the available biodiversity resource information for each tenure and to identify priorities for monitoring. The following adage is true: 'You can't manage anything if you don't measure it', but it is impossible to measure everything. So, it is important to identify the key conservation **assets** and **threats** to them within each forested region, and measure changes in their abundance or extent (Noss 1999; Bunnell and Dunsworth 2010).

Conservation assets may include:

- species of special significance within a particular region;
- iconic species more generally;
- species that are representative of particular ecological niches or functional roles;
- species that are threatened or sensitive to particular ecological processes or management practices (e.g. Kavanagh *et al.* 2004);
- endangered ecological communities, and
- World Heritage Areas and the outstanding universal value contained therein.

Threats to these assets may include:

- introduced predators (e.g. feral cats and foxes);
- introduced herbivores (e.g. rabbits *Oryctolagus cuniculus*, goats *Capra hircus*, pigs *Sus scrofa*, cattle *Bos taurus*, horses *Equus caballus*);

- inappropriate fire regimes;
- habitat loss, degradation and fragmentation (e.g. clearing for agriculture, timber harvesting, weeds);
- direct human impacts (e.g. hunting, vehicle collisions), and
- climate change.

A similar biodiversity monitoring framework, which was developed by the Australian Wildlife Conservancy (Kanowski *et al.* 2018), has been operating successfully in two NSW national parks (Mallee Cliffs National Park and the Pilliga State Conservation Area/Pilliga National Park) over the past 5 years. Other complementary biodiversity monitoring programs exist in NSW parks (e.g. WildCount) and in state forests (e.g. Pilliga Biodiversity Monitoring Program), but these are more limited in scope (e.g. they use fewer sampling methods for a more limited range of species). The Forest Monitoring and Improvement Program is proposing to monitor fauna species using three remote survey techniques (i.e. cameras, song meters, bat detectors) to maximise cost-effectiveness. However, these methods will not detect some high-priority species (e.g. Greater Glider *Petauroides volans*), for which nocturnal, on-site visits are required.

A contrast in approach is required for monitoring fauna or flora. In part, this is due to a focus on species-level metrics (occupancy, abundance) in the case of fauna compared to community-level multi-species approaches, including plant functional groups, which are more common in flora monitoring programs. Species detectability is a major consideration in the design and analysis of fauna monitoring programs because animals are mobile and often cryptic, compared to rooted plants. Consequently, while both animals and plants can be recorded in the same sampling plot or site, there is little certainty that most animal species that are present in the local landscape will be recorded in the plot or site at the time of survey, unlike plants. This means that a range of fauna sampling methods are required to detect all species of interest and, crucially, these methods must be applied on several occasions (days/visits) to estimate detectability and to use this information when estimating occupancy.

3.1.1 Framework components: ecosystem states and drivers for species occupancy and distribution

Climatic drivers (particularly precipitation and temperature) but also topography (e.g. the influence of aspect and position in the landscape on solar radiation and local soil moisture impacts) and soil quality determine forest structure and composition. Forest structure includes variations in the canopy cover of the overstorey (e.g. closed rainforest vs more open eucalypt-dominated forest, and forest vs woodland) and understorey (e.g. herbaceous vs shrubby vs subcanopy tree layers). Forest composition includes differences in rainforest type (subtropical vs warm-temperate vs cool-temperate rainforest) and in the dominant canopy and subcanopy species in eucalypt forests and in the species associated with dry versus mesic and grassy versus shrubby understoreys. The natural and anthropogenic disturbance regime further modifies these environmentally determined forest types, producing a wide variety of successional ecosystem states, in various (e.g. early vs late successional) stages of recovery. Alternatively, anthropogenic disturbance may propel forest stands into new novel trajectories, or retard and arrest succession.

In pre-European times, natural (wildfire) and Aboriginal cultural burning would have been the primary determinants of different forest ecosystem states producing medium and fine-grained spatial granularity or patterning, respectively. In the past 234 years, European-related disturbances (timber harvesting, vegetation clearance, burning, hunting, wildland recreation and vehicular movements), invasive species (introduced predators such as foxes and cats, introduced weeds and the root-rot fungus, *Phytophthora cinnamomi*), climate change (increasing temperatures and frequency of extreme drought and storms), and the increased frequency of extreme wildfire and natural disturbances (such as drought-mediated dieback in eucalypt forests), have produced a much greater variety of forest ecosystem states of varying ecological condition and integrity, including states of far coarser granularity (i.e. greater extent, such as the extensive forest 'destruction' or resetting of the forest successional clock to time zero across vast areas of forest, associated with the recent 2019–2020 bushfires).

In recent times, the critical disturbance-related drivers of forest integrity and condition are the changes in climate (increased temperatures and extreme events such as droughts, storms and wildfires), the fire regime (fire intensity, season and extent), forest clearing and fragmentation, timber harvesting severity and extent, invasive species (foxes, cats, domestic and feral herbivores – cattle, goats, horses, deer, pigs, lagomorphs – introduced weeds such as Lantana *Lantana camara*, and pathogens such as Myrtle Rust *Austropuccinia psidii* and Phytophthora), the impact of these drivers on flora and fauna habitats (e.g. the loss and reduction of species, habitat connectivity, hollow trees, coarse woody debris, moist refugia, and of scattered, localised vulnerable habitats such as upland swamps and bogs), and consequent escalation in the decline and loss of forest plant and animal species.

The 'baseline' for species occupancy against which future results can be compared in a broad-scale forest biodiversity monitoring program will vary depending on region, vegetation composition and structure, disturbance history and contemporary climate.

3.1.1.1 Ecosystem states

In forested environments, the main ecosystem states of interest are forest structure (condition) and extent following significant stand altering events (logging, fire) at the local scale (i.e. within the surrounding 1 km radius, or ~314 ha). Each of these states is likely to have a characteristic assemblage of fauna and flora species and an expected range of abundance for certain species. Faunal species assemblages are likely to differ in their proportions of species that are representative of different ecological niches, including species that are dependent on hollows in old trees for breeding or shelter, species that nest on or near the ground, species that forage on resources that are found primarily in the forest canopy (e.g. arboreal granivores, folivores, insectivores, carnivores, nectarivores, frugivores), species that forage on resources that are found primarily on or near the ground (e.g. terrestrial granivores, grazers, browsers, insectivores, carnivores, fungivores), and species that forage on resources that are found primarily in dense vegetation (e.g. folivores, browsers, insectivores, nectarivores, frugivores).

At least six successional ecosystem states can be recognised in the context of eastern NSW hardwood-dominated forests, with the following characteristics:

1. Old-growth Forest:
    - Patch sizes more than 20 ha (> 250-m radius) within a 1-km radius
    - Large hollow-bearing trees (> 10 per ha) within these patches
    - Coarse woody debris including one or more large fallen trees per ha
    - Canopy cover 30% or more
    - Undisturbed by timber harvesting or fire.
2. Old-growth Forest, confined mainly to riparian zones, steep slopes, or as scattered old trees among largely regrowth forest (as per minimum Regional Forest Agreement management requirements):

- Large hollow-bearing trees (> 5/ha, on average)
- Coarse woody debris including one or more large fallen trees per hectare, on average.

3. Old Regrowth Forest following timber harvesting or fire:
   - Heavily disturbed 30 or more years ago
   - Large hollow-bearing trees (< 5/ha, on average)
   - Coarse woody debris including three or more large fallen trees per hectare, on average.

4. Young Regrowth or Planted Native Forest following timber harvesting or fire:
   - Even-aged forest less than 30 years old
   - Large hollow-bearing trees (< 1/ha, on average)
   - Coarse woody debris including less than one large fallen tree per hectare, on average.

5. Woodland:
   - Similar to Old-growth Forest, but canopy cover less than 30%.

6. Disturbed Woodland following partial clearing, logging, fire and/or grazing:
   - Either greater tree-stem density than Woodland, or a reduction in cover of native trees and shrubs
   - Increased cover of introduced shrubs and/or herbs in the ground layer.

3.1.1.2 Key environmental drivers for the distribution and abundance of fauna species

The forest structural characteristics of these ecosystem states set limits on the suitability of the habitat for many species, noting some species are disturbance-dependent and others prefer long-undisturbed forest. However, each of these ecosystem states can be subdivided by vegetation composition, region and climate (i.e. temperature, rainfall). The main factors responsible for driving changes, or transitions between these ecosystem states, are the frequency and severity of fire and logging disturbances. Strong local effects (e.g. plant death and tree dieback) can also be caused by drought, storms, herbivorous insects, arboreal marsupials, pathogens such as Phytophthora and Myrtle Rust (Old *et al.* 1980; Makinson *et al.* 2020), despotic honeyeaters (e.g. Bell Miner, *Manorina melanophrys*; Wardell-Johnson *et al.* 2005) and lack of fire (Reid and Yan 2000; Jurskis 2005).

Other biotic and abiotic factors are becoming increasingly recognised as drivers exerting a strong influence on species abundance and assemblage composition, even though they may not directly result in changes to the forest structural states described above. For example, climate change is resulting in extended periods of hotter, drier weather extremes in many environments, which is already leading to the collapse of some regional fauna populations (e.g. Lunney *et al.* 2017; Smith and Smith 2020; Wagner *et al.* 2020). Similarly, introduced predators (foxes and cats) are now understood to have played a significant role in the regional and national extinctions of many critical weight range mammals in Australia (Woinarski *et al.* 2015), regardless of ecosystem states and conditions.

Large-scale studies of the relationships between hundreds of fauna species and their environments are rare in Australia. However, those that have attempted this provide important insights into the main factors responsible for structuring ecological communities.

One important case study by Kavanagh and Stanton (2005) examined the relationships between species occurrence (227 species: 52 mammals, 126 birds, 40 reptiles, 9 frogs) and nine environmental variables measured at each of 487 sites in north-eastern NSW (Figure 2).

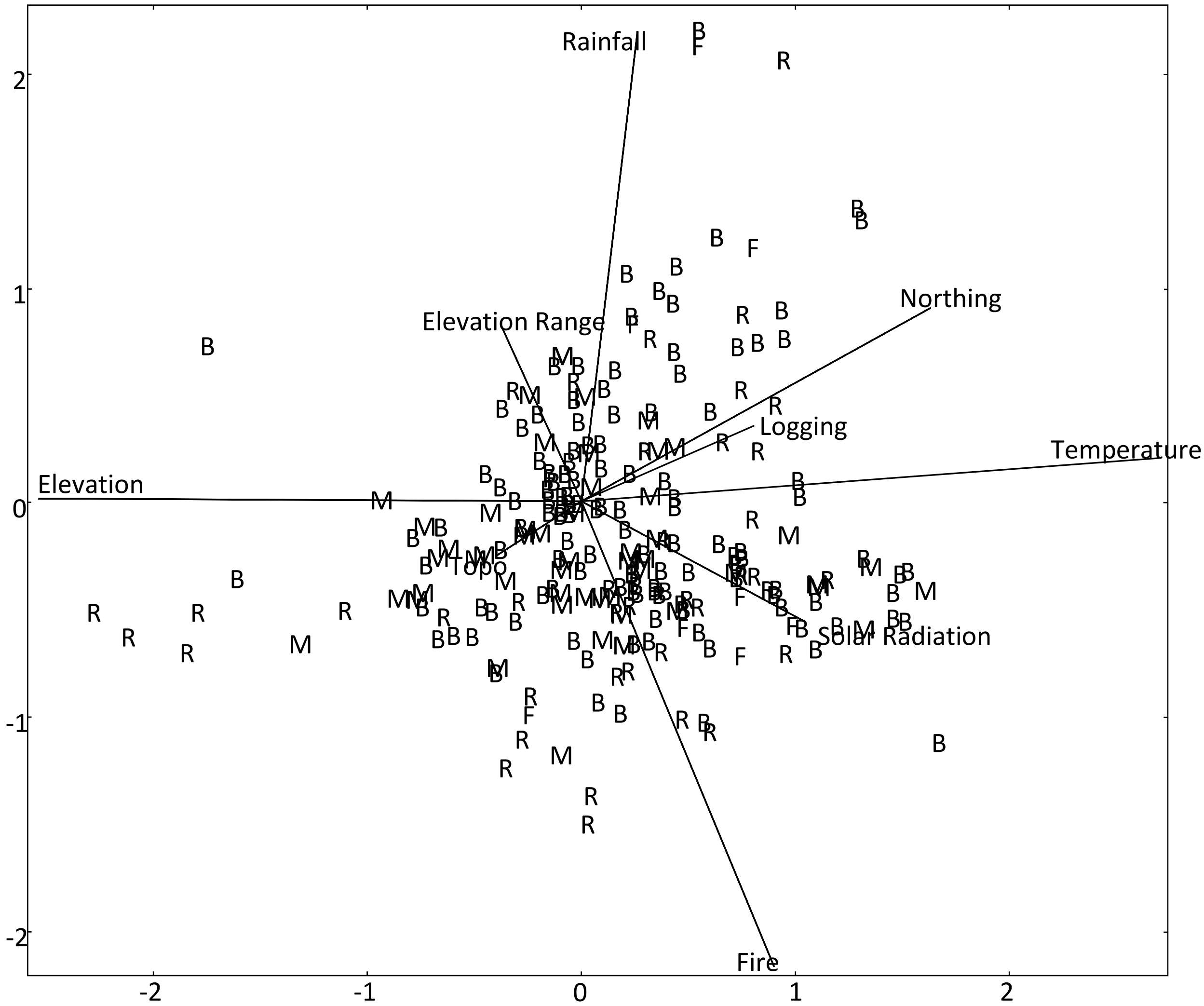

Figure 2. Patterns of fauna species relations with environmental variables in north-eastern NSW forests

Patterns of species relations for 227 species with nine environmental variables measured at each of 487 sites, summarised using canonical correspondence analysis (CCA) (M: mammals; B: birds; R: reptiles; F: frogs). Species names are displayed in Figure 5 in Kavanagh and Stanton (2005)

They found that:

- **elevation** and **temperature** (which were inversely related) were the most important variables structuring forested ecological communities and, together, formed the most important gradient (coast to mountain ranges) accounting for the distribution of forest vertebrates in north-eastern NSW;
- **rainfall** and **fire history** were also important variables and, together, represented a gradient from the wetter to the drier forest types in the region;
- **latitude** (northing) was important, reflecting a north–south gradient and the increased frequency of occurrence of many species in the northern (sub-tropical) half of the region;
- **solar radiation**, **logging intensity**, **elevation range** and **topographical position** had contributing but less important effects on the distribution of species in north-eastern NSW.

Many species displayed strong associations with one or more of these key environmental gradients in the region (Figure 2). The two main forest disturbances, logging and fire, appeared to have different and independent effects on forest fauna assemblages, with many species displaying positive or negative associations with these two factors (Kavanagh and Stanton 2005).

A similar approach was undertaken by Kavanagh *et al.* (1995) who examined the relationships between 16 nocturnal forest bird and mammal species and 17 environmental variables measured at 290 sites in north-eastern NSW. Again, the key drivers of species abundance (and occupancy) were elevation, forest type, forest structure (including understorey density, the number of trees with hollows suitable for breeding and shelter, and tree basal area), logging history and fire history. Topographical position, latitude and aspect of the survey sites were also influential but had a less significant role in structuring of the nocturnal forest fauna community (Figure 3).

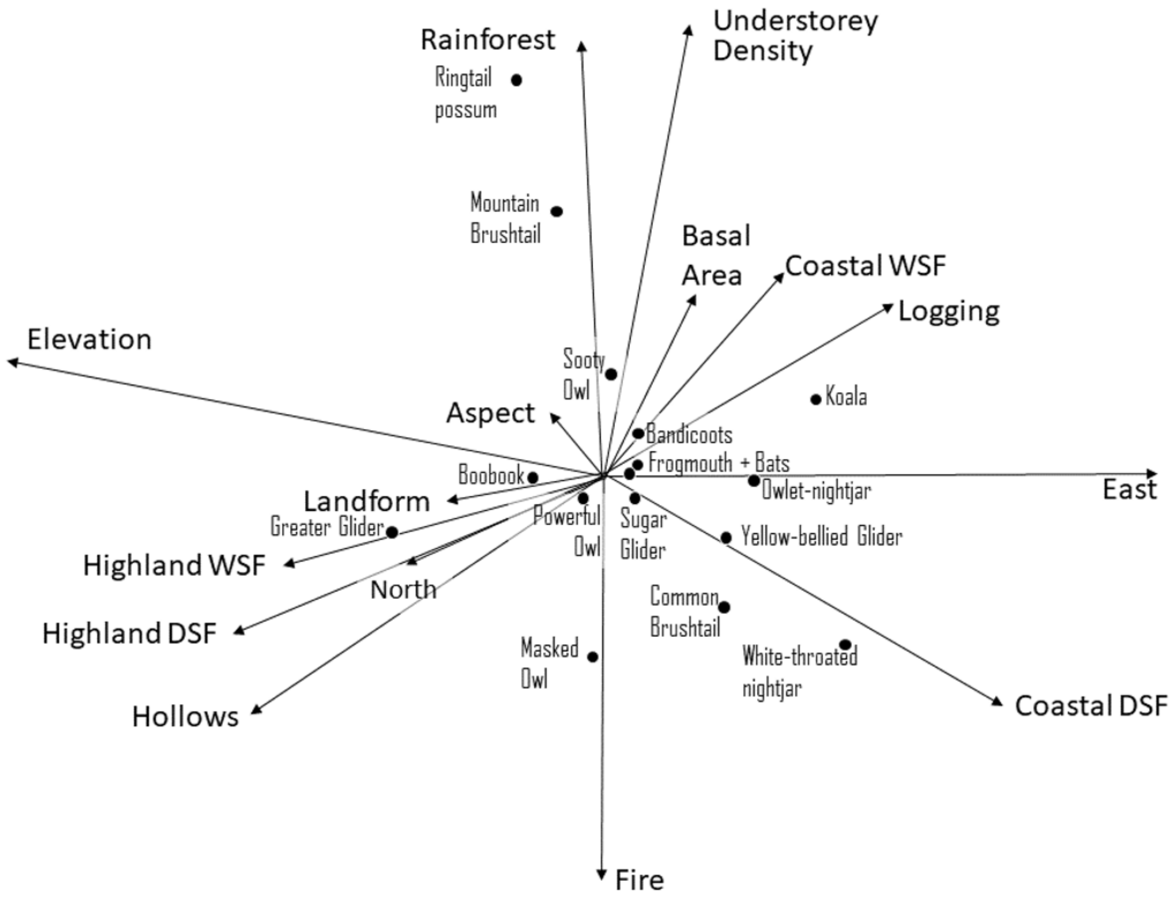

Figure 3. Relations between nocturnal mammals and birds and environmental variables in north-eastern NSW forests

Relations between 16 animal species or species groups (shown as dots) and 17 environmental variables (arrows) across 290 sites in north-eastern NSW using canonical correspondence analysis. The length of the arrows represents the variance explained by each variable and the distance along an arrow subtended perpendicularly by each species represents the degree of association with that variable. Two environmental variables, topography (slope) and understorey height, had a minor contribution to the pattern summarised by the biplot and, for clarity, are not labelled. WSF, wet sclerophyll forest; DSF, dry sclerophyll forest; East, longitude; North, latitude

Another important case study is that provided by Mills (2019) who analysed the results of the first 5 years (2012–2016) of the NSW National Parks and Wildlife Service 'WildCount' camera-trap program across approximately 200 sites in the forests and woodlands of eastern NSW. Species occupancy estimates were developed for 157 species detected on these remote cameras. The role of three important environmental covariates (mean annual precipitation, mean annual temperature and annual radiation) in accounting for the patterns of occupancy of the 22 most frequently recorded species was investigated. Mean annual precipitation and mean annual temperature were significant covariates for all but five and three of these species, respectively, whereas there was no relationship with annual radiation for 11 species. Mills (2019) then considered species relationships for the seven most frequently recorded species with a range of site covariates measured within a small area (0.13 ha; 20-m radius) around each camera trap. None of these variables (e.g. litter depth, strata height, evidence of fire or logging disturbance, etc.) were significant in explaining occupancy or detectability for the seven species that were modelled, most likely because the measurement scale was too small to be representative of the whole site.

Tasker and Dickman (2004) showed that floristic composition and structure of the forest mid-storey, shrub and ground layers had a major influence on the abundance and community composition of small mammal species, and that the distribution of these variable habitat conditions for small mammal species was largely driven by fire frequency and associated cattle grazing in the forests of north-eastern NSW. However, changes in habitat complexity due to fire and grazing led to differing responses among small mammals, with some species most abundant in frequently burnt and grazed sites while others were most abundant in ungrazed and unburnt sites.

Studies of the distribution of reptiles in logged and unlogged forests, and across a moisture gradient from wet to dry forest vegetation types, have been unable to clearly identify the main drivers accounting for the distribution and abundance of these species (Goldingay *et al.* 1996; Daly and Hoye 2016; Daly and Lemckert 2011). In each study, reptile species richness (including arboreal, terrestrial and fossorial species) was similar across vegetation types and logging treatments, although the total abundance of reptiles was greater in logged forests. The increased solar radiation and volume of coarse woody debris following logging were considered the most likely explanations for these results among the more common species. However, the patchy distribution and low abundance for many species, including snakes, prevented resolution of the importance of vegetation type or disturbance. Time since fire has been shown to be an important driver of reptile communities in south-eastern Australia, with reptile species richness, composition and abundance greater in long unburnt (> 80 years) forests and woodlands (Hu *et al.* 2013; Dixon *et al.* 2018).

Frogs have been particularly challenging because of the very high variability in detections and counts due to rainfall and season, even at sites where the species is known to be present (Goldingay *et al.* 1996; Lemckert 1999; Lemckert *et al.* 2004; Daly and Lemckert 2011). In one of these studies, a before–after control–impact (BACI) approach was used to assess whether changes in total frog numbers, number of species and number of individuals of five common species varied significantly between burnt and unburnt forest sites (Lemckert *et al.* 2004). No significant associations were observed between counts and any of the fire assessments made at the eight study ponds, although the study had low power to detect any effects of fire because the within-season counts of frogs varied so greatly.

In another study, counts of frogs were performed at 52 streams and 33 ponds in the Dorrigo area of northern NSW (Lemckert 1999). No single habitat feature was found to consistently explain individual species abundances at ponds or streams. Altitude and longitude were found to have the greatest influence on total species richness. Logging disturbance apparently had either little or favourable effects on the abundance of most species, although negative impacts of logging were recorded for three species. The Great Barred Frog (*Mixophyes fasciolatus*) decreased in numbers in more recently logged areas, the Giant Barred Frog (*Mixophyes iteratus*) decreased in abundance in recently logged areas and at sites where little undisturbed forest was available, and the Tusked Frog (*Adelotus brevis*) appeared to be dependent on patches of undisturbed forest (Lemckert 1999).

3.1.1.3 Key environmental drivers of the distribution and abundance of flora species

The distribution of vascular plant species and the structure of vegetation is strongly related to the major climatic drivers, temperature and precipitation, specifically the mean maximum and minimum temperatures in summer and winter (or temperature range), and the amount and timing of rainfall (Eamus *et al.* 2006). The regolith, particularly the water-holding capacity and fertility of soil, is also an important determinant of vegetation composition and structure, and varies with parent material (or 'geology'). Similarly, topographic position in the landscape affects local plant assemblages through its effect on aspect and insolation, drainage, local soil water-holding capacity and soil fertility. Elevation is often correlated with temperature and precipitation in eastern NSW forests.

Forest structure varies in terms of the foliage density and height of the canopy of the upper tree stratum, and is strongly related to the physical and chemical environment (Specht and Specht 2005). The projected foliage cover (i.e. foliage density) of the overstorey of mature forest is governed by rainfall (Eamus *et al.* 2006), and stand height is correlated with water and nutrient supply. Forest density and height decline with dryness of the atmosphere (i.e. increasing temperature and decreasing precipitation), declining with distance inland on a continental scale (Specht and Specht 2005).

Fire

Most Australian ecosystems are subject to recurrent fire and indeed their long-term persistence is dependent on periodic burning (Gill *et al.* 1981; Noble and Slatyer 1980). Eastern NSW forests and woodlands dominated by sclerophyllous genera such as *Eucalyptus*, *Allocasuarina*, *Melaleuca* and *Callitris* are examples, and only rainforests are not dependent on recurrent fire and are 'fire-sensitive'. Noble and Slatyer (1980) developed a 'vital attributes' scheme to categorise plant species in terms of their ability (or otherwise) to persist and reproduce at different stages of their life cycle after burning. Plants that persist after fire by reproducing from seed ('obligate seeders') as opposed to species that reshoot after fire ('resprouters') are examples of different plant adaptations for surviving periodic burning. This scheme has been developed in NSW into fire management guidelines based on fire frequency, intensity and time since last fire, to ensure the persistence of the broad types of native vegetation (and their associated fauna) across the state, and to avoid plant and animal extinctions due to inappropriate fire regimes (Kenny *et al.* 2004).

Fire is widely used by land managers in NSW forests for several main purposes: for fire hazard reduction, to protect life and property; for forest regeneration after timber harvesting; to produce forage for domestic livestock on grazing leases and private land; and to ensure the continued survival of fire-dependent populations of flora and fauna that would otherwise decline to extinction in the absence of fire. Fire may also be used for cultural purposes and to improve forest condition.

Despite the ubiquity of natural and anthropogenic fire in eastern NSW forests, comprehensive experimental studies of the impacts of fire are few. Two long-term experiments conducted at operational scales and one regional space-for-time study in the forests of south-eastern NSW have revealed that fire severity and fire frequency are major determinants of plant species composition and that time since wildfire has a significant influence on plant species successional changes lasting at least several decades (Penman *et al.* 2008a, 2009, 2011a). In contrast, low-severity fire (prescribed burning) had little influence on understorey plant species distribution and abundance after five or six burns over a 15-year period, partly due to high variability in fire patchiness (Penman *et al.* 2007) and because soil temperatures were not hot enough to stimulate germination of the soil-stored seed-bank (Penman *et al.* 2008b, 2011b). These results differ from those in northern NSW grassy forests where frequent low-intensity fire in association with cattle grazing is widespread (Tasker and Dickman 2004).

In both northern and southern NSW forests, since about the mid 1800s, graziers used to burn the drier forest types regularly (usually every 2–3 years) and over extensive areas to promote grass growth and reduce the woody component of the forest understorey (Hatich 1997; Fanning and Mills 1989; Smith *et al.* 1992, 1994). In northern NSW forests, sites that have been grazed and repeatedly burnt by low-intensity fire are associated with a simplified and grassy understorey structure, reduced or absent shrub layer, reduced coarse woody debris and often lower understorey floristic richness compared to infrequently burnt and ungrazed sites (e.g. Binns 1995a, b; Tasker and Bradstock 2006). In state forests in the Glen Innes, Grafton and Casino Management Areas, fire and grazing interaction was considered, based on survey results, to have changed the understorey from a range of complex shrub and woody communities to a smaller number of simple communities characterised by a layer of fire-tolerant grasses and herbs such as Blady Grass (*Imperata cylindrica*) and Bracken (*Pteridium esculentum*) (Margules Groome Pöyry 1994; Moore and Floyd 1994). In the Morisset Forestry District, fire history was one of the most important factors determining broad floristic and structural patterns: on the Narrabeen sediments, Binns (1996) found there was a strong dichotomy between recently (and probably regularly) burnt areas, which supported grassy forest with usually scattered shrubs, and less recently burnt areas, which supported wet sclerophyll forest. In the Eden region, regular burning of parts of the forest to produce feed for stock likely occurred from first settlement up until the 1980s (Fanning and Mills 1989). The broader landscape-scale effects of fire frequency described here are based on space-for-time surveys and may not adequately account for interactions with other environmental factors such as microclimate and soil properties. In a plea for permanent-plot-based monitoring of NSW forests, and noting the limitations of snapshot surveys, Binns (1995a, p. 55) said: ‘It is clearly not possible to assess the more subtle long-term impact of altered fire regimes from survey data. A comprehensive monitoring program is necessary to provide such information’.

Repeated low-intensity fires have the potential to lead to the decline or local extinction of hard-seeded species that require intense fire for recruitment, as well as obligate seeders that require a long fire-free juvenile period before they are able to reproduce and produce a seed crop in readiness for the next fire (Gill and Bradstock 1995; Kenny *et al.* 2004). Some studies have reported that even a single low-intensity fire may be sufficient to cause the decline or local extinction of forest understorey plants (e.g. Clark 1988; Hamilton *et al.* 1991), although such studies were either limited in scale or controversial (e.g. McCaw 1993). Lack of fire can also lead to the decline of plant species in NSW forests. The absence of fire allows the increase or invasion of fire-sensitive woody plants, both native (e.g. *Pittosporum undulatum*, *Cissus* spp. and other rainforest species) and introduced (e.g. *Lantana camara*, *Ligustrum sinense*, *Cinnamomum camphora*), which then facilitate a compositional shift towards a more mesic understorey and the decline of sclerophyllous vegetation, including threatened species (e.g. *Tetratheca glandulosa*), which require fire to persist (Rose 1997; Rose and Fairweather 1997; Stone *et al.* 2008).

Sites burnt frequently (i.e. more often than every 5 years) have a grassy or herbaceous understorey dominated by monocotyledonous plants (grasses, sedges and lilies) and ferns compared with sites burnt less frequently that are shrub-dominated (Lamb *et al.* 1981; Leigh *et al.* 1987; Catling 1991). In a designed experiment in regenerating Blackbutt (*Eucalyptus pilularis*) forest, a predominantly shrubby understorey in plots unburnt for several decades contrasted markedly with the grassy understorey of plots burnt repeatedly at 2-year intervals (Birk and Bridges 1989). Binns (1996) was concerned that late winter – early spring grazier fires could disadvantage seasonal geophytes that emerge and flower and fruit in spring to early summer. More information on plant species response to fire is required to ensure positive fire management and persistence of the flora in NSW forests (Bradstock *et al.* 1995; Binns 1996; Kenny *et al.* 2004).

Timber harvesting

Binns (1995c) elucidated general principles about the impact of timber harvesting up to the 1990s on the structure and composition of eastern NSW hardwood forests:

> By removing a proportion of the overstorey and destroying part of the understorey, logging clearly has an immediate impact on vegetation structure. In the short term, a forest structure is converted to woodland or open woodland. In the longer term, a logged forest generally includes a relatively higher proportion of smaller trees than an unlogged forest.
>
> Impact on floristic composition is more complex. Logging changes the light, moisture and nutrient regime and the biotic environment. Individual species respond to these changes in various ways. Some will remain essentially unaffected, some may increase and some may decrease. Depending on the scale of observation, some may become locally extinct and others not previously present may invade, at least in the short term. Logging thus has the potential to change the species composition, the relative amount of each species and the total number of species at a site. Local impact may be substantial, at least in the short term.
>
> On a scale of hectares to tens of hectares, logging results in a mosaic of patches of varying degrees of disturbance. Even intensively logged areas include unlogged patches varying in size from tenths of a hectare upwards. This mosaic pattern tends to ameliorate smaller scale locally severe impacts. On a broader scale, of tens to hundreds of hectares and larger, there are areas of reserved, unlogged forest, in various tenures, which further ameliorate regional scale impact.

With regards the scale of impacts associated with timber harvesting operations in eastern NSW forests, state forests comprise only about 30% (1.55 million ha) of the public land in the four Coastal IFOA regions (Slade and Law 2017). Due to conditions and environmental protections associated with timber harvesting operations in state forests, 43% (676,000 ha) of the native state forest estate was set aside for conservation in informal reserves prior to 2018 when the new Coastal IFOA was introduced, with new mitigations. Informal reserves are now estimated to equal 50–60% (excluding western NSW) of the state forest estate. Along with national parks and other formally conserved public land, 83% (4.3 million ha) of the 5.2 million ha of public native forest in the Coastal IFOA regions is set aside for formal or informal conservation.

Experimental studies of the floristic impact of timber harvesting in eastern NSW forests are few. A long-term logging (and fire) experiment conducted in dry sclerophyll forest in south-eastern NSW at the Eden Burning Study Area in Yambulla State Forest, showed that timber harvesting is not a major determinant of plant species composition, unlike fire (Penman *et al.* 2008b, 2009, 2011a). Over a 16-year period, species richness declined in all logging (and burning) treatments (as part of natural, long-term, post-wildfire succession). Logging resulted in significantly greater species richness in the shrub layer (> 1 m height), but had no significant effect on species richness in the ground layer (< 1 m) or total species richness (Penman *et al.* 2008b). Logging also had different effects on obligate seeder versus resprouter shrub species. Obligate seeders responded rapidly to logging, the number of species being significantly greater in logged plots at every measurement post-logging. These species appeared to have rapidly colonised logged plots either through germination of the soil seed bank or through colonisation from adjacent patches. In contrast, the richness of resprouters did not exceed the unlogged treatment until 14 years after logging, following an initial post-logging decline. The initial decline suggests that at least some resprouters may be less able to recover vegetatively from logging damage, compared with damage from low-intensity fire. Logging also resulted in increased species richness and total abundance in the soil seed bank compared with unlogged plots (Penman *et al.* 2011a), largely due to the increase in above-ground shrubs, post-logging.

Binns (1991) studied the impact of high-intensity timber harvesting in wet sclerophyll forest dominated by Tallowwood (*Eucalyptus microcorys*), Sydney Blue Gum (*E. saligna*) and Brush Box (*Lophostemon confertus*) in the Doyles River group of state forests, near Taree. He used a chronosequence approach comparing unlogged and logged stands, 10 and 30 years post-logging. Most woody species occurred in both logged and unlogged plots, and none of the more frequent species occurred solely in unlogged plots. Only three rainforest species (Green-leaved Rose Walnut *Endiandra muelleri*, Black Plum *Diospyros australis* and Orange Thorn *Pittosporum multiflorum*) were less abundant in logged plots than in unlogged plots. Post-logging vegetation included 21 early successional and nomad species (including sclerophyll overstorey species), which had colonised the disturbed sites but were unlikely to successfully regenerate in undisturbed forest. These species included the three canopy dominants, four subcanopy nomads (*Acacia melanoxylon*, *A. irrorata*, *A. binervata*, and *Allocasuarina torulosa*), five secondary succession species (*Callicoma serratifolia*, *Cassinia trinerva*, *Claoxylon australe*, *Persoonia media* and *Polyscias murrayi*) and nine early successional or pioneer species (*Billardiera scandens*, *Breynia oblongifolia*, *Helichrysum diosmifolium*, *Helichrysum rufescens*, *Omalanthus populifolius*, *Piptocalyx moorei*, *Rubus hillii*, *R. rosifolius* and *Smilax glycophylla*). Most of the understorey species demonstrated a high propensity to resprout vegetatively, and resprouts were an important component of post-logging vegetation. Resprouting almost certainly enables these species to persist after recurrent fire and periodic natural disturbance (such as windthrow due to storms and landslips). Binns (1991) concluded that, in terms of understorey floristics, these wet sclerophyll forests were resilient to a single logging event.

In addition to these detailed studies of timber harvesting, several snapshot flora surveys of NSW state forests in the 1980s and 1990s attempted to deduce the impacts of logging on flora. The one major finding about negative impacts of timber harvesting concerned epiphytes: in general, epiphytes appear to be adversely affected by logging, at least in the short to medium term (up to several decades), due to the loss of large habitat trees (Binns 1995c). For example, in the Gloucester and Chichester Management Areas, the epiphytic and lithophytic fern, *Pyrrosia rupestris*, was significantly less frequent in logged than unlogged (but loggable) plots, due to the harvesting impact on large trees. A less certain but consistent finding across several management areas was the large number of infrequent native species only found in unlogged (but loggable) plots. For instance, in Tenterfied Management Area, there were approximately 100 species absent from logged plots (Binns 1995b), and in Gloucester and Chichester Management Areas, 214 species absent from logged plots (Binns 1995c). Therefore, Binns (1995b, c, 1996) could not discount the existence of a suite of widespread but uncommon species that may be adversely affected by timber harvesting. Detailed before–after monitoring of timber harvesting operations was recommended to clarify the situation.

The 1980s and 1990s surveys and studies of state forests also produced evidence of short to medium-term increases in native and introduced plant species due to harvesting. Binns' (1991) findings in this regard have already been mentioned. A similar increase in colonising species, including *Acacia melanoxylon* (Blackwood) and *Eustrephus latifolius* (Wombat Berry), was noted in logged wet sclerophyll forest in the Dorrigo area, unlike logged dry sclerophyll forest where there was no evidence of logging impact *ex post facto* (Binns 1995a). Although there was no evidence of a logging-induced shift in floristic composition in hardwood forest in the Tenterfield, Gloucester and Chichester Management Areas, logged areas had a greater number of native plant species per plot than unlogged (but loggable) areas (Binns 1995b, c). This was due, at least in part, to an increase in colonising and groundstorey species due to the reduction in overstorey and understorey competition, with 17 species significantly more frequent in logged plots, but rare or absent in unlogged (loggable) plots in the Tenterfield Management Area (Binns 1995b), and 22 species in the Gloucester and Chichester Management Areas (Binns 1995c). Grassy sclerophyll forest plots in the Morisset Forestry District logged within the previous 30 years also also had more species per plot than unlogged plots and plots logged > 30 years previously (Binns 1996).

An additional finding of these vegetation and floristic surveys of eastern NSW forests pertained to timber harvesting and significant flora species, that is, species listed as rare or threatened under state or federal legislation or in national inventories. The habitats of many significant flora species in eastern NSW forests are often habitats avoided during eucalypt harvesting operations. In both northern (e.g. Tenterfield, Gloucester and Chichester Mangement Areas) and southern (e.g. Eden Native Forest Management Area) NSW, many of the significant flora species occur mainly or exclusively in non-eucalypt-forest habitats (i.e. swamps, rainforest and rocky habitats, including boulder fields, outcrops, cliffs and rocky slopes that are not directly affected by logging), or in moist gullies, creeks and riparian forest protected from logging by prescription during harvesting (Dodson *et al.* 1988; Binns and Kavanagh 1990; Fanning and Fatchen 1990; Fanning and Clark 1991; Binns 1995b, c). Indeed, the most serious threat to the conservation of significant flora species in the Gloucester Management Area was not timber harvesting but invasion by the introduced shrub, Scotch Broom (*Cytisus scoparius*), and damage to swamps by feral pigs and horses, threats that continue to the present day.

After conducting many floristic surveys and environmental impact assessments of eastern NSW state forests, Binns (1995b) summarised the impact of timber harvesting on forest composition as follows (p. 56):

> Very little is actually known of the response to logging for the vast majority of plant species. Evidence from the subject survey and other recent surveys suggests that most of the more widespread and common species are unaffected, although a few may [be] reduced in abundance, at least temporarily, and there is potentially a suite of less common species which may be adversely affected. The current lack of detailed knowledge of responses of individual species to disturbance prevents management for particular species or assemblages of species. It is also currently not possible to confidently determine which of the less frequent species are sensitive to logging or other management practices and thus need particular attention. This is especially true for those which are less common and thus likely to be of greatest conservation interest, although the small subset of such species of recognised national significance can often be simply accommodated by ensuring known populations are excluded from logging. Refined management for flora conservation will be possible only with much more information on disturbance response of individual species. This requires a long-term, well-planned monitoring system.

Grazing and browsing

Large mammalian herbivores (both wild and domestic) can affect the structure and dynamics of closed and open temperate forests, through direct and indirect impacts on seedling establishment and sapling recruitment, as well as on ground vegetation, soils and other fauna (Hester *et al.* 2000). In eastern NSW forests and woodlands, the impacts of domestic livestock on native forest and woodland understoreys are reasonably well understood. Selective grazing by livestock can have significant impacts on native grasses and forbs, which may decline or be lost from even lightly grazed grassy eucalypt forests and woodlands. These grazing-sensitive species tend to be the less common forbs (e.g. certain daisies, lilies, peas and orchids) and short palatable shrubs that grow between the relatively unpalatable, dominant grasses (Wimbush and Costin 1979a, b; Lunt 1991; Wahren *et al.* 1994; Prober and Thiele 1995). Thus, even light grazing can impact grassy forest understoreys with little effect on the dominant grasses. McIntyre and Lavorel (1995) found that the number of rare native herb species was highest in ungrazed woodland in nature reserves on the Northern Tablelands of NSW, and changes in floristic composition associated with livestock grazing have been widely reported from both the Northern Tablelands (Whalley *et al*. 1978; Lodge and Whalley 1989; Smith *et al.* 1992; Curtis and Wright 1993; McIntyre and Lavorel 1994, 1995) and elsewhere (Wimbush and Costin 1979a, b; Harrington *et al*. 1984; Joss *et al*. 1986; Korte and Harris 1987; Lunt 1991; Sivertsen 1993; Prober and Thiele 1995). The spread of introduced weeds and the structural and functional impacts (Eldridge *et al.* 2016) of domestic livestock grazing in NSW forests are discussed below.

Less is known about the grazing and browsing impacts of feral herbivores in eastern NSW forests, although there is cause for concern. The impact of rabbits (and livestock) in suppressing recruitment of dominant long-lived woody plants in arid and semi-arid south-eastern Australia is well-known (e.g. Crisp and Lange 1976; Lange and Graham 1983; Cooke 2012). However, very low densities of rabbits can also cause recruitment failure in woody plants in temperate forests and woodlands: highly palatable forest and woodland species (e.g. *Allocasuarina* spp.) can be suppressed by densities as low as 0.5 rabbits ha^{-1} and moderately palatable species (e.g. *Bursaria spinosa*) by densities of 2 rabbits ha^{-1} (Mutze *et al.* 2016).

Six species of feral deer (Cervidae) occur in south-eastern Australia and some species are rapidly increasing in distribution and abundance (Davis *et al.* 2016). Exclosure studies in native vegetation have shown that feral deer defoliate, strip bark and break plant stems, leading to reductions in shrub biomass, tree regeneration and understorey plant cover, stunted plant growth, reduced plant species diversity and altered community composition. A study of feral deer impacts in threatened ecological communities (TECs) on the South Coast of NSW showed that average grazing intensity and proportion of grazed herbaceous plants was higher when deer were present, with rushes, cycads, sedges and grasses being more severely grazed (Burns *et al.* 2021); littoral rainforest and Bangalay (*Eucalyptus botryoides*) sand forest were among the TECs that registered significant increases in grazing intensity in the presence of deer.

Feral herbivores often concentrate their grazing and trampling impacts in sensitive habitats in eastern NSW forests, to the detriment of threatened species and ecological communities. Plant species of conservation significance and threatened communities are disproportionately found in upland swamps, moist gullies, streams and riparian alluvial flats in NSW forests, and these are sites where trampling, grazing and rooting damage by feral horses, pigs and livestock is often extreme (Shields *et al.* 1992; Binns 1995a–c). Rocky habitats in NSW forests are similarly important for threatened plants and ecological communities, and these habitats are favoured by feral goats. Feral horse impacts in the nationally Endangered ecological community, Alpine Sphagnum Bogs and Associated Fens, include an increase in low-growing forbs and a reduction in grasses, sedges, rushes, shrubs and pool-edge litter, disadvantaging the threatened Alpine Water Skink (*Euclamprus kosciuskoi*: Critically Endangered, Vic.), Broad-toothed Rat (*Mastacomys fuscus*: Vulnerable, Cwth; Cherubin *et al.* 2019), and possibly the Northern Corroboree Frog (*Pseudophryne pengilleyi*; Foster and Scheele 2019). In the lower Snowy River Valley, feral horses and deer are also responsible for active and extensive soil erosion, denuded stunted understoreys, reduced plant cover and depleted epigeal invertebrate communities in White Cypress Pine (*Callitris glaucophylla*) – White Box

(*Eucalyptus albens*) woodland, a component of the nationally Critically Endangered White Box – Yellow Box – Blakely's Red Gum Grassy Woodland and Derived Native Grasslands TEC (Ward-Jones *et al.* 2019).

Like their introduced and feral counterparts, native herbivores can affect plant survival and community dynamics in native forest and woodland and determine long-term compositional outcomes and ecosystem states (Letnic *et al.* 2012; Mills *et al.* 2020). Over a 12-year period to 2016, grazing severity of bushland plants by kangaroos increased in protected areas in temperate woodlands and forests in the Mount Lofty Ranges, and was comparable to the grazing damage in remnant vegeation on private land (Prowse *et al.* 2019). Like kangaroos, abundant wallabies can also browse and kill native woody plants and deflect or retard succession. Swamp Wallabies (*Wallabia bicolor*) browse and kill seedlings and thwart hardwood, rainforest and coastal dune forest reforestation and restoration programs as well as inhibiting passive forest regeneration on both the North and South Coast of NSW (e.g. Cummings *et al.* 2005; Nilar *et al.* 2019). As with feral herbivores, the reduced biomass and loss of understorey cover and structure due to native herbivore overgrazing can affect grassy forest and woodland faunal assemblages, such as reptiles (Howland *et al.* 2014).

Weeds

Disturbances such as timber harvesting, fire, grazing, roading and wildland recreation create opportunities for invasion by introduced plants (weeds) or their increase in native vegetation. Grazing by large herbivores increases the amount of bare ground (Wimbush and Costin 1979a, b; Leigh *et al.* 1987; Wahren *et al.* 1994), enabling invasive species to establish. Long-term grazing by domestic livestock and feral herbivores in eastern NSW forests is generally associated with the occurrence of introduced weeds. Shields *et al.* (1992) attributed the widespread occurrence of pasture weeds (*Trifolium repens*, *Hypochaeris radicata* and *Cirsium vulgare*) in both logged and unlogged forest to the long history of grazing by feral and domestic cattle and feral horses in Mt Royal State Forest and the adjacent Mt Royal National Park. *Hypochaeris radicata* is widespread in southern NSW forests, as well (Fanning and Mills 1991; Jurskis *et al.* 1995). In the Dorrigo area, Binns (1995a) noted that grazing assists invasion of native vegetation by exotic plant species, to the extent that heavily grazed areas, such as creek flats, become dominated by weeds to the exclusion of many native species. Crofton Weed (*Ageratina adenophora*) is abundant on the banks of larger forest streams near the boundary with grazed private property in the Mt Royal Management Area (Shields *et al.* 1992).

Herbaceous pioneer species, both native and introduced weeds, frequently occur alongside roads in eastern NSW forests as a result of the disturbance associated with traffic and roadside maintenance, but the species generally do not infiltrate adjacent forest in the absence of disturbance (Shields *et al.* 1992). A similar group of native and introduced pioneer species tend to colonise areas disturbed by timber harvesting immediately after logging. The absence of these species from older logged areas suggests that they do not persist above-ground beyond about 5–10 years post-logging, although some undoubtedly persist in the seed-bank (Shields *et al.* 1992).

Although introduced herbs are widespread in eastern NSW forests, woody weeds may be a greater threat to plant biodiversity than herbaceous weeds. Binns (1996) considered Lantana (*Lantana camara*) to be the most serious weed in the Morisset Forestry District. It was locally abundant in sheltered sites in Watagan and Olney State Forests, with the potential to cause long-term declines in the abundance of co-occurring native species. Although Lantana invades native forest after logging and newly established native hardwood plantations, there is evidence in the Urunga – Coffs Harbour

Management Areas that it declines over time once the canopy re-establishes: its frequency declined from 61% (n = 57) of plots logged < 12 years previously to 44% (n = 61) in plots logged > 12 years previously (Tweedie *et al.* 1995). Lantana also tends to decline in native hardwood plantations after canopy closure, and may act as a nurse crop for rainforest regeneration in such situations.

In grassy woodlands of the Northern Tablelands, exotic species richness increases under a wide variety of disturbance regimes including grazing (McIntyre and Lavorel 1995). In grassy woodlands on the inland slopes of southern NSW, grazed remnants have greater weed abundance than little-grazed remnants (Prober and Thiele 1995). As a general rule, overgrazing leads to invasion by unpalatable weedy species that may be toxic to large herbivores (Korte and Harris 1987).

Interactions between fire, grazing and fauna

Several examples in preceding sections have highlighted the importance of interactions between disturbances such as fire and grazing, or of indirect interactions between fire, herbivores and predators, in determining ecosystem outcomes. Indeed, there is emerging evidence that indirect interactions may be more important than direct impacts in determining ecosystem patterns and processes (Hobbs 1996). Such complex interactions are evident in eastern NSW forests and woodlands. Leigh and Holgate (1979) documented several examples where low-intensity fire coupled with native herbivore grazing and browsing by Eastern Grey Kangaroos (*Macropus giganteus*), Common Wombats (*Vombatus ursinus*), Swamp Wallabies and Red-necked Wallabies (*Notamacropus rufogriseus*) had major impacts on tree, shrub, forb and grass survival and recruitment in shrubby dry sclerophyll forest and woodland in the Brindabella Ranges, Australian Capital Territory, and Mundoonen and Gourock Ranges, southern NSW. In a series of exclosure experiments involving burning and manipulation of native herbivore grazing and browsing, fire and grazing exerted profound effects on forest community composition and structure (plant density and height). The survival, reproductive capacity, biomass and morphology of mature plants were affected by grazing or browsing, as was regeneration of vegetation after fire from both seed and stem and root resprouts. For palatable species, such as *Indigofera australis*, grazing by native animals exerted a greater effect on plant survival than fire.

3.1.1.4 Species occupancy baselines

Three of the studies referred to above (Kavanagh *et al.* 1995; Kavanagh and Stanton 2005; Mills 2019), and several others that were also conducted at a regional scale (e.g. Law *et al.* 2021), provide examples of the baselines in species occupancy that might be expected for a large number of forest-dependent fauna species in NSW.

A principal aim of the species modelling work in the current project was to (1) provide a comprehensive 1990s baseline of occupancy estimates for priority fauna species based on the three major corporate surveys (Forest EIS, NEFBS, CRA); and (2) improve on these naïve occupancy estimates by accounting for species detectability in each survey where that was possible, and by assigning the remaining variance in species records to the major environmental covariates operating in each region. In this way, future monitoring programs will have historical (1990s) species benchmarks for occupancy in each region, and in each main landscape stratum (e.g. unlogged, burnt, high elevation, moist forest types) against which contemporary monitoring results can be compared.

3.2 Conceptual model

The following diagram (Figure 4) summarises the key concepts discussed above. It follows that species occupancy and environmental niche modelling of priority species for monitoring forest change will be best informed by spatial variables that reflect or are closely related to the key environmental factors and disturbance drivers that currently determine forest composition, structure, condition and integrity:

i. Temperature
ii. Rainfall
iii. Soil fertility
iv. Topographic position
v. Fire regime
vi. Timber harvesting history
vii. Forest clearing and fragmentation (or its reciprocal, forest extent).

The first four environmental factors are the primary determinants of forest community type (i.e. the dominant species). Unfortunately, spatial information about the most destructive invasive species (e.g. fox, cat, Phytophthora) was unavailable in the 1990s in eastern NSW forests and so we have not attempted to model the distribution and impact of these invasive species on the environmental niche or occupancy of priority forest plant and animal species.

Occupancy modelling or, when not possible, naïve estimates of species occupancy will provide baseline (1990s) estimates of the occupancy of each priority fauna species and priority flora species in the study region (i.e. UNE, LNE, Southern, Eden). Species Occupancy Models and/or species Environmental Niche Models (ENMs) have been used to identify the major environmental and disturbance drivers that are significantly associated with each species' occupancy in the study region in the baseline decade. This will allow future monitoring to determine if and how species' occupancies and environmental correlates have changed since the 1990s.

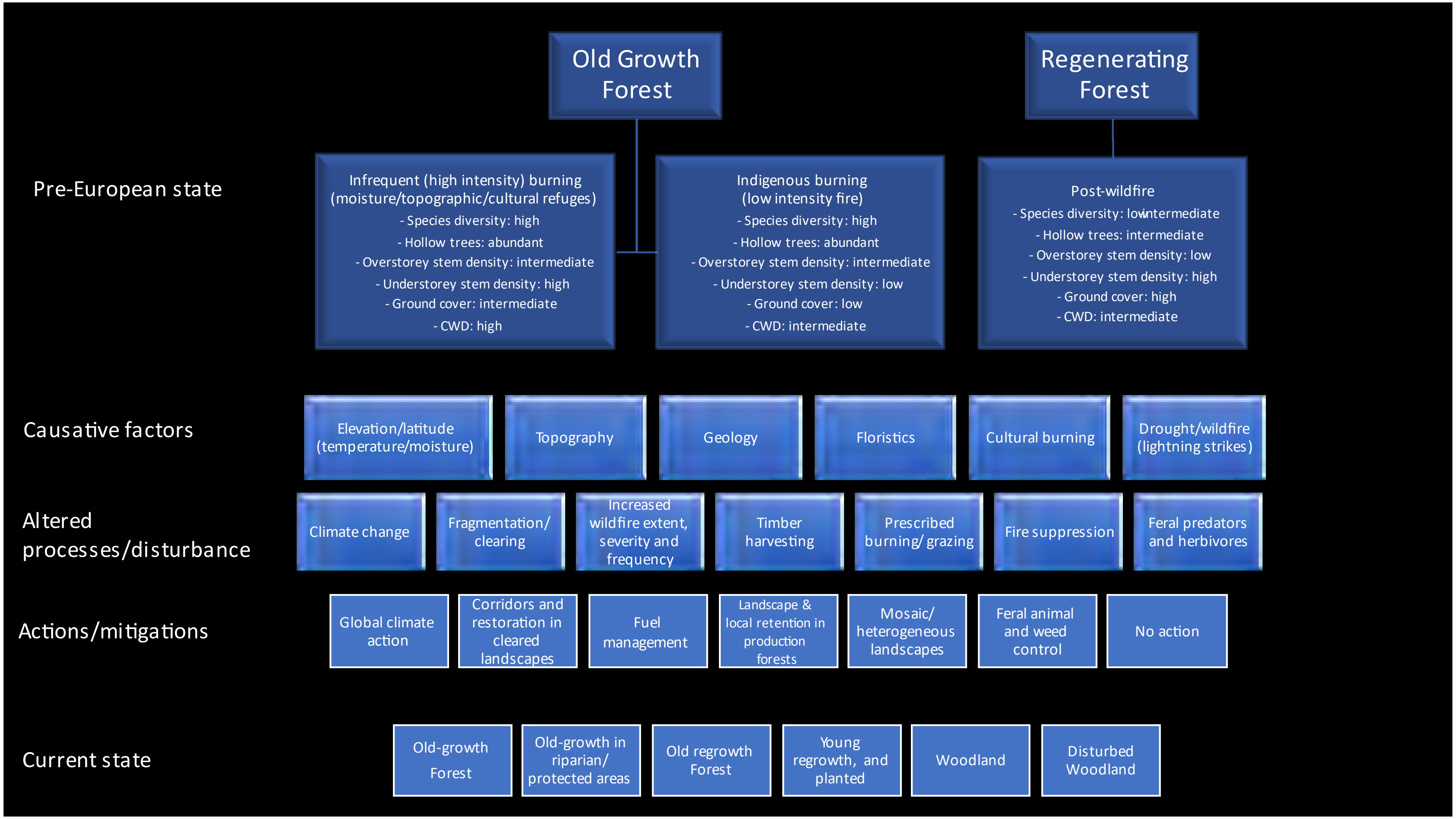

Figure 4. Conceptual model of the principal factors affecting species occupancy, trends and distribution in the eucalypt-dominated forests and woodlands of NSW

4. Fauna species prioritisation

The third deliverable in this project was to identify the 'priority (key) fauna species for the on-ground monitoring of the integrity and condition of eastern NSW forests' (Section 2.1). These are the species that are priorities for statistical modelling in this project, primarily because they represent an important subset of species (focal species) that future monitoring programs are likely to use as indicators of the changing status of the biodiversity of forested lands of different tenures.

The development of species baselines, drivers and trends in species occupancy and distribution is the overarching objective of this project. The purpose of the fauna species modelling work was to extend the results of existing surveys to provide better estimates of species occupancy than those revealed by naïve occupancy alone. Occupancy modelling, where the data are sufficient (i.e. presence of repeat visits to the same survey sites), has the capacity to account for the major sources of variation in the distribution of species across the landscape and provide more accurate estimates (i.e. baselines) for species occupancy in each region. However, where the data were insufficient for occupancy modelling (i.e. surveys lacked repeat visits), environmental niche modelling techniques (e.g. Maxent) have been used to estimate the distribution of suitable habitat for these species.

The criteria by which the fauna priority species were determined included the following (note, not all criteria apply to each species):

- The species is forest-dependent for all or part of its life-cycle. In cases where the species is known or suspected of being dependent on hollows in large live or dead trees for breeding or shelter, this was indicated;
- The species selected from each taxonomic class were chosen to be representative of a range of ecological functional groups, including those categorised as: arboreal folivore, arboreal granivore, nectarivore/omnivore, frugivore, large carnivore (prey size > 120 g), small carnivore (prey size 5–120 g), insectivore (prey size < 5 g), fungivore, ground granivore, ground folivore (grazer) (e.g. Kavanagh and Stanton 2005);
- The species is known or suspected as being sensitive to intensive logging (e.g. Kavanagh *et al.* 2004; Kavanagh and Stanton 2005);
- The species is in the 'critical weight range' (CWR) and is known or suspected to be sensitive to threats caused by introduced predators;
- The species is known or suspected to be sensitive to climate change;
- The species is listed as 'threatened' under the NSW *Biodiversity Conservation Act 2016* (BC Act). But note: some species were selected because they are relatively common and not currently threatened;
- The species is listed as one of the NSW 'Saving Our Species' priorities for modelling (M. Drielsma, pers. comm.);
- The species has been identified under the NSW BC Act as a key threatening process because of its adverse impacts on other species;
- The species is detectable reliably using the survey methods proposed for use in the FMIP and Coastal IFOA biodiversity monitoring programs (i.e. cameras, song meters and bat-call detectors). Where these methods do not adequately detect the presence of priority species, alternative methods that are more appropriate for detecting the species are indicated.

The fauna priority species for modelling, and potentially for inclusion in survey and analysis in future biodiversity monitoring programs, for the reasons provided above, are listed in Table 1 below. This approach resulted in the identification of a short list of 140 fauna priority species, consisting of 53 mammals, 37 birds, 32 reptiles and 18 frogs (Table 1).

Of particular note is the relatively large number of priority species that are not reliably detected using any of the 'standard survey and monitoring methods' that are proposed for use in the proposed FMIP and Coastal IFOA biodiversity monitoring programs. This includes most of the reptiles on the list and several of the highest priority mammals, bird species and probably frogs. To address these deficiencies in the proposed survey methods, it will be important to include nocturnal site visits (e.g. spotlighting for the Greater Glider) and diurnal site visits (e.g. hand searches for reptiles) to reliably detect the presence of these important species. It is acknowledged that monitoring of some of these species may need to occur as targeted programs rather than state-wide monitoring.

The naïve occupancy for these species, as determined from two previous large-scale surveys, is provided in Table 1 as a guide to their relative abundance and distribution. We note that naïve occupancy can be a misleading indicator of species abundance and distribution where detection probability is low. The second-last column (Freq %) is the naïve occurrence for species occurring at ≥ 1% sites (n = 619) during the North Coast EIS surveys in 1991–1993 (from Kavanagh and Stanton 2005). These surveys used a range of survey techniques as appropriate for the species. In the last column (Wcams %), the proportion of sites (n = 200) that each species was detected using remote cameras only during the NPWS WildCount program (2012–2016) is indicated (Mills 2019). Naïve occupancies for the complete list of fauna species from 1990s surveys and preferred survey method are given in Table 21, and by survey and survey method in the electronic datafiles provided as part of the deliverables for this project.

Note: fauna taxonomy is continually changing and, in this report, we had to rely on the taxonomy used in the 1990s corporate datasets that formed much of the basis for this project, but updated where changes were required (e.g. different names used for the same taxon by different surveys). We have provided the corresponding current taxonomy for fauna species (Australian Faunal Directory) in Appendix 1. In this project, all Mountain Brushtail Possums were assigned, according to recent convention, to either *Trichosurus caninus* if they were observed in northern NSW or *T. cunninghami* if they were observed in southern NSW. However, there is doubt that the genetic divergence is sufficient to support the case for two separate species and, indeed, whether *T. cunninghami* occurs in NSW (Lindenmayer *et al.* 2002). The species listed in Table 2 are a subset of those already listed in Table 1.

While the ecological characteristics and conservation status of these 140 fauna species clearly justify their inclusion in the list as priorities for modelling and potentially for future monitoring, the existing data for many species is insufficient for robust statistical analysis. The survey methods required to detect many of these species are also beyond the scope of the proposed FMIP and Coastal IFOA species monitoring programs. Accordingly, an abbreviated list of fauna priority species was developed in consultation with the FMIP (Table 2). The 31 species listed in Table 2, with one notable exception (i.e. Greater Glider), are those which potentially could be surveyed remotely using one of three survey techniques: cameras, song meters or bat-call detectors. Whether adequate data can be obtained for analysis using these survey methods is yet to be determined, and most species require the development of new call-recognisers or image-recognition software to enable automated species identifications and rapid data processing techniques to be used. As discussed above, certain fauna groups (e.g. reptiles) have been omitted from this list because alternative survey methods are required to reliably detect these species. Table 2 is flagged later in the report in relation to environmental niche modelling (Table 7), species detected using cameras in the WildCount program (Section 7.4.8) and faunal species' sensitivity to disturbance (Section 8.1.1.1).

Table 1. List of priority fauna species for occupancy modelling, environmental niche modelling and climate change projections in this project and for future monitoring

Column heading and table entry abbreviations are explained at the end of the table

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Mammals													
Platypus	*Ornithorhynchus anatinus*		Spotlighting/ Trapping/e DNA	Insectivore	Y		Y		Y			na	na
Short-beaked Echidna	*Tachyglossus aculeatus*	Y	Signs	Insectivore	Y			Y				14.2	25.4
Spotted-tailed Quoll	*Dasyurus maculatus*	Y	Trapping	L_carnivore	Y H	Y		Y	Y	Y		5.0	6.2
Brush-tailed Phascogale	*Phascogale tapoatafa*		Trapping	S_carnivore	Y H	Y			Y	Y		<1	na
Long-nosed Bandicoot	*Perameles nasuta*	Y	Trapping	Insectivore	Y			Y				12.9	24.2
Northern Brown Bandicoot	*Isoodon macrourus*	Y	Trapping	Insectivore	Y			Y				3.7	12.3
Southern Brown Bandicoot	*Isoodon obesulus*	Y	Trapping	Insectivore	Y			Y	Y			na	<2.5
Common Wombat	*Vombatus ursinus*	Y	Signs	G_folivore	Y							1.1	34.8
Koala	*Phascolarctos cinereus*	Y	Spotlighting	A_folivore	Y		Y	Y	Y	Y		6.6	<2.5
Yellow-bellied Glider	*Petaurus australis*	Y	Spotlighting	Nectar_omn	Y H	Y			Y			18.6	na
Squirrel Glider	*Petaurus norfolcensis*		Spotlighting/ Trapping	Nectar_omn	Y H	Y			Y	Y		<1	na
Sugar Glider	*Petaurus breviceps*	Y	Spotlighting	Nectar_omn	Y H	Y						28.6	na
Greater Glider	*Petauroides volans*		Spotlighting	A_folivore	Y H	Y	Y		Y P			58.6	na
Mountain Brushtail Possum	*Trichosurus caninus*		Spotlighting	A_folivore	Y H		Y					13.9	6.6
Common Brushtail Possum	*Trichosurus vulpecula*		Spotlighting	A_folivore	Y H	Y						19.2	55.3
Common Ringtail Possum	*Pseudocheirus peregrinus*		Spotlighting	A_folivore	Y			Y				15.8	5.1
Feathertail Glider	*Acrobates pygmaeus*		Spotlighting	Nectar_omn	Y H	Y						3.4	na
Eastern Pygmy Possum	*Cercartetus nanus*		Trapping	Nectar_omn	Y H			Y	Y	Y		<1	na
Long-nosed Potoroo	*Potorous tridactylus*	Y	Trapping	G_folivore	Y			Y	Y			<1	4.2

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Red-necked Pademelon	*Thylogale thetis*	Y		G_folivore	Y			Y	Y			2.4	6.7
Red-legged Pademelon	*Thylogale stigmatica*	Y		G_folivore	Y		Y	Y	Y	Y		<1	3.1
Rufous Bettong	*Aepyprymnus rufescens*	Y		G_folivore	Y	Y		Y	Y	Y		2.3	<2.5
Parma Wallaby	*Notamacropus parma*	Y		G_folivore	Y			Y	Y	Y		3.2	<2.5
Red-necked Wallaby	*Notamacropus rufogriseus*	Y		G_folivore	Y	Y						22.8	29.3
Black-striped Wallaby	*Notamacropus dorsalis*	Y		G_folivore	Y			Y	Y	Y		<1	<2.5
Grey-headed Flying-fox	*Pteropus poliocephalus*	Y	Spotlighting	Frugivore/nectarivore	Y		Y		Y	Y		1.6	na
Gould's Long-eared Bat	*Nyctophilus gouldii*		Harp trapping	Insectivore	Y H	Y						18.6	na
Lesser Long-eared Bat	*Nyctophilus geoffroyi*		Harp trapping	Insectivore	Y H							3.7	na
Large Bent-wing Bat	*Miniopterus orianae*	Y		Insectivore	Y				Y			10.2	na
Little Bent-wing Bat	*Minopterus australis*	Y		Insectivore	Y	Y			Y	Y		8.6	na
Large-eared Pied Bat	*Chalinolobus dwyeri*	Y		Insectivore	Y	Y			Y			1.0	na
Greater Broad-nosed Bat	*Scoteanax rueppellii*	Y		Insectivore	Y H	Y			Y	Y		3.4	na
Eastern Broad-nosed Bat	*Scotorepens orion*	Y		Insectivore	Y H	Y						6.3	na
Golden-tipped Bat	*Phoniscus papuensis*		Harp trapping	Insectivore	Y	Y	Y		Y	Y		1.1	na
Eastern False Pipistrelle	*Falsistrellus tasmaniensis*	Y		Insectivore	Y H	Y			Y			10.7	na
Southern Forest Bat	*Vespadelus regulus*	Y		Insectivore	Y H	Y						18.9	na
Large Forest Bat	*Vesapdelus darlingtoni*	Y		Insectivore	Y H	Y						na	na
Eastern Forest Bat	*Vespadelus pumilus*	Y		Insectivore	Y H	Y						18.4	na
Eastern Cave Bat	*Vespadelus troughtoni*	Y		Insectivore	Y	Y			Y			na	na
Large-footed Macropus	*Myotis macropus*	Y		Insectivore	Y H	Y			Y			1.0	na
East Coast Freetail Bat	*Micronomus norfolkensis*	Y		Insectivore	Y H	Y			Y			1.8	na
Eastern Freetail Bat	*Ozimops ridei*	Y		Insectivore	Y H	Y						na	na

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Yellow-bellied Sheath-tailed Bat	*Saccolaimus flaviventris*	Y		Insectivore	Y H	Y			Y	Y		1.0	na
White-striped Freetail bat	*Austronomus australis*	Y		Insectivore	Y H							15.7	na
Hastings River Mouse	*Pseudomys oralis*		Trapping	G_folivore	Y		Y	Y	Y	Y		<1	na
Smoky Mouse	*Pseudomys fumeus*	Y	Trapping	G_granivore	Y			Y	Y			na	na
European Red Fox	*Vulpes vulpes*	Y	Trapping, signs	L_carnivore	Y						Y	<1	39.7
Feral Cat	*Felis catus*	Y	Trapping, signs	S_carnivore	Y						Y	2.9	17.6
Dog/Dingo	*Canis familiaris*	Y	Trapping, signs	L_carnivore							Y	5.7	8.5
Feral Goat	*Capra hircus*	Y	Signs	G_folivore							Y	<1	5.6
Fallow Deer	*Dama dama*	Y	Signs	G_folivore							Y	<1	3.8
Feral Pig	*Sus scrofa*	Y	Signs	Fungivore							Y	2.1	10.1
European Rabbit	*Oryctolagus cuniculus*	Y	Signs	G_folivore							Y	2.9	11.0
Birds													
Grey Goshawk	*Accipiter novaehollandiae*		Survey	S_carnivore	Y	Y						1.6	na
Square-tailed Kite	*Lophoictinia isura*		Survey	S_carnivore	Y	Y			Y	Y		<1	na
Bush Stone-curlew	*Burhinus grallarius*	Y		Insectivore				Y	Y	Y		<1	na
Wompoo Fruit-dove	*Ptilinopus magnificus*	Y		Frugivore	Y				Y	Y		4.7	na
Glossy Black Cockatoo	*Calyptorhynchus banksii*	Y	Signs	A_granivore	Y H	Y			Y	Y		7.9	na
Yellow-tailed Black Cockatoo	*Zanda funerea*	Y		A_granivore	Y H	Y						5.2	na
Australian King Parrot	*Alisterus scapularis*	Y		Frugivore	Y H	Y						36.0	na
Crimson Rosella	*Platycercus elegans*	Y		A_granivore	Y H	Y						66.9	na
Little Lorikeet	*Parvipsitta pusilla*	Y		Nectar_omn	Y H	Y			Y	Y		3.6	na
Sooty Owl	*Tyto tenebricosa*	Y	Call-playback	L_carnivore	Y H	Y			Y	Y		10.8	na
Masked Owl	*Tyto novaehollandiae*	Y	Call-playback	S_carnivore	YH	Y			Y			7.0	na

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Powerful Owl	*Ninox strenua*	Y	Call-playback	L_carnivore	YH	Y			Y	Y		12.3	na
Barking Owl	*Ninox connivens*	Y	Call-playback	S_carnivore	YH	Y			Y	Y		<1	na
Southern Boobook	*Ninox novaeseelandiae*	Y		S_carnivore	YH							41.2	na
White-throated Nightjar	*Eurostopodus mystacalis*	Y		Insectivore	Y			Y				4.0	na
Superb Lyrebird	*Menura novaehollandiae*	Y		Insectivore	Y							27.1	36.5
Rufous Scrub-bird	*Atrichornis rufescens*	Y	Call-playback	Insectivore	Y		Y	Y	Y	Y		<1	na
Red-browed Treecreeper	*Climacteris erythrops*	Y		Insectivore	Y H	Y			Y			47.7	na
Brown Treecreeper	*Climacteris picumnus*	Y		Insectivore	Y H	Y			Y	Y		1.5	na
Speckled Warbler	*Chthonicola sagittata*	Y		Insectivore	Y	Y		Y	Y	Y		<1	<2.5
Buff-rumped Thornbill	*Acanthiza reguloides*	Y		Insectivore	Y	Y						16.8	na
Brown-headed Honeyeater	*Melithreptus brevirostris*	Y		Nectar_omn	Y	Y						1.9	na
White-naped Honeyeater	*Melithreptus lunatus*	Y		Nectar_omn	Y	Y						49.8	na
Bell Miner	*Manorina melanophrys*	Y		Nectar_omn	Y						Y	7.4	na
Noisy Miner	*Manorina melanocephala*	Y		Nectar_omn	Y						Y	2.3	na
Grey-crowned Babbler	*Pomatostomus temporalis*	Y		Insectivore	Y	Y			Y			<1	na
Spotted Quail-thrush	*Cinclosoma punctatum*	Y	Survey	Insectivore	Y	Y		Y				4.9	9.6
Varied Sittella	*Daphoenositta chrysoptera*	Y		Insectivore	Y	Y			Y	Y		22.6	na
Crested Shrike-tit	*Falcunculus frontatus*	Y		Insectivore	Y	Y						15.5	na
Olive Whistler	*Pachycephala olivacea*	Y		Insectivore	Y		Y		Y	Y		1.0	na
Dusky Woodswallow	*Artamus cyanopterus*	Y	Survey	Insectivore	Y	Y			Y	Y		1.8	na
Leaden Flycatcher	*Myiagra rubecula*	Y		Insectivore	Y	Y						30.9	na
Satin Flycatcher	*Myiagra cyanoleuca*	Y		Insectivore	Y	Y						9.1	na
Scarlet Robin	*Petroica boodang*	Y		Insectivore	Y	Y			Y	Y		7.4	na

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Flame Robin	*Petroica phoenicea*	Y		Insectivore	Y				Y	Y		7.9	na
Pale Yellow Robin	*Tregellasia capito*	Y		Insectivore	Y	Y						12.4	na
Mistletoebird	*Dicaeum hirundinaceum*	Y		Frugivore	Y	Y						53.3	na
Reptiles													
Robust Velvet Gecko	*Nebulifera robusta*		Survey	Insectivore	Y							na	na
Southern Leaf-tailed Gecko	*Saltuarius swaini*		Survey	Insectivore	Y	Y						2.1	na
Rosenberg's Goanna	*Varanus rosenbergi*	Y	Survey	S_carnivore	Y				Y	Y		na	na
Lace Monitor	*Varanus varius*	Y	Survey	S_carnivore	Y	Y						7.6	7.8
Southern Angle-headed Dragon	*Lophosaurus spinipes*		Survey	Insectivore	Y	Y						2.9	na
Red-tailed Calyptotis	*Calyptotis ruficauda*		Survey/ Trapping	Insectivore	Y							8.2	na
Scute-snouted Calyptotis	*Calyptotis scutirostrum*		Survey/ Trapping	Insectivore	Y							14.2	na
Litter Skink	*Lygisaurus foliorum*		Survey/ Trapping	Insectivore	Y							na	na
Three-toed Snake-tooth Skink	*Coeraniscincus reticulatus*		Survey/ Trapping	Insectivore	Y				Y	Y		na	na
Cunninghams Skink	*Egernia cunninghami*		Survey/ Trapping	Insectivore	Y							2.7	na
Major Skink	*Egernia frerei*		Survey/ Trapping	Insectivore	Y							na	na
Eastern Crevice Skink	*Egernia mcpheei*		Survey/ Trapping	Insectivore	Y							3.1	na
Black Rock Skink	*Egernia saxatilis*		Survey/ Trapping	Insectivore	Y							1.8	na
Yellow-bellied Water-skink	*Eulamprus heatwolei*		Survey/ Trapping	Insectivore	Y							8.2	na
Martin's Bar-sided Skink	*Concinnia martini*		Survey/ Trapping	Insectivore	Y							2.6	na
Murray's Skink	*Eulamprus murrayi*		Survey/ Trapping	Insectivore	Y							16.0	na
Greater Bar-sided Skink	*Concinnia tenuis*		*Survey/ Trapping*	Insectivore	Y	Y						8.7	na
Rainforest Cool-skink	*Harrisoniascincus zia*		Survey/ Trapping	Insectivore	Y					Y		na	na
Garden Sun-Skink	*Lampropholis delicata*		Survey/ Trapping	Insectivore	Y							61.2	na

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Maccoy's Skink	*Anepischetosia maccoyi*		Survey/ Trapping	Insectivore	Y							na	na
Southern Forest Cool-skink	*Carinascincus coventryi*		Survey/ Trapping	Insectivore	Y	Y						na	na
Short-limbed Snake Skink	*Ophioscincus truncatus*		Survey/ Trapping	Insectivore	Y	Y						3.1	na
Spencer's Skink	*Pseudemoia spenceri*		Survey/ Trapping	Insectivore	Y							na	na
Three-toed Skink	*Saiphos equalis*		Survey/ Trapping	Insectivore	Y							20.8	na
Weasel Skink	*Saproscincus mustelinus*		Survey/ Trapping	Insectivore	Y							7.1	na
Rose's Skink	*Saproscincus rosei*		Survey/ Trapping	Insectivore	Y							na	na
Diamond/Carpet Pythons	*Morelia spilota*	Y	Survey	L_carnivore	Y H							1.1	na
Green Tree Snake	*Dendrelaphis punctulatus*		Survey	S_carnivore	Y H							na	na
Golden-crowned Snake	*Cacophis squamulosus*		Survey	S_carnivore	Y							na	na
Pale-headed Snake	*Hoplocephalus bitorquatus*		Survey	S_carnivore	YH				Y	Y		na	na
Stephen's Banded Snake	*Hoplocephalus stephensii*		Survey	S_carnivore	YH	Y			Y	Y		na	na
Eastern Small-eyed Snake	*Cryptophis nigrescens*		Survey	S_carnivore	Y	Y						2.1	na
Frogs													
Pouched Frog	*Assa darlingtoni*	Y	Survey	Insectivore	Y		Y		Y	Y		1.0	na
Giant Burrowing Frog	*Heleioporus australiacus*	Y	Survey	Insectivore	Y				Y	Y		<1	na
Stuttering Frog	*Mixophyes balbus*	Y	Survey	Insectivore	Y	Y			Y	Y		<1	na
Fleay's Barred Frog	*Mixophyes fleayi*	Y	Survey	Insectivore	Y				Y			<1	na
Giant Barred Frog	*Mixophyes iteratus*	Y	Survey	Insectivore	Y				Y	Y		<1	na
Loveridge's Frog	*Philoria loveridgei*	Y	Survey	Insectivore	Y		Y		Y	Y		<1	na
Sphagnum Frog	*Philoria sphagnicola*	Y	Survey	Insectivore	Y		Y		Y			<1	na

Common name	Scientific name	D_Cam-SongBat	D_Other	Ecol_group	FD	S_Log	S_Climate	S_Pred	NSW BC Act	SOS	ThreatP	Freq (%)	Wcams (%)
Red-crowned Toadlet	*Pseudophryne australis*	Y	Survey	Insectivore	Y				Y			<1	na
Red-backed Toadlet	*Pseudophryne coriacea*	Y	Survey	Insectivore	Y							7.9	na
Booroolong Frog	*Litoria booroolongensis*	Y	Survey	Insectivore	Y		Y		Y			<1	na
Blue Mountains Tree Frog	*Litoria citropa*	Y	Survey	Insectivore	Y							<1	na
Davies' Tree Frog	*Litoria daviesae*	Y	Survey	Insectivore	Y		Y		Y			<1	na
Bleating Tree Frog	*Litoria dentata*	Y	Survey	Insectivore	Y							1.9	na
Littlejohn's Tree Frog	*Litoria littlejohni*	Y	Survey	Insectivore	Y				Y	Y		<1	na
Southern Leaf Green Tree Frog	*Litoria nudidigita*	Y	Survey	Insectivore	Y							na	na
Pearson's Tree Grog	*Litoria pearsoniana*	Y	Survey	Insectivore	Y							na	na
Leaf Green Tree Frog	*Litoria phyllochroa*	Y	Survey	Insectivore	Y							<1	na
Glandular Frog	*Litoria subglandulosa*	Y	Survey	Insectivore	Y				Y			<1	na

Listing criteria:

- **D_CamSongBat:** Species detectable reliably using the survey methods proposed (FMIP and Coastal IFOA monitoring program) – cameras, songmeters, bat-call detectors
- **D_Other:** Survey method most appropriate for detecting this species (e.g. trapping, spotlighting or other specialised surveys)
- **Ecol_group:** Species functional group (Kavanagh and Stanton 2005): arboreal folivore, arboreal granivore, nectarivore/omnivore, frugivore, large carnivore (prey size > 120 g), small carnivore (prey size 5–120 g), insectivore (prey size < 5 g), fungivore, ground granivore, ground folivore (grazer)
- **FD:** Forest-dependent for all or part of their life-cycle; H = hollow-dependent
- **S_Log:** known or suspected to be sensitive to intensive logging (Kavanagh *et al.* 2004; Kavanagh and Stanton 2005)
- **S_Pred:** known or suspected to be sensitive to introduced predators (includes CWR species)
- **S_Climate:** known or suspected to be sensitive to climate change
- **NSW BC:** listed as 'threatened' under NSW BC Act
- **SOS:** listed as NSW 'Saving Our Species' priorities for modelling (M. Drielsma, pers. comm.)
- **ThreatP:** key threatening process

- **Freq (%):** naïve frequency of occurrence for species occurring at ≥ 1% sites, n = 619 sites) using 'standard' survey procedures (using North Coast EIS data)
- **Wcams (%):** WildCount mean site frequency 2012–2016 using cameras (n = 200 sites)

H – Tree-hollow dependent

P – Endangered populations in NSW, but listed nationally as threatened (*Environment Protection and Biodiversity Conservation Act 1999* Cwth)

Notes: *This list includes species that are difficult to detect using 'standard survey and monitoring methods' (e.g. most reptiles and frogs, and some priority mammals and birds), suggesting that additional survey techniques will need to be included in fauna monitoring programs.

Table 2. Abbreviated list of 31 priority fauna species

Priority fauna species for monitoring in the Forest Monitoring Improvement Program and the Coastal Integrated Forest Operations Approvals Program

Species	**Included in the FMIP priority species list**	**Included in the Coastal IFOA monitoring program priority species list**
Barking Owl	Yes	Yes
Bell Miner	*Replaces Noisy Friarbird for call recogniser program as an indicator/driver of change*	
Brown Treecreeper	Yes	Yes
Common Wombat	Yes	No
Eastern False Pipistrelle	Yes	Yes
East-coast Freetail bat	Yes	Yes
Giant Barred Frog	Yes	Yes
Glossy Black-cockatoo	Yes	Yes
Greater Broad-nosed Bat	Yes	Yes
Greater Glider	No	Yes
Grey-crowned Babbler	No	Yes
Grey-headed Flying Fox	Yes	Yes
Koala	Yes	Yes
Large-eared Pied Bat	Yes	No
Long-nosed Bandicoot	Yes	Yes
Long-nosed Potoroo	Yes	Yes
Masked Owl	Yes	Yes
Powerful Owl	Yes	Yes
Rufous Bettong	Yes	Yes
Rufous Scrub-bird	No	Yes
Sooty Owl	Yes	Yes
Southern Boobook	Yes	Yes
Southern Brown Bandicoot	Yes	Yes
Southern Myotis	Yes	Yes
Spotted-tail Quoll	Yes	Yes
Squirrel Glider	Yes	Yes
Stuttering Frog	Yes	Yes
Sugar Glider	Yes	Yes
Varied Sittella	Yes	Yes
Yellow-bellied Glider	Yes	Yes
Yellow-bellied Sheath-tailed Bat	Yes	Yes

5. Flora species prioritisation

Priority flora species for this project were selected by identifying native species deemed to be the most responsive to (i.e. sensitive to or tolerant of) the main drivers of forest ecosystem change or, in the case of weeds, introduced species capable of causing significant forest ecosystem change. The main drivers were: (1) forest harvest operations, (2) fire, (3) climate change, (4) weeds, (5) Root-rot Fungus or Phytophthora (*Phytophthora cinnamomi*), and (6) Myrtle Rust (*Austropuccinia psidii*). For species selected due to harvest forest operations, fire and climate change, we chose species that are reasonably widespread in eastern NSW forests and from a range of life-forms in order to maximise the likelihood that, should they become a focus of future flora monitoring of NSW forests, such monitoring will be efficient (with at least a modest probability of encountering priority species), and should new threats to plant biodiversity arise, the range of life-forms will maximise the chance that some of these priority species are impacted. The criterion of 'reasonably widespread' was relaxed for priority weeds to include species with the potential to increase through time, and for species susceptible to Phytophthora and Myrtle Rust in order to include the species most sensitive to these pathogens. Threatened plant species were not included in the list of priority flora species for this project because most threatened plant species are rare or highly restricted in distribution and bespoke monitoring programs have or are being developed for many of these species by the NSW Government's 'Saving Our Species' program (see https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-program). The needs of a state-wide forest flora monitoring program are unlikely to serve the specific needs of individual rare flora species, which deserve customised programs going forward.

In order to identify reasonably widespread species most likely to be affected by (1) forest harvest operations, (2) fire, and (3) climate change, we used the NSW Government database of 5,248 full-floristic survey plots collected between 1987 and 2000 by government agencies (described in Section 6.1.2).

We could not locate accurate consolidated spatial information about the type, timing and intensity of forest harvest operations in the study region up to 1998, so we used the reciprocal of forest harvest operations, mapped candidate old-growth (COG) forest, in order to identify species strongly associated or dissociated with COG. COG mapping was developed as part of the Comprehensive Regional Assessment (CRA) process, which also formed the basis for many of the fauna surveys that inform the occupancy models. 'Candidate' old-growth forest was so-named because it was mapped by aerial photographic interpretation in the 1990s. Field validation to confirm the mapping did not occur.

Timber harvesting has been permanently excluded from these mapped areas since the early 2000s under revised forestry rule sets. In the absence of a robust historical harvesting layer, the COG spatial layer was used as surrogate for logging history and to mask out 'undisturbed' areas. However, it is important to note there are significant and known inaccuracies with the COG layer, including capturing areas of forest that do not meet the definition of old-growth forest and some areas where timber harvesting had occurred prior to the early 2000s. The COG layer was derived from forest growth-stage mapping of the varying proportions of senescent and regrowth trees in the forest canopy. In this study, candidate old growth represented areas in the mid-1990s where at least 10% of the forest canopy included 'senescent' trees and less than 10% was even-aged 'regrowth' following clearing, intensive logging or wildfire. Accordingly, COG mapped areas represented areas in the 1990s that included elements (e.g. old, hollow-bearing trees) of long-undisturbed forest (i.e. old-growth or mature forest).

Spatial fire information layers (Number of Fires since 1962 at a Site, and Number of Years since the Last Fire at a Site) were available to identify fire-responsive species. COG and fire history variables are more fully described in Section 6.1.4.

To identify species sensitive to climate change, we used the range in elevation, latitude, temperature and precipitation of the survey plots referred to above in which each species occurred. We reasoned that species that occupy a narrow range of any of these climate-critical variables and that also occur near the upper or lower limits of these variables are likely to be species least able to colonise other parts of the landscape as climate changes in the medium to longer term. Weeds were selected by identifying the species most likely to influence the ecosystem dynamics of eastern NSW forests, either by invading and changing the composition, structure or dynamics of undisturbed forest or changing, deflecting or arresting forest succession after disturbance. Priority weed species were identified from the list of Weeds of National Significance (CISS 2021). Flora species sensitive to Phytophthora and Myrtle Rust were identified by reviewing national lists of highly susceptible species and selecting the species that occur in eastern NSW forests.

The complete list of 192 priority flora taxa (191 species including two subspecies of *Chrysanthemoides monilifera*) is shown in Table 3. As the baseline flora dataset contained records of over 3,000 native and introduced vascular plant species (Section 7.1.2.3), we focused flora species distribution modelling in this project on these 191 priority flora species (Section 7.2.2.3). Similarly, climate projection modelling was confined to the priority flora species selected for likely climate sensitivity (Section 7.3.2). These 192 priority taxa are also a suitable focus of flora monitoring in the FMIP and Coastal IFOA programs going forward.

The commercial grazing of cattle and grazing by feral herbivores (deer, goats, pigs, horses) were identified as important drivers of ecosystem change in eastern NSW forests (Sections 3.1 and 3.2), However, we could not locate suitable spatial layers of historic information (in the period up to 2000) relating to the distribution of commercial grazing leases or the abundance of cattle or feral herbivores in eastern NSW forests to help identify affected flora species.

Note: flora taxonomy is continually changing. In this report, flora nomenclature is that used in PlantNet (https://plantnet.rbgsyd.nsw.gov.au/) at the time the data for this project were compiled (October 2020). For some taxa, this taxonomy differs from that currently accepted in the Australian Plant Census (APC, https://www.anbg.gov.au/chah/apc/). Appendix 2 provides a list of species with equivalent or closest matching APC names current at July 2021.

Table 3. The priority flora species selected for modelling habitat suitability and climate projections in this project and for future flora monitoring

Priority codes indicate the reason(s) the species was included in the priority list: C = climate change; F = fire; M = Myrtle Rust; O = candidate old-growth (COG) forest; P = Phytophthora; W = weed. Species response to fire: Y (+) = more frequent in unburmt areas; Y (−) = more frequent in burnt areas. Species response to COG: Y (+) = more frequent in COG; Y (−) = more frequent in forest disturbed by timber harvesting operations. Naïve occupancy is the percentage frequency of the species in 5,248 vegetation survey plots sampled between 1987 and 2000 (Section 6.1.2). Introduced species are indicated with an asterisk. Data for W, M and P species descriptions were sourced from PlantNET: NSW Flora Online *and* Atlas of Living Australia

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Acacia concurrens	Locally abundant small tree or shrub occurring at low elevations in the north-east, widespread in dry forest on low to medium fertility soils	2.74	Y					
Acacia dealbata	Common but temperature-restricted small tree or shrub, widespread in shrubby and grassy sclerophyll forests on the Southern Tablelands and locally common in parts of the Northern Tablelands, often on fertile soils; more frequent in unburnt areas in Eden region, than those with 3 or more fires	7.41	Y	Y (+)				
Acacia irrorata	Widespread tree, more frequent in Southern region in areas burnt 16–30 years ago than unburnt and slightly but not significantly more frequent in at least some burning classes relative to unburnt in northern regions	8.57		Y (−)				
Acacia mearnsii	Widespread and locally common South Coast tree occurring especially in drier areas	4.52	Y					
Acacia melanoxylon	Very widespread tree more frequent in unburnt areas relative to at least some burnt classes, in UNE, LNE and Southern regions	13.74		Y (+)				
Acacia obtusifolia	Widespread shrub or small tree more frequent in disturbed areas (not COG) in Eden region, more frequent in burnt areas in Southern region, but with contrary although less marked responses in other regions	6.19		Y (−)	Y (−)			
Acacia terminalis	Widespread shrub in dry shrubby forests, common on soils of low fertility, especially on the South Coast	4.61	Y					
Ackama paniculosa	Rainforest and wet sclerophyll canopy or understorey tree with a consistently higher occurrence in unburnt areas in both UNE and LNE and a higher frequency in disturbed areas in UNE	6.49		Y (+)	Y (−)			
Acmena smithii	Rainforest and wet sclerophyll tree with consistently higher frequency in unburnt areas in three regions and higher frequency in COG in LNE	9.13		Y (+)	Y (+)			

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Acrothamnus hookeri	Small shrub widespread in grassy forests at higher elevations on the Southern Tablelands and parts of the Northern Tablelands but rarely abundant	2.27	Y					
Adiantum hispidulum	Terrestrial fern with higher frequency in COG in LNE, but weaker and contrasting response in UNE; one of very few terrestrial ferns with a significant response to COG	4.80			Y (+)			
Alectryon subcinereus	Rainforest and wet sclerophyll tree and one of very few species with a significantly higher frequency in COG, in this case in UNE	4.74			Y (+)			
Alpinia caerulea	Giant herb very common in wet sclerophyll forests on the North Coast	4.67	Y					
Angophora costata	Canopy tree very widespread in coastal areas at low elevation, mostly in shrubby forests, on soils of low to moderate fertility, in both wet and dry forests	3.35	Y					
Angophora subvelutina	Widespread tree common in grassy forests in North Coast valleys, especially on soils of moderate fertility	3.28	Y					
Angophora woodsiana	Canopy-dominant tree of coastal lowlands and low ranges north from Coffs Harbour, usually on low fertility sandy soils on slopes and flats	1.81	Y					
**Anredera cordifolia*	Widely naturalised vine with stems to 20 m long in mainly moist situations in coastal districts; invasive weed of rainforest margins	0.02						Y
Archirhodomyrtus beckleri	Small tree, mostly in wet sclerophyll understorey, consistently more frequent in unburnt areas and also adversely sensitive to Myrtle Rust	4.76		Y (+)		Y		
Archontophoenix cunninghamiana	Palm that is more frequent in unburnt areas in UNE; one of three palm species in NSW	3.73		Y (+)				
Aristida ramosa	Grass widespread on North and South Coast, in drier forests on low fertility soils	2.32	Y					
**Asparagus aethiopicus*	Ornamental shrub with sprawling to pendent perennial stems to 2 m long, extensively naturalised and a serious weed of bushland, especially in Sydney region	0.08						Y
**Asparagus asparagoides*	Climbing herb with annual stems to 3 m long cultivated as an ornamental; naturalised and widespread in coastal districts but extending inland west of study region and a major weed especially in the Sydney region	0.04						Y
Asperula scoparia	Low herb or subshrub, common in grassy forests on Southern Tablelands	5.39	Y					

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Asplenium australasicum	Epiphyte more frequent in unburnt areas in UNE; epiphytes as a plant form are expected to be adversely affected by various types of disturbance	6.04		Y (+)				
Astroloma humifusum	Mat-forming shrub with branches ascending to 50 cm high, often growing in disturbed sites on ridges and slopes in dry sclerophyll forest over sandstone, shales or basalt, south from Newcastle; sensitive to Phytophthora	1.73					Y	
Backhousia leptopetala	Shrub or tree, grows on rainforest margins on poorer soils, often near watercourses or on ridges in wet sclerophyll forest, north from Wollongong; sensitive to Myrtle Rust	0.00				Y		
Banksia oblongifolia	Shrub in heathy forest and woodland in coastal lowlands and low coastal ranges north from Ulladulla, usually on sandy soils and often in areas of seasonally impeded drainage	2.21	Y					
Banksia spinulosa	Dry sclerophyll shrub more frequent in burnt areas in UNE and LNE, although banksias are potentially sensitive to high frequency fire; higher frequency in COG in UNE is most likely an artefact of the higher likelihood of COG in low-nutrient heathy forest	6.00		Y (−)				
Bedfordia arborescens	Small tree or shrub, abundant in wet sclerophyll forests in coastal and escarpment ranges in Eden region and southern part of Southern region	2.65	Y					
Blechnum cartilagineum	Terrestrial fern with higher frequency in unburnt areas in UNE, but weaker and contrasting response in Southern region; example of a terrestrial fern with significant response to fire	16.22		Y (+)				
Boronia parviflora	Herb or low shrub to 1 m, widespread in heathy swamps, especially along the coast between Ulladulla and South West Rocks, but also inland in UNE; sensitive to Phytophthora	0.15					Y	
Bossiaea cinerea	Erect or spreading shrub to 1 m, in coastal sandy heath and sclerophyll forest, south from Bega; sensitive to Phytophthora	0.00					Y	
Bossiaea neo-anglica	Low shrub of dry sclerophyll forest on the Northern Tablelands, usually on sandy soils on granite or sandstone	1.60	Y					
Brunoniella pumilio	Widespread herb in lowland dry sclerophyll forest on sandstone, mainly on the Central Coast and northern part of the South Coast	1.94	Y					
Cassinia aculeata	Common southern shrub with a higher frequency in disturbed areas and in unburnt relative to very recently burnt areas in Southern region	5.47		Y (+)	Y (−)			

Species	**Description**	**Naïve occupancy (%)**	**Climate change**	**Fire**	**Candidate old growth**	**Myrtle Rust**	**Phytoph-thora**	**Weed**
Cassinia trinerva	Shrub, locally common in wet sclerophyll forests in coastal ranges, mainly on the South Coast	2.19	Y					
Ceratopetalum apetalum	Common and widespread rainforest canopy tree more frequent in unburnt areas and weakly more frequent in COG areas	2.61		Y (+)	Y (+)			
**Chrysanthemoides monilifera* subsp. *monilifera*	Erect relatively short-lived (10–20 years) shrub to 2–3 m, spreading by seed and with potential to significantly increase in native undisturbed vegetation including grasslands, scrub, woodlands and open forests, in particular in coastal fringe, south from Sydney	0.02						Y
**Chrysanthemoides monilifera* subsp. *rotundata*	Sprawling shrub to 1–2 m in height, occasionally forming a canopy 10 m high, growing on sand dunes and forest margins near beaches and actively invading coastal dune vegetation in NSW where it out-competes and can totally eliminate native flora	0.55						Y
Chrysocephalum apiculatum	Widespread but scattered herb in drier grassy forests in all regions except Eden (C).	3.14	Y					
Cissus hypoglauca	Rainforest and wet sclerophyll vine more frequent in unburnt areas in UNE and LNE	17.00		Y (+)				
Coprosma hirtella	Southern Tablelands shrub common in shrubby wet sclerophyll and wetter dry sclerophyll forests	2.32	Y					
Correa lawrenceana	Widespread shrub or small tree, 0.6–9 m high, in rainforest and sclerophyll forest throughout study region; sensitive to Phytophthora	0.17					Y	
Correa reflexa	Widespread shrub common in dry shrubby forests on South Coast and ranges; less common on North Coast	3.13	Y					
Corymbia maculata	Widespread stand-dominant canopy tree more frequent in disturbed areas (not COG) in UNE and Southern regions, possibly due to most areas where this species occurs having been logged. Note: *C. maculata* and *C. variegata* were combined because early records did not consistently distinguish among these vicariant species.	7.77			Y (−)			
Croton verreauxii	Small tree or shrub widespread and often abundant in wet sclerophyll forests and rainforest margins, on coast and in foothills of ranges in north	2.53	Y					
Cyathea australis	Tree fern more frequent in disturbed areas in UNE and less frequent in unburnt areas in Eden	10.71		Y (−)	Y (−)			

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
**Cytisus scoparius*	Erect, ascending or procumbent shrub to 2.5 m, naturalised in cooler regions south from Glen Innes district; invasive in woodland and difficult to eradicate (e.g. Barrington Tops NP, Blue Mountains); several orchid species and a daisy shrub at Barrington Tops are at risk from invasion	0.23						Y
Daviesia wyattiana	Sporadic sparse shrub to 1–2.5 m in dry sclerophyll forest on ridges with skeletal soils north from Woolgoolga and south from Budawang Range; sensitive to Phytophthora	0.25					Y	
Decaspermum humile	Shrub or tree to 15 m in coastal or riparian rainforest, north from Gosford area; sensitive to Mrtle Rust	0.10				Y		
Dendrobium pugioniforme	Epiphyte more frequent in undisturbed (COG) areas in UNE; epiphytes as a plant form are expected to be adversely affected by various types of disturbance	2.12			Y (+)			
Denhamia bilocularis	Small tree or shrub widespread in dry rainforests and associated shrubby eucalypt forests on the North Coast and escarpment	3.24	Y					
Dillwynia glaberrima	Widespread erect shrub to 1–2 m in heath and dry sclerophyll forest on stony to sandy substrates in coastal districts; sensitive to Phytophthora	0.55					Y	
Dillwynia sericea	Erect shrub 0.5–1 m in exposed heath, woodland and dry sclerophyll forest on a variety of substrates in southern regions and western part of UNE; sensitive to Phytophthora	0.72					Y	
Dodonaea triquetra	Very widespread, relatively short-lived shrub, locally abundant in coastal ranges in all regions	2.71	Y					
**Dolichandra unguis-cati*	Invasive woody climber reaching up to 30 m in height when climbing over tall trees in disturbed rainforest, sclerophyll forest, woodland, scrub and riparian vegetation, often in gullies and creekbanks; chiefly in coastal districts north from Sydney	0.00						Y
Echinopogon ovatus	Widespread grass more frequent in disturbed (not COG) areas in LNE and in unburnt areas in Southern and Eden	10.12		Y (+)	Y (−)			
Embelia australiana	Rainforest and wet sclerophyll vine and one of very few species more frequent in undisturbed (COG) areas, in this case in UNE; also more frequent in unburnt areas in UNE and LNE	3.53		Y (+)	Y (+)			
Epacris impressa	Common shrub in dry sclerophyll forests in Eden region, especially on low fertility soils	3.94	Y				Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Epacris paludosa	Erect bushy shrub to 100 cm, rarely to 150 cm, in swamps, bogs and wet heath on sandstone and granite up to 1700 m elevation; south from Sydney and Blue Mountains; sensitive to Phytophthora	0.38					Y	
Eragrostis leptostachya	Widespread and common grass in drier grassy forests in all regions	3.64	Y					
Eremophila debilis	Prostrate shrub with scattered distribution in drier grassy forests of UNE region, often on soils of medium to high fertility	1.98	Y					
Eucalyptus agglomerata	Common canopy-dominant tree mostly on ridges and upper slopes in Southern and Eden regions and southern parts of LNE, with scattered localised occurrences further north	3.98	Y					
Eucalyptus biturbinata	Widespread canopy-dominant tree of mainly grassy forests on drier parts of coastal ranges and escarpment in UNE and LNE regions	2.78	Y					
Eucalyptus brunnea	Canopy-dominant tree in eastern Northern Tablelands, usually occurring in grassy forest on flat to undulating topography on moderately fertile soils	1.71	Y					
Eucalyptus caliginosa	Canopy-dominant tree of grassy forests in drier parts of Northern Tablelands	2.63	Y					
Eucalyptus cameronii	Canopy-dominant tree of grassy or shrubby forests of eastern parts of Northern Tablelands and higher parts of escarpment	3.56	Y					
Eucalyptus campanulata	Canopy-dominant tree abundant and very widespread at higher elevations in UNE and LNE	9.24	Y					
Eucalyptus cypellocarpa	Widespread canopy-dominant tree in gullies and lower slopes in coastal ranges of South Coast, especially Eden region, with scattered localised occurrences in drier areas at higher elevations in LNE region	6.97	Y					
Eucalyptus dalrympleana	Very widespread canopy-dominant tree in tablelands grassy forests in all regions	5.03	Y					
Eucalyptus elata	Locally dominant South Coast canopy tree, mainly in gullies and on lower slopes at low to mid elevations	2.57	Y					
Eucalyptus fastigata	Canopy-dominant tree widespread in cooler areas of Southern Tablelands and escarpment and southern parts of Northern Tablelands, often on soils of high fertility; more frequent in undisturbed (COG) areas in Eden, although this may be an artefact of COG assessment of older stands of regrowth; a climate-restricted species	5.13	Y		Y (+)		Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Eucalyptus fraxinoides	Tree to 40 m, locally frequent, in wet or dry sclerophyll forest on range country of coast and eastern tablelands; south from Sassafras; sensitive to Phytophthora	1.03					Y	
Eucalyptus imlayensis	Mallee to 7 m high, known from one stand in sclerophyll woodland on skeletal soil on steep granite slopes of Mt Imlay, near Vic border; sensitive to Phytophthora	0.00					Y	
Eucalyptus laevopinea	Canopy-dominant tree occurring commonly on the escarpment and adjacent tablelands and higher ranges, north from Mount Royal	4.02	Y					
Eucalyptus longifolia	Canopy-dominant tree of coastal lowlands of South Coast, usually on moderately fertile soils on alluvial flats or lower slopes	1.47	Y					
Eucalyptus macrorhyncha	Canopy tree occurring mainly in western part of Southern RFA region around the slopes of Bago Plateau	3.13	Y					
Eucalyptus melliodora	Canopy tree in all regions, occurring sporadically in cooler, drier sites, mainly on tablelands and adjacent escarpment, with isolated occurrence at lower elevations in coastal ranges	2.55	Y					
Eucalyptus moluccana	Canopy-dominant tree occurring mostly on coastal lowlands in UNE and LNE regions, most frequently on flat to undulating topography and often in lower parts of landscape	2.38	Y					
Eucalyptus muelleriana	Canopy-dominant tree common in gullies and on lower slopes in wet sclerophyll forest in Southern and Eden regions	4.71	Y					
Eucalyptus obliqua	Canopy-dominant tree widespread at higher elevations on escarpment and eastern tablelands in UNE and LNE and on escarpment and coastal ranges in Southern and Eden regions	6.94	Y					
Eucalyptus paniculata	Canopy tree occurring mostly in coastal lowlands and low coastal ranges in Southern region	2.10	Y					
Eucalyptus pauciflora	Canopy-dominant tree in grassy forests at higher elevations on tablelands and adjacent escarpment in all regions, and especially abundant in western part of Southern region	4.46	Y					
Eucalyptus pilularis	Widespread stand-dominant canopy tree, more frequent in disturbed areas (not COG) in UNE; this is possibly partly an artefact of most areas where this species occurs having been logged	8.61			Y (−)			
Eucalyptus planchoniana	Canopy-dominant tree mainly of low coastal ranges mostly north from Coffs Harbour, occurring in shrubby dry sclerophyll forest on stony ridges and upper slopes on low fertility sandy soil	1.54	Y					

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Eucalyptus propinqua	Widespread stand-dominant canopy tree common in coastal lowlands and foothill ranges in UNE and LNE, often in wet sclerophyll forests on lower slopes and alluvial flats but also in grassy forests; more frequent in unburnt areas in UNE, relative to areas burnt 16–30 years ago; also temperature-restricted	5.95	Y	Y (+)				
Eucalyptus radiata	Canopy tree common in coastal ranges of Southern and Eden regions and less common at high elevations in UNE and LNE	6.00	Y					
Eucalyptus robertsonii	Relatively restricted but locally common stand-dominant tree in western parts of Southern region, especially on the Bago Plateau; more frequent in disturbed areas but also restricted by temperature and rainfall	2.36	Y		Y (−)			
Eucalyptus saligna	Widespread stand-dominant canopy tree; less frequent in unburnt areas relative to areas burnt 16–30 years ago in UNE	10.54		Y (−)				
Eucalyptus sieberi	Abundant and widespread southern stand-dominant canopy tree of dry sclerophyll forest on ridges and upper slopes in Eden region, more frequent in disturbed areas (not COG) in Eden and less frequent in unburnt areas in Southern and Eden, relative to recently burnt or more frequently burnt areas, respectively; also rainfall-restricted	8.56	Y	Y (−)	Y (−)			
Eucalyptus smithii	Canopy tree widespread in escarpment and foothills ranges of South Coast, usually in gullies and on sheltered slopes in steep topography	1.47	Y				Y	
Eucalyptus viminalis	Common canopy-dominant tree of alluvial flats, gullies and lower slopes of Eden and Southern regions and of scattered occurrence at high elevation in UNE and LNE where may be confused with *E. nobilis*	3.93	Y					
Euroschinus falcatus var. *falcatus*	Canopy tree widespread but rarely common, occurring mostly in coastal ranges in rainforest or in gullies and on lower slopes in wet sclerophyll forest	2.72	Y					
**Genista monspessulana*	Highly invasive shrub to 3–5 m, invading native woodlands and grasslands in temperate areas, out-competing other vegetation by shading and nitrogen fixation and forming dense impenetrable thickets. Cultivated and widely naturalised in southern regions and Northern Tablelands, scattered occurrences elsewhere	0.00						Y
Glochidion ferdinandi	Common tree of coastal lowlands, mainly on North Coast, occurring as an understorey tree or canopy tree in rainforest and eucalypt forest, often along creeks or in depressions	5.21	Y					

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Gompholobium latifolium	Widespread shrub occurring in all regions, locally common in dry sclerophyll shrubby forests, often on soils of low fertility	2.39	Y					
Gompholobium pinnatum	Low shrub occurring in dry sclerophyll forest on sandy soil on coastal lowlands and low coastal ranges, mainly North Coast	1.92	Y					
Goodenia ovata	Small, mostly wet sclerophyll, shrub more frequent in burnt areas in Eden region and more frequent in disturbed areas in Sothern and Eden	4.90		Y (−)	Y (−)			
Goodenia rotundifolia	Prostrate or trailing herb, common in grassy and shrubby forest in drier parts of northern regions	2.57	Y					
Goodia lotifolia	Small, mostly wet sclerophyll shrub more frequent in burnt areas in Eden region	2.92		Y (−)				
Gossia acmenoides	Shrub or small crooked tree to 18 m in dry rainforest and subtropical rainforest to a less er extent; chiefly north from the Hunter Valley but as far south as the Illawarra region; sensitive to Myrtle Rust	0.13				Y		
Gossia fragrantissima	Rare shrub or small tree to 7 m in subtropical rainforest in coastal districts north from around Lismore; sensitive to Myrtle Rust	0.00				Y		
Gossia hillii	Shrub or small crooked tree to 12 m in subtropical and dry rainforest, inland coastal ranges north from Coffs Harbour district; sensitive to Myrtle Rust	0.13				Y		
Grevillea irrasa subsp. *irrasa*	Spreading to erect shrub, 1.5–3 m high in lower-altitude dry sclerophyll forest, inland from Pambula and Moruya; sensitive to Phytophthora	0.00					Y	
Grevillea obtusiflora	Spreading shrub to usually 0.2–2 m in sandy loam soils in open low scrub beneath dry sclerophyll forest in the Kandos area; sensitive to Phytophthora	0.00					Y	
Grevillea victoriae	Spreading to erect shrub, 0.2–4 m high, in rocky montane habitats in dry or wet sclerophyll forest, heath or snow gum woodland; usually in well-drained acidic soils on ridges, slopes, or creek margins; often on granite but known also from a wide range of acidic to basic igneous and sedimentary substrates; south from the ACT; sensitive to Phytophthora	0.46					Y	
Haloragodendron lucasii	Rare straggling clonal shrub mostly to 1–1.5 m in dry sclerophyll open forest on sheltered slopes near creeks on sandstone in Sydney area; sensitive to Phytophthora	0.00					Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Hibbertia calycina	Rare small shrub to 30 cm in woodland on rocky slopes on the Central and Southern Tablelands; sensitive to Phytophthora	0.11					Y	
Hibbertia circinata	Erect shrub to 1.5 m in shrubby woodland dominated by *Eucalyptus sieberi*; known only from summit area of Mount Imlay, south-west of Eden; sensitive to Phytophthora	0.15					Y	
Hibbertia vestita	Low shrub of coastal lowlands of North Coast, common in heathy forest and often on sandy soils	2.38	Y					
Hibbertia virgata	Widespread but uncommon erect or diffuse shrub to 150 cm, in heath on sandy soils in coastal and inland areas, from Sydney district south; sensitive to Phytophthora	0.00					Y	
Hierochloe rariflora	Abundant grass of ranges and escarpment of Eden and Southern regions, with disjunct localised occurrences in northern regions	3.81	Y					
Hybanthus stellarioides	Widespread and common herb of drier grassy and shrubby forests in northern regions	3.94	Y					
Imperata cylindrica	Very widespread and often locally abundant, mostly lowland dry sclerophyll grass; more frequent in unburnt areas in Southern and Eden, in contrast to expected, but weaker, higher frequency in burnt areas in northern regions	28.28		Y (+)				
**Lantana camara*	Erect sprawling or scandent shrub, often growing in dense impenetrable thickets, normally to 1–4 m, but can scramble up into trees and in favourable conditions can grow to 6 m; widespread weed in sclerophyll forest and disturbed rainforest in coastal districts north from Bega area	9.70						Y
Lenwebbia prominens	Shrub or small tree to 9 m, in subtropical rainforest, often on stream banks, north from Lismore district; sensitive to Myrtle Rust	0.04				Y		
Lepidosperma urophorum	Common and widespread sedge occurring mostly on low fertility soils in coastal ranges in Eden and Southern regions	4.34	Y					
Leptinella filicula	Prostrate herb in grassy forests of cooler parts of tablelands, especially in Southern region	1.39	Y					
Leptospermum trinervium	Shrub or small tree to 2–5 m, in dry sclerophyll forest, heath and scrub in deep or shallow sandy soil, along coast and inland to upper Hunter Valley, and Northern and Southern Tablelands; sensitive to Myrtle Rust	4.94				Y		
Leucopogon ericoides	Widespread slender shrub to 0.9 m, in dry sclerophyll forest and heath on sandy soils, south from Byron Bay; sensitive to Phytophthora	1.05					Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Lomandra spicata	Rainforest and wet sclerophyll tussock graminoid more frequent in COG areas in LNE and also more frequent in unburnt areas in UNE	5.28		Y (+)	Y (+)			
Lomatia ilicifolia	Widespread common understorey shrub in dry sclerophyll shrubby forest in Southern and Eden regions, especially on sandy soils of moderately low fertility; more frequent in areas burnt once than unburnt areas in Eden region and in COG areas in Southern, although latter may be an artefact of occurring in rarely disturbed low-fertility environments; rainfall restricted	4.71	Y	Y (−)				
Lophostemon suaveolens	Canopy-dominant or subcanopy tree, abundant on alluvial flats or poorly-drained gentle slopes in warmer areas of coastal lowlands, mostly north from Coffs Harbour	1.66	Y					
Macrozamia communis	Large lowland cycad widespread and sometimes locally dominant in low coastal ranges and lowlands in Southern region, with scattered, more localised occurrences in other regions; less frequent in areas burnt twice than in unburnt areas in Southern region; elevation-restricted	2.92	Y	Y (−)				
Mallotus philippensis	Rainforest canopy or understorey tree in wet sclerophyll forest, often dominant in warmer areas of dry rainforest in North Coast coastal ranges and lowlands	2.67	Y					
Melaleuca nodosa	Widespread shrub usually to 1–4 m in a variety of habitats, especially in coastal heath and dry sclerophyll forest, north from Campbelltown; sensitive to Myrtle Rust	1.14				Y		
Melaleuca quinquenervia	Widespread tree usually 10–15 m high, in coastal swamps and around lake margins, north from Botany Bay; sensitive to Myrtle Rust	1.12				Y		
Melaleuca squamea	Shrub to 3 m high in heath communities on wet ground in coastal districts and adjacent ranges, south from Tweed R; sensitive to Phytophthora	0.00					Y	
Melichrus procumbens	Low shrub widespread but rarely abundant in shrubby dry sclerophyll forest on low coastal ranges	1.58	Y					
Monotoca glauca	Densely branched understorey shrub or small tree with slender branches, often 2–3 m tall, found on the margins of wet eucalypt and mixed forest and logged areas; susceptible to Phytophthora	0.00					Y	
Nematolepis rhytidophylla	Densely leaved shrub to 3 m high, in shrubland in rocky sites and as understorey shrub in sclerophyll forest in ranges southeast of Bombala; susceptible to Phytophthora	0.00					Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Nematolepis squamea	Shrub or tree to 12 m high, chiefly in coastal districts in wet sclerophyll forest and rainforest in moist gullies; susceptible to Phytophthora	0.25					Y	
Notelaea venosa	Wet sclerophyll small tree or shrub weakly more frequent in COG areas in Eden; one of very few species in any region more frequent in COG	6.96			Y (+)			
Olearia argophylla	Small tree or shrub common in wet sclerophyll forest understorey along southern escarpment and adjacent foothills	2.25	Y					
Oreomyrrhis eriopoda	Widespread herb of tableland grassy forests in LNE and Southern regions; less frequent in other regions	2.97	Y					
Orites excelsus	Rainforest and wet sclerophyll tree more frequent in unburnt areas in UNE and LNE and more frequent in COG areas in LNE	2.82		Y (+)	Y (+)			
Oxylobium ellipticum	Widespread erect to procumbent shrub to ≥ 2 m on ranges in open forest and woodland on skeletal soils, particularly in southern regions; susceptible to Phytophthora	0.69					Y	
Ozothamnus argophyllus	Shrub occurring mostly in wet sclerophyll forest, widespread on South Coast	1.60	Y					
Ozothamnus cuneifolius	Locally common shrub, mainly in dry sclerophyll forest in Eden region	1.52	Y					
Panicum effusum	Tussock grass sometimes locally common in dry sclerophyll forests in all regions, often on soils of low fertility	3.26	Y					
Parsonsia straminea	Very widespread vine, mainly in wet sclerophyll forest; more frequent in unburnt areas in UNE and LNE, but inconsistently favours burnt areas in Southern region where it is recorded less frequently	8.97		Y (+)				
**Pereskia aculeata*	Woody shrub, at first erect but branches often long and scrambling, to 10 m long, forming large impenetrable thickets; large spiny stems and branches make control of large infestations difficult; naturalised along river banks, lower Clarence River and in Sydney region	0.00						Y
Persoonia chamaepeuce	Prostrate shrub widespread in cooler sites on tablelands, mainly Southern Tablelands	1.87	Y					
Persoonia cornifolia	Erect to spreading shrub in woodland to dry sclerophyll forest on granite, sandstone and metasediments, north from Moonbi Range; susceptible to Phytophthora	1.47					Y	
Persoonia oleoides	Shrub in grassy and shrubby forests on Northern Tablelands	2.12	Y					

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Persoonia silvatica	Shrub in wet sclerophyll forest of eastern tablelands and escarpment of southern regions; sensitive to Phytophthora	1.71	Y				Y	
Persoonia stradbrokensis	Widespread and abundant small tree of wet and dry sclerophyll forests of coastal lowlands and adjacent ranges in UNE region	4.00	Y					
Pimelea axiflora	Widespread but rarely abundant shrub in Eden region and parts of Southern region	2.10	Y					
Platycerium bifurcatum	Epiphyte more frequent in unburnt areas in UNE and LNE; epiphytes likely to be adversely affected by various types of disturbance	5.91		Y (+)				
Platylobium formosum	Widespread shrub occurring in range of forest types but especially common in dry shrubby forests in western section of Southern region	4.69	Y				Y	
Platysace ericoides	Small subshrub common in shrubby or grassy dry sclerophyll forests in northern regions, often on soils of low fertility derived from sandstone	2.88	Y					
Poa ensiformis	Tufted grass common along gullies and creeks in Southern and Eden regions	2.31	Y					
Poa meionectes	Widespread and abundant tussock grass of a range of grassy and shrubby forests, mostly dry sclerophyll forests, especially in Eden region but also parts of Southern region	12.21	Y					
Pomaderris aspera	Small tree often locally dominant in shrubby wet sclerophyll forest on sheltered sites, widespread in Eden and Southern regions	3.22	Y					
Prostanthera lasianthos	Tall shrub mainly in wet sclerophyll forest in gullies or on sheltered slopes, widespread in southern regions but also at Barrington Tops in LNE region	2.02	Y					
Psychotria daphnoides	Small shrub occurring in drier types of rainforest and wet sclerophyll forest in seasonally dry areas on coast and ranges, mainly north from Casino; sensitive to Phytophthora	1.54	Y				Y	
Pultenaea altissima	Erect shrub growing in heath to dry sclerophyll woodland on sandy substrates, often in swampy areas or near watercourses, south from Guyra district; susceptible to Phytophthora	0.08					Y	
Pultenaea baeuerlenii	Erect shrub growing in swamp heath on sandstone and confined to the Budawang Range; susceptible to Phytophthora	0.00					Y	
Pultenaea benthamii	Erect shrub growing in dry sclerophyll forest in coastal and subcoastal forests in Eden region; susceptible to Phytophthora	0.34					Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Pultenaea daphnoides	Widespread locally common shrub in shrubby forests in Eden and Southern regions, on soils of low to moderate fertility; sensitive to Phytophthora	2.44	Y				Y	
Pultenaea juniperina	Erect shrub growing in wet sclerophyll forest on sandy soil on granite, in Armidale area and south from Brindabella Range; susceptible to Phytophthora	0.59					Y	
Pultenaea paleacea	Prostrate to spreading shrub growing in dry sclerophyll forest on sandy to clayey soils, from Jervis Bay to Port Stephens; susceptible to Phytophthora	0.17					Y	
Pultenaea parrisiae	Procumbent shrub growing in dry sclerophyll woodland on swamp margins, south from Wadbilliga National Park; susceptible to Phytophthora	0.02					Y	
Pultenaea villosa	Common shrub often locally dominant in understorey of shrubby dry sclerophyll forests in higher rainfall parts of North Coast lowlands and coastal ranges, also occurring less frequently in Southern region	2.12	Y					
Pyrrosia rupestris	Epiphyte more frequent in undisturbed (COG) and unburnt areas in LNE; epiphytes as a plant form are likely to be adversely affected by various types of disturbance	6.25		Y (+)				
Rhodamnia argentea	Tree to 30 m high growing in warmer rainforest, north from Hastings River; susceptible to Myrtle Rust	0.23				Y		
Rhodamnia maideniana	Rare bushy shrub, 1.5–3 m high, in subtropical rainforest in coastal districts north from Richmond River; susceptible to Myrtle Rust	0.00				Y		
Rhodamnia rubescens	Mainly wet sclerophyll understorey tree, more frequent in disturbed (not COG) areas and unburnt areas relative to recently burnt areas in UNE; also highly sensitive to Myrtle Rust	7.15		Y (+)	Y (−)	Y		
Rhodamnia whiteana	Tree to 18 m high in dry rainforest on basaltic soil in Border Ranges; susceptible to Myrtle Rust	0.00				Y		
Rhodomyrtus psidioides	Shrub or small tree to 12 m in warmer rainforest and on rainforest margins in coastal districts north from Gosford district; susceptible to Myrtle Rust	0.72				Y		
**Rubus fruticosus* aggregate	Spreading semi-deciduous shrub to 2 m (or to 3 m when growing through or over other vegetation) forming impenetrable prickly thickets in native vegetation in wetter cool to warm temperate areas, preventing germination of trees and shrubs and affecting succession	3.18						Y

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Rubus moluccanus	Very widespread, mainly wet sclerophyll vine, more frequent in disturbed (not COG) areas in LNE	6.19			Y (−)			
Sarcochilus falcatus	Epiphyte more frequent in undisturbed (COG) and unburnt areas in LNE; epiphytes as a plant form are likely to be adversely affected by various types of disturbance	2.15		Y (+)	Y (+)			
Scleria mackaviensis	Herb of grassy forests, widespread in drier parts of North Coast foothills and escarpment	1.39	Y					
Solanum hapalum	Understorey shrub more frequent in COG and unburnt areas (relative to areas burnt with moderate frequency) in LNE	5.64		Y (+)	Y (+)			
Solanum pungetium	Understorey shrub more frequent in COG and unburnt areas in Eden	2.59		Y (+)	Y (+)			
Sorghum leiocladum	Tussock grass often locally dominant in grassy forests in drier parts of escarpment ranges in UNE and LNE regions	5.37	Y					
Sprengelia incarnata	Erect shrub to 0.5–2 m, growing in swampy shrubland and in heath on sand, south from Coffs Harbour; susceptible to Phytophthora	0.19					Y	
Stephania japonica	Very widespread mainly wet sclerophyll vine, more frequent in disturbed (not COG) areas in UNE and LNE, and more frequent in unburnt areas in LNE and Eden	6.33		Y (+)	Y (−)			
Syzygium anisatum	Rare rainforest tree to 45 m restricted to Nambucca and Bellinger Valleys; susceptible to Myrtle Rust	0.00				Y		
Syzygium hodgkinsoniae	Small tree in subtropical rainforest or gallery forest, north from the Richmond River; susceptible to Myrtle Rust	0.04				Y		
Tasmannia purpurascens	Shrub 1–3 m high in *Nothofagus moorei* and eucalypt forest between 1,200 and 1,520 m in Barrington Tops – Gloucester Tops area and Ben Halls Gap area; susceptible to Phytophthora	0.46					Y	
Tetrarrhena juncea	Widespread and abundant grass in Eden region, occurring less frequently in other regions; more frequent in areas burnt once relative to unburnt, in Eden region and more frequent in burnt areas in LNE and Southern, although not meeting occupancy thresholds in those regions; rainfall-restricted	3.60	Y	Y (−)				
Tetratheca bauerifolia	Locally common shrub in dry sclerophyll forest and woodland in cooler parts of Southern Tablelands	1.45	Y					
Tetratheca subaphylla	Straggling shrub which occurs sporadically on rocky slopes in dry sclerophyll forest, mainly south of Eden. Susceptible to Phytophthora	0.10					Y	

Species	Description	Naïve occupancy (%)	Climate change	Fire	Candidate old growth	Myrtle Rust	Phytoph-thora	Weed
Themeda triandra	Very widespread, often dominant grass more frequent in unburnt areas in Eden, in contrast to weaker negative response to unburnt in UNE and LNE; inconsistent response between northern and southern regions	27.86		Y (+)				
Trochocarpa laurina	Common and widespread northern wet sclerophyll understorey tree more frequent in unburnt areas relative to very frequently burnt areas in LNE; an outstanding host for vascular epiphytes	13.21		Y (+)				
**Ulex europaeus*	Erect or ascending spiny shrub to 1–3 m, readily invading native woodlands and grasslands in cool to warm temperate areas and forming dense impenetrable thickets that exclude desirable fauna and provide harbour for pest animals	0.00						Y
Xanthorrhoea australis	Arborescent monocotyledon (grass tree) with trunk, often branched, to 3 m, in sclerophyll forest south of Nowra; susceptible to Phytophthora	0.95					Y	
Xanthorrhoea concava	Arborescent monocotyledon (grass tree) more frequent in burnt areas in Southern region	1.92		Y (−)				
Xanthorrhoea glauca	Arborescent monocotyledon (grass tree) with branched or single trunk, 1–5 m high, in all regions; susceptible to Phytophthora	0.84					Y	
Xanthorrhoea latifolia	Arborescent monocotyledon (grass tree) locally common in shrubby dry sclerophyll forests, usually on sandy soils of low fertility; more frequent in frequently burnt areas, relative to unburnt areas, in UNE; also climate-restricted	2.23	Y	Y (−)				

6. Methods

6.1 Baseline datasets

6.1.1 Baseline fauna surveys

A significant effort at the early stages of the project was expended in locating and extracting the results of three extensive and comprehensive fauna surveys conducted in the north-eastern NSW RFA regions (both UNE and LNE) in the 1990s, as well as two other substantial regional datasets that were collected by individual researchers at approximately the same time:

1. The Forestry EIS Biological Surveys (EIS: York *et al.* 1991), 1991–1993, 1995. These represent consistently-designed and executed fauna and flora surveys in each forest management district within the two RFA regions.
2. The North East Forest Biodiversity Study (NEFBS: Ferrier 1993), 1991–1993.
3. The Comprehensive Regional Assessment (CRA: Andren *et al.* 1998, DUAP and DPMC 1999).
4. The nocturnal listening, call-playback and spotlighting surveys of large forest owls and arboreal marsupials (Kavanagh *et al.* 1995).
5. The nocturnal listening, call-playback and spotlighting surveys of large forest owls and arboreal marsupials (Debus 1995). This study contributed data to the NEFBS study listed above.

Fauna surveys for the Southern and Eden RFA were extracted from BioNet, and augmented by Forestry EIS surveys held by DPIE and surveys conducted by other forest scientists (e.g. Kavanagh and Bamkin 1995). The distribution of the combined set of fauna survey sites used in analyses for this project is shown in Figure 5. In total, 5,719 sites were surveyed for fauna during the study period (Table 4).

6.1.1.1 EIS Surveys

Fauna survey for many taxonomic groups involved the use of standardised survey methods along a 500-m transect centered over the flora plots (typically five 1000-m² flora plots at 100-m spacing). Methods included small mammal survey (Elliott traps), spotlighting, harp trapping, diurnal and nocturnal bird, mammal, reptile and amphibian searches. The conceptual layout for these 500-m transect surveys is shown in Figure 6.

6.1.1.2 NEFBS surveys

Survey areas were based on a landscape-scale stratification incorporating broad geology, vegetation and physiography (Ferrier 1993). Fauna survey sites were then located at a local landscape scale using a ridge–midslope–gully stratification (GMR), centered on the gully site as shown in Figure 7. Survey sites were nominally 50 m × 20 m.Transects associated with site survey were typically conducted along roads connecting or adjacent to the sites.

The NEFBS vertebrate fauna survey employed a range of survey methods, including: (1) standard site-based methods; (2) additional methods at each gully site; (3) 2-km road transect methods; (4) methods conducted at additional sites within survey areas; (5) non-standard methods, and (6) Australian Museum invertebrate pitfall buckets.

Full details of these methods are provided in Appendix 3.

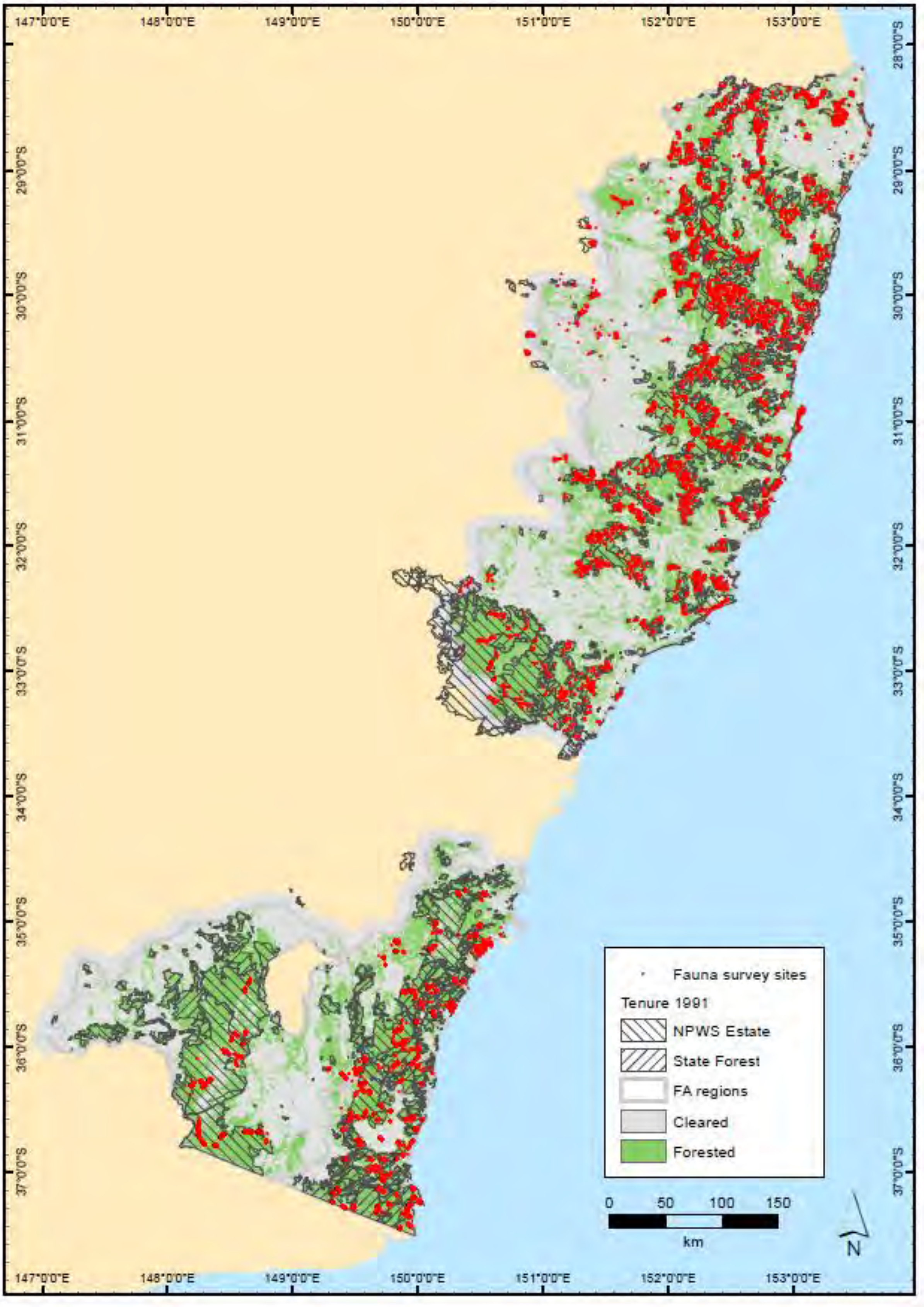

Figure 5. Map of fauna survey sites from NSW government agency surveys undertaken between 1991 and 1998

Table 4. Distribution of 1990s systematic (A) fauna and (B) flora sites by survey, RFA region and dates

A. Fauna Surveys	**Number of sites**	**Dates**	**UNE**	**LNE**	**Southern**	**Eden**
State Forests EIS program, North	989	1991–1995	612	377		
North East Forests Biodiversity program	1,295	1991–1995	730	565		
Northern CRA	911	1996–1998	212	699		
Debus	402	1989–1992	216	186		
Kavanagh *et al.* (1995)	291	1991	274	17		
State Forests EIS program, South	636	1992–1995			636	
Southern CRA	1,008	1996–1999			676	332
Kavanagh and Bamkin (1995)	187	1992				187
Total	5,719		2,044	1,844	1,312	519
B. Flora Surveys	**Number of plots**	**Dates**	**UNE**	**LNE**	**Southern**	**Eden**
State Forests EIS program, North	1,475	1987–1994	741	734		
State Forests EIS program, South	327	1990–1996			176	151
South East Forests combined	696	1991–1994				696
North East Forests biodiversity	690	1992–1993	425	265		
NRAC	341	1994	339	2		
Southern CRA	1,149	1995–2000			1,149	
Northern CRA	570	1997–1998	290	280		
Total	5,248		1,795	1,281	1,325	847

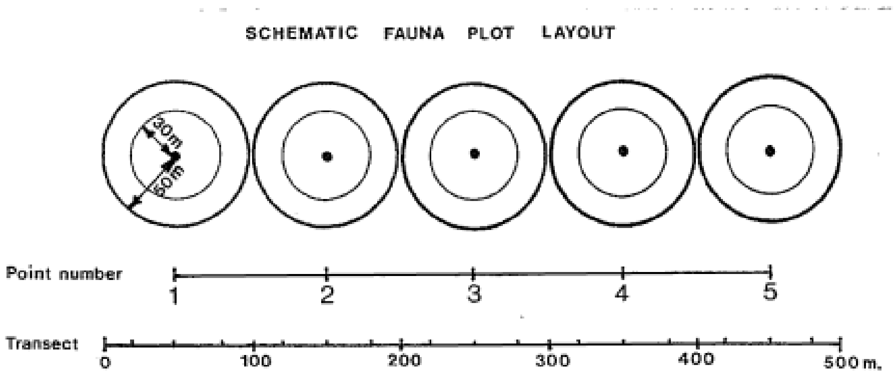

Figure 6. Forest EIS fauna survey design

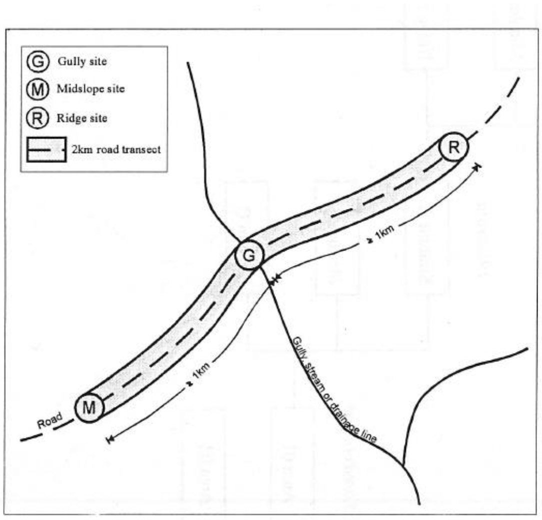

Figure 7. NEFBS fauna survey design

6.1.1.3 CRA surveys

The CRA survey was designed as a follow-on to the NEFBS survey, and focused on locations not adequately covered in the former. Similar techniques were employed in order to maintain consistency in results. Refer to Appendix 3 for details.

6.1.1.4 Additional 1990s nocturnal call-playback surveys

While nominally part of the NEFBS survey effort, the Nocturnal Call-Play Back (NOCPB) surveys undertaken by Debus and Kavanagh had well-constrained methodologies, as detailed below.

Listening, call-playback and spotlighting procedure: Debus
Debus undertook a 40-minute survey at each site, plus drive spotlighting between sites:

1. Initial listening period – 15 minutes
2. Call broadcast for Masked Owl – 5 minutes, followed by 1–2 minutes spotlight sweeps at site
3. Call broadcast for Sooty Owl – 5 minutes, followed by 1–2 minutes spotlight sweeps at site
4. Call broadcast for Powerful Owl – 5 minutes, followed by 1–2 minutes spotlight sweeps at site
5. Final listening period – 5 minutes
6. Drove to next site (~1 km away), spotlighting *en route*. Results split between adjacent sites
7. Inclusion of any incidental records of calling owls during non-survey periods of the night.

Listening, call-playback and spotlighting procedure: Kavanagh
Kavanagh *et al.* (1995) undertook an 80-minute survey at each site:

1. Initial listening period – 60 minutes
2. Call broadcast for Sooty Owl interspersed with short periods of listening for a response – 5 minutes
3. Call broadcast for Powerful Owl interspersed with short periods of listening for a response – 5 minutes
4. Call broadcast for Masked Owl interspersed with short periods of listening for a response – 5 minutes

Spotlight search at site for owls, possums and gliders – 5 minutes.

The surveys reported by Kavanagh and Bamkin (1995) in the Eden RFA region used a similar methodology, but the initial listening period was reduced to 15 minutes and the spotlighting period was increased to 10 minutes.

A summary of the survey methods used to record fauna groups in the EIS, NEFBS and CRA fauna surveys of NE NSW, including whether repeated site 'visits' were part of the method (in bold), is presented in Table 5. Only few methods were implemented in a manner that enabled the survey results to be analysed using occupancy modelling. Of these methods, only harp trapping and cage trapping were implemented in a similar and repeated manner across all three major surveys, but only at relatively few of the total number of sites in each survey. The EIS surveys employed the largest range of survey methods that were each implemented in a repeated manner (e.g. diurnal bird surveys, nocturnal listening, call-playback and spotlighting surveys for nocturnal birds and arboreal marsupials, Elliott trapping for small mammals, harp trapping for bats, use of bat-call detectors, wire cage traps for medium-sized ground mammals, and pitfall traps). While the NEFBS and CRA surveys also often used these survey methods, the method was either implemented on one occasion only, or the results were aggregated across several sampling occasions and were not suitable for analysis using occupancy modelling (Table 5).

Table 5. Summary of survey methods used to record fauna groups in the EIS, NEFBS and CRA fauna surveys of NE NSW, showing whether repeated site 'visits' were included (in bold).

Fauna group	Survey method	EIS	NEFBS	CRA
Diurnal birds	Systematic diurnal bird surveys	**Five survey points, 100 m apart along a 500-m transect, each counting numbers of birds seen/heard in 10 minutes, on 4 separate occasions (days)**	No	20 minutes search of 2-ha plot recording all birds seen or heard, on 1 occasion only
Diurnal birds	Opportunistic surveys	Yes	Yes – cumulative species list at each site; variable search effort	Yes
Nocturnal birds	Systematic listening, call-playback, spotlighting	**10 minutes listening, followed by 50 minutes of spotlighting using 2 observers along a 500-m transect, followed by call playback for 3 large forest owl species for 15 minutes, then an additional 10 minutes waiting for a response, on 2 separate occasions**	15 minutes of call playback and listening for responses by 3 large forest owls from roadside adjacent to each site, preceded and followed by about 5 minutes (total 10 minutes) spotlighting, on 1 occasion only	20 minutes of call playback and listening for responses by 4 large forest owls at each site, preceded and followed by about 5 minutes (total 10 minutes) spotlighting, on 1 occasion only
Nocturnal birds	Opportunistic surveys	Yes. Includes call playback for 3 owl species, plus 10 minutes waiting for a response, as part of arboreal mammal 5-km road transects	Yes	Yes
Arboreal mammals	Systematic listening and spotlighting (includes call playback for large forest owls, which can elicit responses from arboreal mammals)	**10 minutes listening, followed by 50 minutes of spotlighting using 2 observers along a 500-m transect (followed by call playback for 3 large forest owl species for 15 minutes, then an additional 10 minutes waiting for a response), on 2 separate occasions**	10 minutes of spotlighting at each site (as well as 15 minutes of call playback and listening for responses by 3 large forest owls and sometimes for targeted arboreal mammals) from roadside adjacent to each site, on one occasion only	10 minutes of spot-lighting at each site (and 20 minutes of call playback and listening for responses by 4 large forest owls and sometimes for targeted arboreal mammals), on 1 occasion only

Fauna group	Survey method	EIS	NEFBS	CRA
Arboreal mammals	Spotlighting surveys along roads	5-km spotlighting surveys from back of a moving vehicle, done once. Includes 200 m of spotlighting on foot and call playback for 3 owl species, plus 10 minutes waiting for a response	2-km road spotlighting surveys between ridge-midslope-gully sites from back of a moving vehicle, on 1 occasion	2-km road spotlighting surveys on foot between ridge-midslope-gully sites, on 1 occasion. Plus opportunistic surveys while driving vehicle between sites
Bats	Harp trapping	**Harp traps and/or mist nets used at varying number of sites, on 2 separate occasions**	**Harp traps used at varying number of sites (usually gully sites), on 2 separate occasions**	**Harp traps used at varying number of sites (usually gully sites), on 2 separate occasions**
Bats	Bat call detectors	**Ball calls recorded at a varying number of sites, on 2 separate occasions**	30 minutes of bat call recording on each site, on 1 occasion	30 minutes of bat call recording on each site, on 1 occasion
Bats	Opportunistic surveys (e.g. triplining, mist-netting)	Yes	No	Yes
Small arboreal mammals	Elliott trapping in trees	**25 Elliott traps set on brackets in trees along 500-m transects, and checked on 4 separate mornings**	No	No
Small mammals	Elliott trapping on the ground	No	**Opportunistic only. At sites where this was conducted, 10 Elliott traps were set and checked on 4 separate mornings**	**Opportunistic only. At sites where this was conducted, 10 Elliott traps were set and checked on 4 separate mornings**
Small mammals	Cage traps on the ground	**10 wire cage traps set along 500-m transects, and checked on 4 separate mornings**	**10 wire cage traps set 220 m apart on road verges of each 2-km road transect, and checked on 4 separate mornings**	**Cage trapping done at 3 locations only. 10 wire cage traps set 220 m apart on road verges of each 2-km road transect, and checked on 4 separate mornings**
Small mammals	Pitfall traps	**By-catch in reptile pitfall traps**	**By-catch in reptile pitfall traps**	**By-catch in reptile pitfall traps**

Fauna group	Survey method	EIS	NEFBS	CRA
Small mammals	Hair tubes	10 hair tubes set along 500-m transects, and checked after approx. 1 week	6 hair tubes set at each site, and 10 hair tubes set along road verges of each 2-km transect; all checked after 10 days	10 hair funnels set at each site, and 20 hair funnels set along 2-km transect; all checked after 10 days
Small mammals	Predator scats – opportunistic surveys	Yes	Yes, including searches on foot along 2-km transects	Yes
Large terrestrial mammals	Incidental observations made during other survey methods/ visits	Yes	Yes	Yes
Reptiles	Pitfall traps	**10 'wet/kill' or 'dry/live' pitfall traps set along 500-m transects, and checked on at least 5 separate occasions (in case of dry pitfalls)**	**Opportunistic only. At sites where this was conducted, 3 dry pitfall traps were checked on 4 separate occasions**	**Opportunistic only. At sites where this was conducted, 20 dry pitfall traps were set and checked on an unspecified number of mornings**
Reptiles	Systematic hand searching	2 hours of passive and active searching along 500-m transects, on 1 occasion	1 hour of passive and active seaching on a 1-ha plot, on 1 occasion	1 hour of passive and active seaching on a 0.5-ha plot, on 1 occasion
Reptiles	Opportunistic surveys	Yes	Yes	Yes
Amphibians	Pitfall traps	**By-catch in reptile pitfall traps**	**By-catch in reptile pitfall traps**	**By-catch in reptile pitfall traps**
Amphibians	Nocturnal listening and hand searching	2 hours of nocturnal passive and active searching along selected creek lines, on 1 occasion	1 hour of passive and active searching along selected creeklines (usually gully sites), on 1 occasion	1 hour of passive and active searching along selected creeklines (usually gully sites), on 1 occasion
Amphibians	Opportunistic surveys	Yes, including during road transects at night and as by-catch during transect-based diurnal reptile searches	Yes, including driving and walking along forest tracks after rain	Yes, including driving and walking along forest tracks after rain, sometimes including call playbacks

6.1.2 Baseline flora surveys

Flora surveys were conducted between 1987 and 2000 by the NSW government forestry department (during that period named 'Forestry Commission of NSW' and then 'State Forests of NSW') and environment department (during that period named 'National Parks and Wildlife Service' and then 'Department of Environment and Conservation') (Figure 8). The surveys were conducted for the purpose of environmental impact assessment and regional conservation assessment, respectively. The forestry department surveys were conducted on State Forests only, in the UNE and LNE RFA regions (except State Forests in the Kendall Management Area), in Queanbeyan–Badja and Bago–Maragle Management Areas in Southern RFA region and in Nullica and Nalbaugh State Forests in Eden RFA region. The environment department surveys were conducted on state forests, national parks, nature reserves and vacant Crown land, in all RFA regions.

All surveys used temporary plots of either 20 m × 20 m or 20 m × 20 m nested within 50 m × 20 m. For each survey, plot locations were stratified either by mapped vegetation type or by combinations of environmental factors (climate and lithology). In most cases plot locations were initially marked on maps and then located in the field as close as practicable to the mapped grid reference to minimise subjectivity of sampling. Most plots were within 500 m of road access, except where more remote locations were necessary to sample a particular vegetation type or environment stratum.

For the present project, floristic data from these surveys was obtained from the systematic flora survey module of BioNet (http://www.bionet.nsw.gov.au/). In the case of nested plots, only data from the 20 m × 20-m subplot was used if subplots were distinguished in BioNet. Dates and numbers of plots from each survey for each RFA region are listed in Table 4. For each plot, all vascular plant species were recorded, as far as possible at least to species level, and a cover-abundance code recorded for each species. For all surveys except 'South East Forests combined', codes were based on field estimates of abundance and cover using six class limits: (1) few individuals or uncommon and up to 5% cover, (2) many individuals or common and up to 5%, (3) up to 25%, (4) up to 50%, (5) up to 75%, and (6) > 75%. The 'South East Forests combined' survey used similar class limits except that the third class was up to 20%. Taxonomy used was that in PlantNet (https://plantnet.rbgsyd.nsw.gov.au/) at the time the data were compiled (October 2020). For some taxa, the taxonomy differs from that currently accepted in the Australian Plant Census (APC, https://www.anbg.gov.au/chah/apc/). Appendix 2 provides a full list of species with currently accepted (July 2021) equivalent or closest matching APC names.

6.1.3 Survey gap analysis

Survey Gap Analysis (SGA) is a widely used technique to determine the adequacy of a set of sample collection points to span an environmental ordination space. It is based on the premise that any representative survey of biological diversity across a region requires even sampling across environmental space (Faith and Walker 1996). The general approach can equally be applied to the problem of selecting an optimal set of survey sites or selecting optimal additional sites to an existing set of sites; or it can also provide an indication of how well each part of a region is sampled.

A key point of relevance to this project is that the environmental space occupied by the large number of fauna and flora survey sites available for analysis can be investigated to determine whether the modelling results that were obtained elsewhere in this project (e.g. species occupancy estimates) are representative of the full environmental space occurring within forests, and whether these results are likely to apply equally across the four land tenure classes (i.e. national park, state forest, private native forests and Crown forest lands).

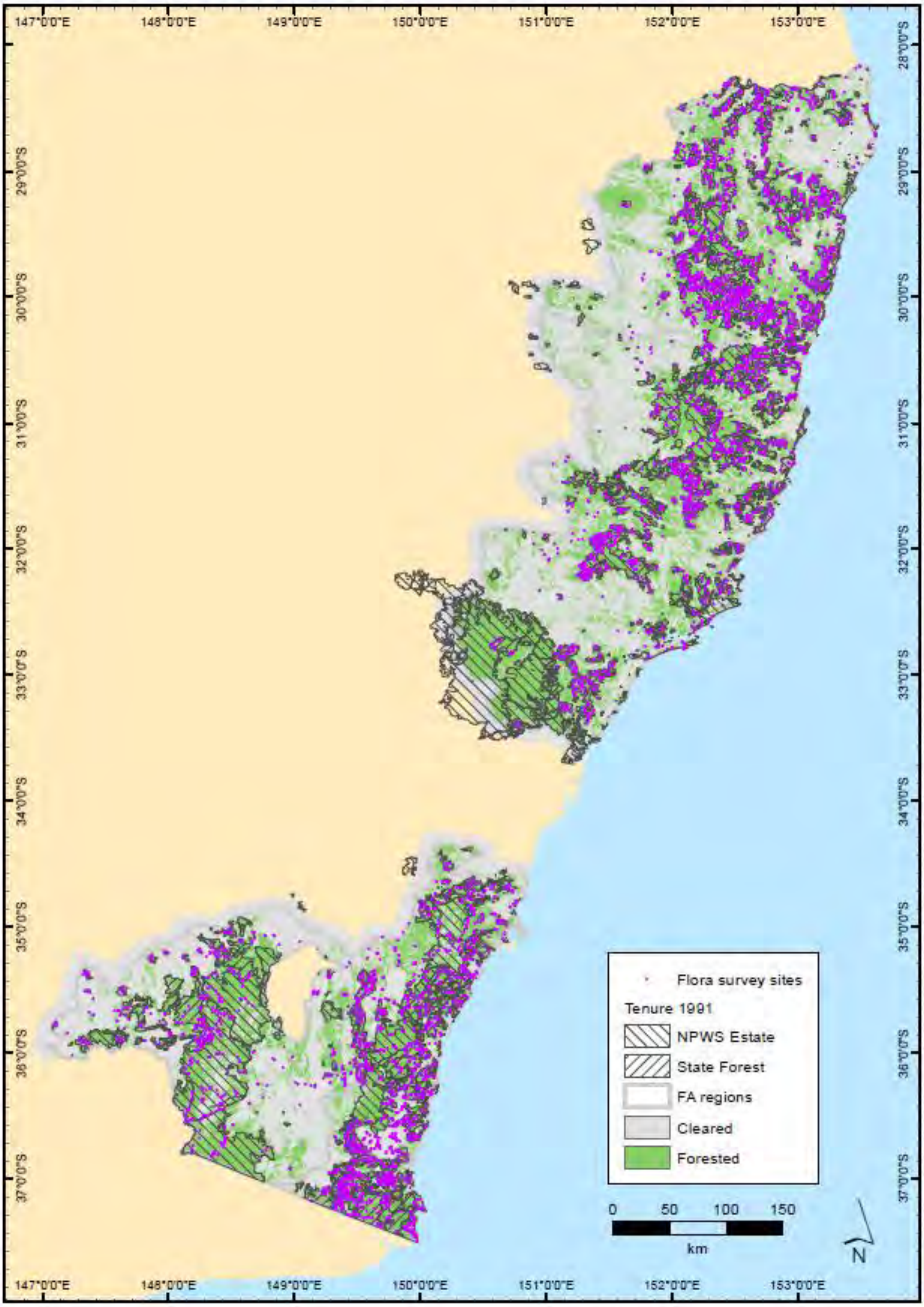

Figure 8. Map of flora sites from NSW government agency surveys conducted between 1987 and 2000

The survey-gap analysis tool analyses the survey coverage of a region in relation to the underlying continuous environmental and geographical space based on a Generalised Dissimilarity Model (GDM; Ferrier 2002; Manion and Ridges 2009).

The SGA tool operates in GDM model space where Manhattan Distance is used to measure the environmental distance between locations (grid cells). This equates to the sum of the absolute 'distances' across the transformed grid predictors in the GDM model. For survey design, the aim is to minimize Global P-Median: the summed environmental distance between each location in the study region and its nearest existing survey site. The smaller this value the better the set of survey sites span the model space. Local P-Median, which can be mapped to each grid cell across a region, is a measure of how each location would reduce the Global P-Median if it were surveyed.

The SGA tool is designed to automatically select any number of survey sites. It is deterministic in that each new selection will affect the next iteration's selection. Manion and Ridges (2009) described how the tool can optimise coverage of environmental space with a given number of site selections, avoiding the inefficiency of a 'greedy algorithm' approach. However, the process can also be done manually, adding a single site at a time, so that external considerations such as access to the nearest location can be considered for user defined selections. In this mode, at each iteration the SGA tool will suggest regions of optimal candidate sites from which the user can choose a feasible (e.g. accessible) site.

For the current project, survey gap analysis was conducted with respect to three datasets – fauna (combined survey sites for NEFBS, CRA, and EIS); combined flora (1987–2020), and WildCount sites, as a measure of recent survey effort – each analysis spanned the combined UNE, LNE, Southern and Eden RFA regions. The GDM model used in the SGA was developed as part of the Biodiversity Impacts and Adaptation Project (OEH 2016). It was produced at 250-m grid cell resolution across the region covered by the NARCliM 1.0 climate projections, spanning all NSW, the ACT, Victoria, southern Queensland and eastern South Australia. NARCliM 2.0 is currently in a testing phase. A new 90-m GDM is planned for 2022 based on NARCliM 2.0 and a range of improved spatial predictor surfaces.

In this baseline assessment, global P-Median was calculated for each dataset; local P-Median was mapped across the study region as a continuous-value 250-m resolution grid; and zonal statistics of local P-Median were tabulated by RFA region and tenure. The analysis was masked to the forested region of the four RFA regions. Subsequent analysis can be improved by using the new forest extent layer, which is a deliverable of FMIP Baseline Project 1.

6.1.4 Covariates

The term covariates (or 'variables' in Maxent) is used to designate environmental layers such as climate, terrain, soil and environmental disturbance variables that influence a species' distribution in the landscape. The covariates are gridded surfaces (rasters), and for this project were derived from two main sources: the DPIE State Vegetation Type Map (SVTM) Modelling Grid Collection (https://datasets.seed.nsw.gov.au/dataset/svtm-modelling-grid-collection) and the NARCliM (NSW and ACT Regional Climate Modelling) layers from AdaptNSW (https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM). Maps of the covariate surfaces used in modelling are gven in Appendix 12.

All covariate data were spatially referenced to GCS GDA 94 (EPSG 4283). The DPIE layers were developed by Xu and Hutchinson (2011), Wilson and Gallant (2000) or in-house by DPIE. Additional covariates were developed as follows:

- Vegetation: State Vegetation Type Mapping (SVTM; DPIE 2021c) was rasterised at the Keith Formation level. As rasterisation at 90 m produced many single-cell formations, which may not have been representative of the dominant immediate surrounds, a 3 × 3 majority filter was applied to capture the locally dominant vegetation. Where a unique majority could not be derived, the centre cell of the 3 × 3 window was filled with the original cell value. SVTM data were sourced from the generic DPIE directory as follows:
  - https://datasets.seed.nsw.gov.au/dataset?q=svtm
- Fire: NPWS Fire History and Fire Extent and Severity Mapping (FESM) were sourced as follows:
  - https://datasets.seed.nsw.gov.au/dataset/fire-history-wildfires-and-prescribed-burns-1e8b6
  - https://datasets.seed.nsw.gov.au/dataset/fire-extent-and-severity-mapping-fesm
- Fire: fauna analysis. The NPWS fire history was used to create annual event layers (1989–1998) to model the number of fires that affected each sample site as well as the time since most recent fire. A fire footprint (1950–1993) was used to model burnt–unburnt areas. The 1950 cut-off was established based on the assumption that (a) full biodiversity was re-established after fires earlier than 1950, and (b) fire history extent and completeness prior to 1950 was likely to be unreliable.
- Fire: flora. To assess the impact of fire on vegetation species, a Boolean layer (1962–1991) was used to establish burnt–unburnt areas. The 30-year interval was based on expert knowledge (D. Binns, pers. comm. 2021) that the expected full floristic complement of species had re-established by 30 years post-fire.
- Fire: climate projection. For flora climate projection, a separate Boolean layer that incorporated the FESM layer (referred to above) and NPWS fire history was developed. This allowed a similar 30-year fire history (1989–present) as well as incorporating additional burn extent due to the 2019 wildfires (FESM footprint).
- Tenure_Estates: The extent of 'NPWS estate' areas reserved under the *National Parks and Wildlife Act 1974* (NSW). Areas included national parks, nature reserves, regional parks, state conservation areas, Aboriginal areas, historic sites and karst conservation reserves.*
- Tenure_SF: Dedicated legal state forest boundary as defined by cadastre.
  - *Note that the extent of both state forest and NPWS estate in 1991 was developed following current boundaries, adjusted and digitised where necessary based on scanned paper maps of the 1991 state forest and NPWS estate, published by FCNSW in 1991, and provided by Dr Rod Kavanagh. These adjustments were necessary as there were substantial conversions of state forest to NPWS estate between 1991 and the present.
- Tenure_PP: All land not included in state forest or NPWS estate.
- Candidate Old Growth (COG) Forest was derived from vegetation succession data (Items a-c, below). For the UNE–LNE RFA, COG was an explicit attribute, so the data were incorporated directly. An unpublished reference layer 'CRA_Sthn_OldGrowth.tif' provided by the SEED

data broker was adopted for COG in the Southern RFA. No such attribution was available for the Eden RFA region, and derivation of equivalent COG is outlined below.

- https://datasets.seed.nsw.gov.au/dataset/successional-stages-for-cra-upper-north-east-vis_id-389302b97
- https://datasets.seed.nsw.gov.au/dataset/successional-stages-for-cra-lower-north-east-vis_id-3892bbee9

- COG Eden RFA: comparison with published and unpublished data and expert knowledge established that the growth stage and senescence attributes, tA, tB, tC, sA, tAF, tBF, tCY and sAF, were representative of COG. The attribute codes were as follows: 't' and 's' represented < 10% regrowth and 10–30% regrowth, respectively; A, B and C represented > 30% senescence, 10–30% senescence, and < 10% senescence, respectively. Category F represented fire disturbed, and category Y (uncommon) represented selective logging. This selection of attributes aligned with the CRAFTI interpretation outline in 'Old-growth Forest Related Projects – Eden Region' as per the link below.
  - https://datasets.seed.nsw.gov.au/anzlic_dataset/eucalypt-forest-growth-stage-eden-rfa-area-2001-vis_id-41506ef76/resource/fd6a65df-2a82-4124-a739-a8e93d1e1f13

- COG boundary conditions: since old-growth forest boundaries are both gradational and difficult to interpret, a 500-m radius focal filter was applied, essentially resulting in a 1000-m gradient buffer from 1 (COG) to 0 (not COG).

- Normalised Difference Vegetation Index (NDVI) data were based on cloud-free Landsat imagery (Paths 89–91, Rows 80–86) captured in August 1991 (UNE–LNE) and December–January 1992 (Southern–Eden) and downloaded directly from the United States Geological Survey website (https://espa.cr.usgs.gov/). A median 7 × 7 square filter was applied to the raw NDVI images in order to eliminate localised canopy – canopy-gap variations, and to mitigate low NDVI anomalies due to small (~50-m) point and linear features such as clearings and fire road corridors. Individual tiles were mosaiced with a stacking order that minimised edge effects from different tiles. NDVI tile codes are given below:

LT05_L1TP_089080_19900818_20170130_01_T1	LT05_L1TP_089083_19940728_20170113_01_T1
LT05_L1TP_089080_19910821_20170126_01_T1	LT05_L1TP_089083_19950715_20170107_01_T1
LT05_L1TP_089080_19920722_20170123_01_T1	LT05_L1TP_089084_19920112_20200914_02_T1
LT05_L1TP_089080_19930810_20170117_01_T1	LT05_L1TP_089085_19920112_20200915_02_T1
LT05_L1TP_089080_19940728_20170113_01_T1	LT05_L1TP_089086_19920112_20200915_02_T1
LT05_L1TP_089080_19950715_20170107_01_T1	LT05_L1TP_090080_19900910_20170129_01_T1
LT05_L1TP_089081_19900818_20170128_01_T1	LT05_L1TP_090080_19910929_20170125_01_T1
LT05_L1TP_089081_19910821_20170126_01_T1	LT05_L1TP_090080_19920729_20170123_01_T1
LT05_L1TP_089081_19920722_20170123_01_T1	LT05_L1TP_090081_19900910_20170130_01_T1
LT05_L1TP_089081_19930810_20170117_01_T1	LT05_L1TP_090081_19910929_20170125_01_T1
LT05_L1TP_089081_19940728_20170113_01_T1	LT05_L1TP_090081_19920729_20170122_01_T1
LT05_L1TP_089081_19950715_20170107_01_T1	LT05_L1TP_090082_19900910_20170128_01_T1
LT05_L1TP_089082_19900818_20170130_01_T1	LT05_L1TP_090082_19910929_20170125_01_T1
LT05_L1TP_089082_19910821_20170125_01_T1	LT05_L1TP_090082_19920729_20170122_01_T1
LT05_L1TP_089082_19920722_20170123_01_T1	LT05_L1TP_090083_19900910_20170130_01_T1
LT05_L1TP_089082_19930810_20170117_01_T1	LT05_L1TP_090083_19910929_20170125_01_T1
LT05_L1TP_089082_19940728_20170113_01_T1	LT05_L1TP_090083_19920729_20170122_01_T1

LT05_L1TP_089082_19950715_20170107_01_T1	LT05_L1TP_090084_19920119_20200914_02_T1
LT05_L1TP_089083_19900818_20170128_01_T1	LT05_L1TP_090085_19911218_20200915_02_T1
LT05_L1TP_089083_19910821_20170125_01_T1	LT05_L1TP_090086_19911116_20200915_02_T1
LT05_L1TP_089083_19920722_20170123_01_T1	LT05_L1TP_091084_19920126_20200914_02_T1
LT05_L1TP_089083_19930810_20170117_01_T1	LT05_L1TP_091085_19920126_20200914_02_T1

Table 6 lists the covariates used in this project for building fauna and flora ENMs and Maxent climate projections for flora species. The specific layers used in site analysis, modelling, prediction and projection are referred to in the relevant sections of this document.

6.2 Species modelling

A range of species modelling tasks were undertaken in this project, summarised in Table 7. The methods used and species modelled using each approach are described in detail in the remainder of this section.

6.2.1 Spatial independence of occurrence data

Spatial auto-correlation (SAC) refers to the natural phenomenon in nature where nearby samples are more similar than those spaced further apart. SAC causes issues for statistical tests and models relating observations of biological systems to their environments because SAC violates a fundamental assumption of statistical inference and linear modelling, that of sample independence. Temporal auto-correlation (TAC) may also be present in ecological samples when repeated samples are taken at the sample sites. Both forms of auto-correlation may lead to faulty inference from statistical tests and poor model performance unless measures are taken to adjust for their effects.

SAC and TAC were present to some degree in all forms of data used in the present study. Data obtained by systematic survey methods may have been auto-correlated because of the proximity of sample sites, which arises from several factors (e.g. pooling of results from different surveys using the same sampling method to improve statistical power). Repeated samples may have been taken at some sites for certain sampling methods (e.g. harp trapping, nocturnal call-playback and spotlighting, diurnal bird surveys, small mammal trapping). Non-systematic occurrence records such as museum and herbarium data, combined with casual observations and sourced from repositories such as the Atlas of Living Australia (ALA), may exhibit strong spatial biases (clustering) in accumulated records due to non-random sampling effects (see discussion in Phillips *et al.* 2006, 2009; Boria *et al.* 2014; Fourcade *et al.* 2014).

Moran's-I is the most widely used method available for quantifying SAC, but choices must be made about how it is applied to covariates, model output or residuals of model output. Assessment must also be made about the level of impact considered detrimental to the purpose for which the model was developed. This primarily consists of making judgements about the risk of adverse decisions arising from statistical tests or inaccurate spatial predictions (Crase *et al.* 2014). Quantifying SAC and assessing the impact it had on our modelling results is an area for further work. There are different implications of SAC and TAC for the two types of modelling undertaken in the present study, which are discussed briefly here.

Species occupancy modelling (SOM)

SAC may have been present in systematic survey data used in SOM due to the proximity of sample sites arising through biases in the location of sample sites (e.g. to accessible areas, restriction to certain land tenures) or clustering of closely spaced sites when survey results from different studies were pooled. TAC is not a constraint for SOM because the modelling method was explicitly designed to use repeat samples at sites to estimate the probability of detection and then infer probability of presence as a function of environmental covariates (MacKenzie *et al.* 2003).

Table 6. Environmental covariates used in species occupancy and ENM modelling (at 90 m) and Maxent flora climate projection modelling (at 250 m)

Covariate layers were mainly sourced from DPIE (https://datasets.seed.nsw.gov.au/dataset/svtm-modelling-grid-collection). Definitions are adapted from information supplied by Jillian Thonnell, NSW DPIE. Variable definitions which include the abbreviation 'bioNN' refer to the expanded Bioclim variable set (Xu and Hutchinson, ANUCLIM 6.1 User Guide, https://fennerschool.anu.edu.au/files/anuclim61.pdf).

Data name	Description	Fauna ENM	Fauna SOM	Flora ENM	Flora climate projectn
Fauna and Flora ENMs and fauna SOMs					
ce_radann90	Annual Mean Radiation (bio20, continuous)	Y	Y	Y	
cog_100m90	Candidate Old Growth Forest within 100-m Radius of Focal Grid Cell (categorical)			Y	
cog_2000m90	Candidate Old Growth Forest within 2-km Radius of Focal Grid Cell (continuous)	Y	Y		
CountFire	Number of Fires, on a per-year basis (continuous)		Y		
ct_temp_maxsum90	Average Daily Maximum Temperature - Summer	Y			
ct_tempann90	Annual Mean Temperature (bio1, continuous)	Y	Y	Y	
ct_tempmtcp90	Min Temperature of Coldest Period (bio6)	Y			
ct_tempmtwp90	Max Temperature of Warmest Period (bio5)	Y			
ct_tempseas90	Temperature Seasonality: Coefficient of Variation (bio4, continuous)	Y	Y	Y	
cw_etaaann90	Average Areal Actual Evapotranspiration – Annual (continuous)	Y	Y	Y	
cw_precipann90	Annual Precipitation (bio12, continuous)	Y	Y	Y	
cw_precipdp90	Precipitation of Driest Period (bio14, continuous)	Y	Y	Y	
cw_precipseas90	Precipitation Seasonality: Coefficient of Variation (bio15, continuous)	Y	Y	Y	
dl_strmdstall	Euclidean Distance to All Streams (i.e. all orders: 1 to 9)		Y		
fire_62_91_bool90	Burnt–Unburnt Areas in Interval 1962–1991 Derived from NPWS Fire Records (categorical)			Y	
lf_cti90	Compound Topographic Index (CTI), also known as Wetness Index, Topographic Wetness Index. Based on DEM-H (for flow direction and accumulation, continuous)	Y	Y	Y	
lf_tpi0250_90	Topographic Position Index using Neighbourhood of 250-m Radius (continuous)		Y	Y	
lf_rough0100_90	Neighbourhood Topographical Roughness Based on Standard Deviation of Elevation in Circular 100-m Neighbourhood. Derived from DEM-S (continuous)	Y	Y	Y	

Data name	Description	Fauna ENM	Fauna SOM	Flora ENM	Flora climate projectn
Keith Formation classes	Dry Sclerophyll Forest – shrubby understorey Dry Sclerophyll Forest – shrub-grass understorey Forested Wetland Grassy Woodland Rainforest Wet Sclerophyll Forest – shrubby understorey Dry Sclerophyll Forest – grassy understorey Other (all Keith Formation categories not specified above) (categorical)		Y		
NDVI_7median_NS_90	Normalised Difference Vegetation Index (NDVI) with 7-cell Median Filter Assigned to Focal Cell (continuous)	Y	Y	Y	
sp_awc90	Available Water Capacity Based on Proportionally Combined Depths from 0 to 100 cm (continuous)	Y	Y	Y	Y
sp_cly90	Clay Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)	Y		Y	Y
sp_slt90	Silt Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)	Y		Y	Y
sp_snd90	Sand Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)	Y		Y	Y
YearsSinceFire	Number of Years Since Last Recorded Fire (back to 1950)		Y		Y
ce_radann (NARCliM)	Annual Mean Radiation (bio20, continuous)				Y
COG	Candidate Old Growth Forest (Boolean, i.e. no gradient buffer was assigned to COG–non-COG boundary, categorical)				Y
ct_tempann (NARCliM)	Annual Mean Temperature (bio1, continuous)				Y
ct_tempseas (NARCliM)	Temperature Seasonality: Coefficient of Variation (bio4, continuous)				Y
cw_precipann (NARCliM)	Annual Precipitation (bio12, continuous)				Y
cw_precipdp (NARCliM)	Precipitation of Driest Period (bio14, continuous)				Y
cw_precipseas (NARCliM)	Precipitation of Seasonality: Coefficient of Variation (bio15, continuous)				Y
fire_npws_fesm_gt_89	Burnt–Unburnt Areas from 1989 to 2020 Derived from NPWS and FESM Fire Records (categorical)				Y
lf_rough500	Neighbourhood Topographical Roughness Based on Standard Deviation of Elevation in Circular 500-m Neighbourhood. Derived from DEM-S (continuous)				Y
lf_tpi250	Topographic Position Index using Neighbourhood of 250-m Radius (continuous)				Y
NDVI_7median	Normalised Difference Vegetation Index (NDVI) with 7-cell Median Filter Assigned to Focal Cell (continuous)				Y

Data name	Description	Fauna ENM	Fauna SOM	Flora ENM	Flora climate projectn
sp_awc	Available Water Capacity Based on Proportionally Combined Depths from 0 to 100 cm (continuous)				Y
sp_cly	Clay Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)				Y
sp_slt	Silt Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)				Y
sp_snd	Sand Content Based on Proportionally Combined Depths from 0 to 100 cm (continuous)				Y
Tenure_Estates	Extent of 'NPWS Estate' Areas Reserved under the NPW Act 1974. Areas include National Parks, Nature Reserves, Regional Parks, State Conservation Areas, Aboriginal Areas, Historic Sites and Karst Conservation Reserves		Y		
Tenure_SF	Dedicated Legal State Forest Boundary as defined by Cadastre		Y		
Tenure_PP	All Land not included in State Forest or NPWS Estate		Y		

Ecological niche models (ENMs)

In contrast to the literature regarding the impact of SAC on linear modelling methods (e.g. Generalised Linear Modelling, particularly logistic regression), the number of studies directly assessing the implications of SAC for the machine learning methods used for ENMs in the present study is limited, and the results are mixed. De Oliviera *et al.* (2014) found that SAC made significant differences to the predictive performance of Maxent models, with the presence of SAC reducing model performance scores. In contrast, Naimi *et al.* (2011) found that SAC in covariates had a positive impact on Maxent model quality by reducing the negative influence of position errors in occurrence records.

SAC was not explicitly considered when generating Maxent ENMs for flora and fauna species in this study. However, the protocols used for each reduced the impact of SAC on the resulting predictions of environmental suitability. The relevant protocols included removing duplicate records by selecting only one record from covariate grid cells into which more than one record fell (fauna and flora ENMs; see Sections 6.2.5 and 6.2.7), and further thinning of records for fauna models using an adaptation of the method in Inman *et al.* (2021) and Guiterrez-Velez and Wiese (2020). Moreover, stratified sampling designs and spatial threshold limits on proximity of sites were established in each of the main surveys that we relied upon for baseline fauna and flora data (see Sections 6.1.1 and 6.1.2). In the case of the flora datasets, the median distance between plots was 700 m and 97% of plots were > 100 m to the nearest neighbour. It was assumed that most sites were sufficiently distant for spatial correlation to have made only a minor contribution to variation, compared to environmental and disturbance factors.

For Maxent ENMs we needed to balance thinning to reduce spatial sample bias, and thus partially reduce SAC, against the risk of removing samples to the extent that retained samples no longer adequately represented the range of environments associated with a species. Achieving this balance was an objective of the second-stage filtering used for the fauna ENMs.

Table 7. Species modelling approaches and the number of species modelled for this project

Not all modelling approaches and models were successful, conclusive or satisfactory. This table reports the number of species considered during each set of analyses. Subsequent chapters and the Appendices report the outcomes.

Modelling approach	Vertebrate fauna			Flora		
	Region	Species	Period	Region	Species	Period
Species occupancy (Section 6.2.2)	Combined northern (UNE & LNE)	28 priority spp. (14 mammal, 14 bird)	1991–98	N/A		
Species occupancy	Combined southern (Sthn & Eden)	16 priority spp. (5 mammal, 11 bird)	1991–98	N/A		
Species occupancy	Combined northern (UNE and LNE)	4 priority bat spp.	2003–18	N/A		
Environmental niche – Maxent (Sections 6.2.5 Fauna & 6.2.7 Flora)	All RFA regions (UNE, LNE, Sthn, Eden)	468 spp. (92 mammal, 230 bird, 96 reptile, 50 amphibian)	1991–98	All RFA regions (UNE, LNE, Sthn, Eden)	191 priority spp.	1987–2000
Environmental niche – Boosted Regression Tree (Section 6.2.6)	All RFA regions (UNE, LNE, Sthn, Eden)	252 spp.* (46 mammal, 148 bird, 45 reptile, 13 amphibian)	1991–98	N/A		
Climate projection – Maxent with NARCliM climate covariates (Section 6.4.1)	N/A			All RFA regions (UNE, LNE, Sthn, Eden)	81 climate-sensitive priority spp.	2000–2030 & 2000–2070
Climate projection – Maxent or Maxent + REMP with NARCliM climate covariates (Section 6.4.2 *et seq.* & 7.3.1)	NSW	7 spp. (2 mammal, 4 bird, 1 amphibian) & 78 spp. † (identity not provided)	Unrestricted up to 2020; 2020–2070	N/A		
Trend analyses – mostly Dynamic occupancy modelling, but some activity or abundance count time series (Sections 6.5 & 7.4.1–7.4.7)	Various parts of 4 RFA regions (UNE, LNE, Sthn, Eden)	17 spp. (species–site or species–district case studies: 14 mammal, 6 bird, 2 amphibian)	Variable, between 1988 and 2019	N/A		
Species occupancy – WildCount re-analysis (Sections 6.5 & 7.4.8)	Combined northern (UNE & LNE)	24 spp. (21 mammal, 2 bird, 1 reptile)	2012–2016	N/A		
Species occupancy – WildCount re-analysis (Sections 6.5 & 7.4.8)	Combined southern (Sthn & Eden)	16 spp. (15 mammal, 1 bird)	2012–2016	N/A		

* Intially datasets for 427 taxa were screened for BRT modelling but due to lack of data, ultimately only 252 species generated 281 models (species–survey models, since some species were commonly recorded by two or more different survey methods) – see Section 6.2.6

† Other than the seven focus species, these models are preliminary and are not presented in this report

The implications of SAC on the performance of Boosted Regression Tree (BRT) models were evaluated by Crase *et al.* (2012, 2014), who concluded that even without explicit correction of SAC effects, BRT models could account for some SAC effects. However, there are limitations to the degree of correction possible using standard implementations of BRT models. Crase *et al.* (2012, 2014) developed an auto-regressive version of the BRT method that substantially improved performance.

In summary, for the ENMs fitted to both flora and fauna species in the present study, the impact of SAC on model performance and spatial distribution of environmental suitability is not known, but is assumed to be of less importance than many well-understood impacts on ENM performance. However, further application of ENMs could be undertaken with an improved protocol, which may include explicit examination of the impacts of spatial auto-correlation (using, for example, Moran's I), and the use of more comprehensive treatment of spatial sampling bias in flora ENMs. Future analyses should include assessment of SAC.

6.2.2 Species occupancy models

Modelling was undertaken separately for the combined northern (UNE and LNE) and combined southern (Southern and Eden) RFA regions. A single-season occupancy modelling framework was used to account for imperfect detection of each modelled species. To restrict the number of models, we employed a hierarchical approach (Jathanna *et al.* 2015) whereby we first modelled probability of detection (ρ) while holding site occupancy (Ψ) constant. Since some datasets only had a single visit, it was assumed that detection and/or occupancy at these sites were a function of the set of covariates that influenced these parameters at sites with more than two visits. This is a limitation of the modelling and should be considered when interpreting the modelling results.

Modelling and model selection were carried out in R using the RPresence package (MacKenzie 2021), as depicted in Figure 9. When modelling detectability, three different models were evaluated from which the top model was selected and carried forward for occupancy modelling. In addition to a null model (where detectability was held constant), the influence of survey season and survey dataset on detectability was assessed.

When modelling occupancy, a staged approach was taken whereby single covariates were first assessed. The top single covariate model (n) was then built upon by adding an additional covariate in a 2-covariate additive model. If a 2-covariate model (n + 1) improved on the AIC score of model n by > 2 AIC points, it was retained and carried forward in further modelling that added additional covariates (i.e. a 3-covariate model and so). This process was continued until the addition of an extra covariate did not improve the AIC score by > 2 AIC points. Models with poor coefficient convergence were excluded when selecting both the detection and occupancy models.

Covariates used to model ρ and Ψ are listed in Section 6.1.4. All continuous covariates were standardised prior to analysis, and both the linear and quadratic forms were evaluated when selecting the top model. For categorical covariates, each individual category was evaluated independently, in addition to also considering the covariate as a whole.

Lastly, supported candidate models were model-averaged to provide estimates of all parameters. Supported models were those that were within 2 AIC points of the top model, for both detection and occupancy. Parameters calculated and shown for each species were:

1. Supported covariate plots highlighting the relationship between a covariate over the survey sampling range and species detectability / occupancy;

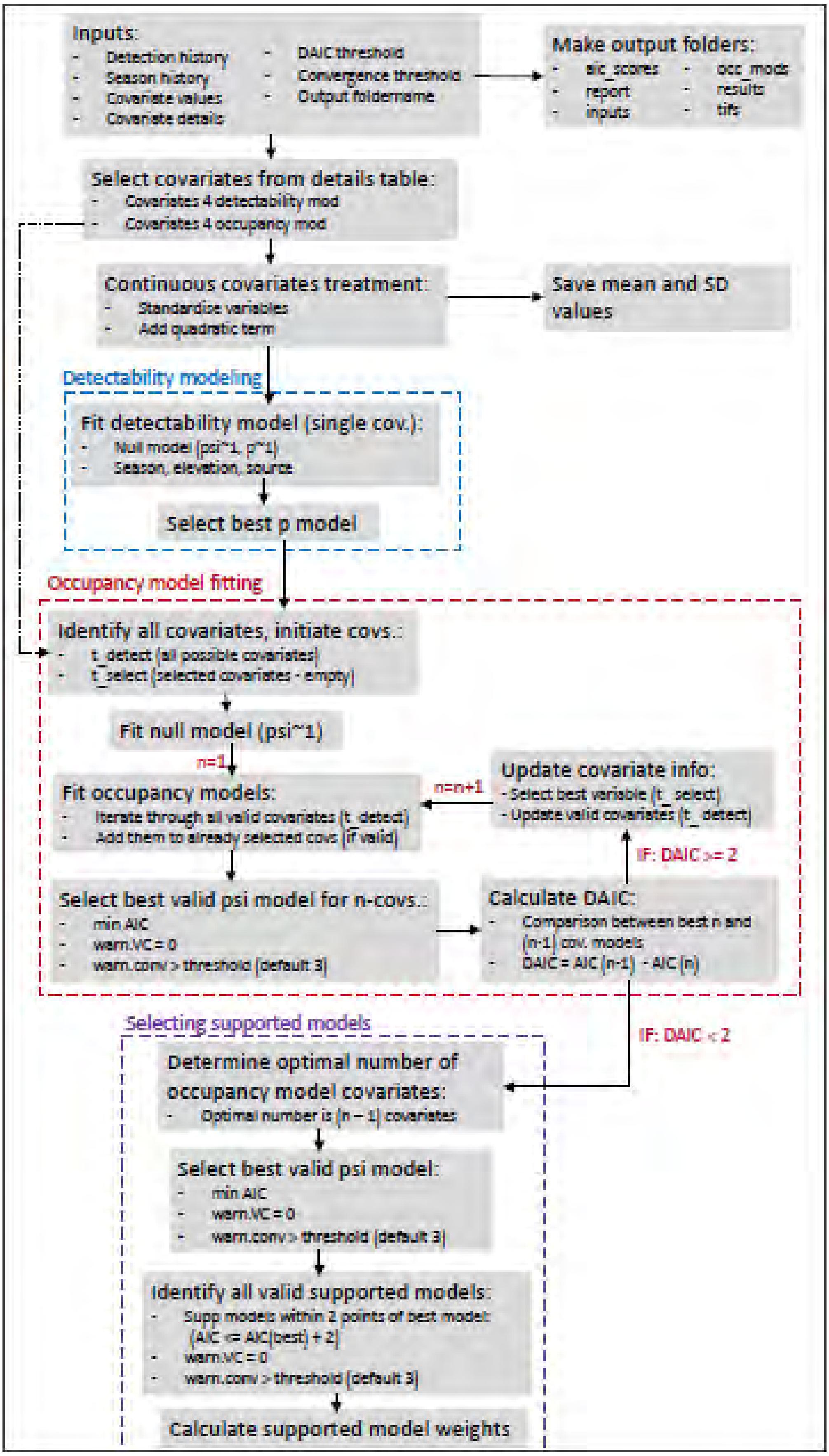

Figure 9. Schematic overview for species occupancy modelling and model selection

2. Median species detectability / occupancy probability based on the survey data;
3. Maps showing probability of occupancy and standard error.

Median detectability and occupancy values were estimated by holding all supported continuous variables at the median value of the survey data, while the mode was used for categorical variables. When producing supported covariate plots, all but the target covariate was held at their median or modal value. An assessment of model fit was undertaken using a Pearson chi-square test statistic and parametric bootstrapping procedure (MacKenzie and Bailey 2004). Models with a p-value < 0.05 were considered to be a poor fit to the data. Occupancy and standard error maps were generated for each species using the relationships established between supported covariates and occupancy. The extent of each map was the combined northern or southern RFA region being modelled. A non-woody mask was applied to maps to only display predicted occupancy and standard error for the forested extent in each RFA region.

6.2.3 Power analyses

Extending results from the species occupancy models, we undertook a power analysis to assess the sampling effort required to detect trends in occupancy for fauna. Our approach evaluated two scenarios for monitoring:

1. Detect a trend equivalent to a 30% decline in 10 years with 5 years of monitoring;
2. Detect a trend equivalent to a 30 % decline in 10 years with 10 years of monitoring.

These parameters (i.e. a 30% decline in 10 years) were chosen because they reflect the IUCN Red List categories and criteria (IUCN 2001) for identifying whether a taxon is Vulnerable when the best available evidence indicates that 'an observed, estimated, inferred or suspected population size reduction of ≥ 30% over the last 10 years or three generations, whichever is the longer', has occurred. The first scenario is for a monitoring program that measures the same rate of decline but over a shorter period (5 years); this was evaluated to assess whether it is plausible to monitor fauna over a shorter period of time than 10 years as per IUCN Red List criteria. The main implications are that many more monitoring sites will be required to detect this rate of change in half of the time (Section 8.2.1).

For each scenario, we calculated the sampling effort (number of sites conditional on the number of repeat visits) required to achieve power of 0.8 with an alpha of 0.1. To make the analyses relevant for future monitoring programs that may use different sampling methods to those used in the historic datasets of this project, generic curves were generated for a number of different starting occupancy (hereafter, initial occupancy) and detection probability classes (e.g. initial occupancy of 0.6 with curves representative of detection probabilities of 0.2, 0.4, 0.6, and 0.8). We also provide an example to demonstrate the influence of the desired power (i.e. 0.8 vs 0.9) on the sampling effort needed to achieve both levels of power.

All curves were generated following the approach of Guillera-Arroita and Lahoz-Monfort (2012), determining the sample size required to detect a difference in occupancy with a given power between two points in time.

6.2.4 Environmental niche models

Environmental niche models (ENMs), also referred to as species distribution models (SDMs) or habitat suitability models (HSMs), provide representations of the relationship between the occurrence of a taxon and environmental conditions. ENMs assess the suitability of a location for a given species based upon the assumption that the species' environmental tolerances can be described by the location of its current populations (Elith and Leathwick 2009). That is, these models attempt to infer the realised niche of a taxon. ENMs can be used to map the distribution of suitable habitat for the species, identify suitable areas beyond the species' known range, and assess habitat suitability under scenarios of climate change. The process of applying a fitted model to new environmental conditions is known as 'model projection'.

Two broad classes of ENM are possible: those which fit models to presence-absence data and those which allow models to be fitted to presence-only data. Presence–absence data is occurrence data collected by methods which record the detection (presence) or non-detection (presumed absence) at each sampling location and time. Data of this kind is produced by systematic flora and fauna surveys. Presence-only data records only the presence of the species at a location and time, with occurrence data typically drawn from museum and herbarium records, and the rapidly expanding incidental observation data sets (e.g. citizen-science data). Presence–absence modelling methods include various forms of generalised linear models, generalised additive models (GAMs) and some forms of machine learning methods such as Boosted Regression Tree (BRT) models. The output from a presence–absence model is a prediction of probability of occurrence given the occurrence data and environmental predictors used in the fit.

In contrast, presence-only models can only reliably provide a prediction that the environment at occurrence locations differs relative to a reference set of locations. In most presence-only modelling methods a randomly chosen set of 'background' locations is used to provide the reference set. Using appropriate methods to select the background samples is a major issue in fitting presence-only ENMs (VanDerWal *et al.* 2009; Barbet-Masin *et al.* 2012; Iturbide *et al.* 2018). The most widely used presence-only ENM method is the Maxent algorithm (Phillips *et al.* 2006), but other frequently applied methods include random forests (Prasad *et al.* 2006) and BRT models (Elith *et al.* 2006). Finally, it is possible to re-calibrate the output from some presence-only ENMs to estimate occurrence probability (e.g. Dormann 2020) but this is an area of active research and there is no widely supported method to make such re-calibrations.

6.2.4.1 Critical factors determining the quality and performance of ENMs

While ENMs are useful tools for identifying suitable habitat for a species, there are several factors that should be kept in mind when interpreting their output. First, ENMs identify potentially suitable habitat with respect to the environmental variables used to calibrate the models – they do not identify the species' distribution *per se*. It is possible that an area is classified as suitable, yet there are no records of the species from that locality. This may be because of dispersal limitations or biotic factors. Alternatively, it could indicate that an important predictor variable, such as disturbance history, has not been included in the model.

Second, the set of occurrences used to calibrate the model may not fully describe the breadth of a species' environmental tolerances. This is particularly relevant for species whose distributions may have been impacted by human activities, resulting in truncation of their niche. Thirdly, models can only be as good as the data provided to them and they cannot be expected to perform well when deficiencies exist in data availability.

Numerous factors influence the performance of an ENM. These include (but are not limited to) the algorithm used and the environmental predictor variables. There are multiple ENM algorithms available, ranging from simple quantile matching (e.g. BIOCLIM, Nix 1986; Booth *et al.* 2014) to machine learning techniques (Elith and Leathwick 2009). These models differ in complexity, data requirements and ease of use. Unfortunately, multi-model comparisons indicate that there is no single 'best' performing model (Elith *et al.* 2006; Diniz-Filho *et al.* 2010; Qiao *et al.* 2015). However, there are some models that consistently perform strongly, and these include two machine learning algorithms, Maxent and Boosted Regression Trees (Elith *et al.* 2006).

6.2.4.2 Critical factors affecting ENM quality

Spatial or temporal bias in occurrence records: numerous studies have highlighted the importance of spatial or temporal sampling biases in occurrence data to ENM quality. Failure to adjust for biases in occurrence data can significantly degrade the quality of ENMs. Of relevance to the present study, Muscatello *et al.* (2021) demonstrated the impact that failure to account for sampling bias has on the application of ENMs to conservation decisions and that, overall, methodological decisions on how ENMs are built can alter locations of conservation priority areas up to 90%.

Number of occurrence records (prevalence): in addition to the impact of sample bias, the number of occurrence records has also been shown to be a major influence on ENM performance. Maxent is particularly robust to small sample sizes allowing ENMs to be fitted to as few as five occurrence records. However, the value of models fitted to less than between 30 and 100 occurrences is known to significantly degrade Maxent ENM quality.

Choice of predictors (environmental covariates): although climate variables are known to be a major factor influencing a species' distribution, the inclusion of relevant non-climatic environmental predictors may also be important for the prediction of habitat availability and species distributions (Austin and Van Niel 2011; Hageer *et al.* 2017). Therefore, it is highly recommended to assess appropriate environmental and climate variables to improve the predictive performance of ENMs. As such, ENM fitting should begin with an assessment of the available environmental variables and their hypothesised importance for the taxa being modelled. That is, we should apply a first stage 'ecological filter' to prospective environmental variables (Williams *et al.* 2012) keeping in mind the intended use of the fitted model (Guillera-Arroita *et al.* 2015; Brodie *et al.* 2020).

Choice of settings controlling the fitting process: many assessments of ENM fitting protocols have concluded that an important aspect of model fitting is the selection of optimal settings for a given modelling method (Anderson and Gonzalez 2011; Merow *et al.* 2013). The process of selecting optimal settings is referred to as 'model tuning'.

6.2.4.3 Measures of model performance

All modelling methods developed to make predictions (e.g. ENMs) require two aspects of model performance to be measured and optimised. The first is to have some measure of how well a model fits to the data used to train or calibrate the model. The second, and most important, is some measure of how well the model predicts environmental suitability for species occurrences withheld from model fitting steps to serve as a test set. In most applications of ENMs we do not have access to independent test occurrence data, and therefore standard practice is to randomly split the available occurrence data into training (i.e. model fitting) and test (i.e. model evaluation) sub-sets, a process referred to as cross-validation. Given the stochastic nature of model fitting and occurrence records, it is best practice to repeat the split–train–test process numerous times. The stability of performance measures under cross-validation can provide deeper insights into the quality of an ENM.

In addition to these statistical measures of model performance, it is important that the resulting predictions make ecological sense and reflect current knowledge. We asked relevant species experts (RK, BL, LG & NR for fauna; NR for flora) to rank (i.e. good, indicative = satisfactory, poor) the ecological reliability of each ENM and SOM model in terms of its mapped prediction of potential habitat availability or species distribution against known ALA occurrences and habitat.

6.2.4.4 Our approach to using ENMs

In this project, we elected to use both Maxent and BRT to model habitat suitability for the selected fauna taxa. Maxent was used to fit models to all species considered in the project. As a presence-only method, Maxent can provide a measure of environmental suitability and has been found to a robust and reliable modelling method. Boosted Regression Tree models have also been shown to perform well and have the advantage of being useful for both presence-only and presence–absence data. BRT models were fitted for as many species and survey methods as allowed for by available survey data sets. Below we describe the general approach taken for both ENM methods.

It is important to note that supplementary data collected in the RFA regions over the period 1991–1998 and sourced from ALA was used in the development of the Maxent models, whereas the BRT models had to be restricted to using the same systematic 1990s survey plot data that were available for analysis in the Species Occupancy Models.

6.2.5 Maxent fauna modelling

The maximum entropy method fits multivariate models to data searches for the combination and weighting of predictors that maximise the correct classification of conditions associated with known occurrences when compared to a selection of reference measurements (Jaynes 1957a, b). The optimal model is found when the 'entropy' of the system being measured is a maximum. Phillips *et al.* (2006) developed an adaptation of the maximum entropy principle to fitting ENMs to presence-only data. The tool they developed, Maxent, models the relationship between occurrence locations and a reference set supplied by a random selection of non-occurrence or 'background' locations. The quantity used to measure the fitness of the model is the difference in information content between the two classes. Elith *et al.* (2011) showed that the maximum entropy condition is satisfied when the relative information content (relative entropy) between occurrence locations and background locations is minimised.

Maxent has become the most widely-used tool for producing ENMs, in part due to the availability of an easily used Java application, and because it has been shown be a very effective method in multi-method comparative studies (e.g. Elith *et al.* 2006). More recently, Fithian and Hastie (2013) showed that the Maxent approach to ENMs was mathematically equivalent to a form of generalised linear modelling with appropriate weights given to occurrence and background data. This finding led to the development of an R-package Maxent (https://CRAN.R-project.org/package=maxnet) that allows Maxent models, identical to the Java implementation of Maxent, to be produced within the powerful and freely available R statistical environment.

The development of advanced machine learning methods for fitting presence-only ENMs has been a significant breakthrough in the past 15 years as it has allowed the use of vast and rapidly growing repositories of presence data such as museum and herbarium data, and an ever-growing body of citizen-science data. In addition, Fithian *et al.* (2015) and Fletcher *et al.* (2019) have shown that it is possible to combine occurrence data from many sources, including data collected by diverse sampling methods, into a unified data set for analysis using presence-only methods. This can enable a better representation of the range of environments utilised by species and therefore provide the opportunity to fit models of greater utility.

The list of fauna to be modelled included 468 species (470 taxa). For these species, occurrence records were obtained from the Atlas of Living Australia (ALA) and the corporate systematic surveys, filtered to include only those from within the combined RFA regions and collected between 1991 and 1998, inclusive. However, after applying this spatio-temporal filter, there was a large range of prevalence values, with many taxa having occurrence records reduced to very low numbers (Table 8). This necessitated a multi-faceted approach to fitting Maxent models for fauna taxa. Most taxa (385) were fitted using a full cross-validation protocol (Sections 6.2.5.1 and 6.2.5.2 below), which applied a method to adjust for spatial bias in the occurrence records. A further 59 taxa had numbers of independent occurrence records too low to apply the bias-reducing cross-validation method. This group was subjected to a simplified model fitting protocol based on the findings of Shcheglovitova and Anderson (2013). The remaining group of 26 taxa had numbers of occurrence records too low to fit sensible Maxent models and were excluded from further analysis.

6.2.5.1 Bias-adjusted Maxent protocol

The method of tuning Maxent models to adjust for sampling biases in occurrence data were based on the grid cell aggregation method. Previous efforts to apply a less resource-intensive filtering by spatial distance (e.g. Boria *et al.* 2014; Aiello-Lammens *et al.* 2015) between occurrence records was not able to counter the impact of the current project's spatio-temporal filter, produced poor quality ENMs and was abandoned. Trials indicated that better performing models were possible using a grid cell aggregation filtering method to reduce spatio-temporal sampling bias in occurrence records (Inman *et al.* 2021; Gutierrez-Velez and Wiese 2020).

A sequence of grid cell aggregations (aggregation factors of 8, 16 and 32 cells of the original covariate raster grid cell size) was applied and a random selection of the multiple occurrence records falling in the aggregated cells was taken to produce a sub-sampled set of occurrence records. This was replicated five times so that each taxon had five sub-sampled occurrence sets at each aggregation level. Each occurrence set was subjected to 5-fold cross-validation Maxent model fitting along a sequence of regularisation values from 1 (no regularisation) to 10 in steps of one. Model performance was measured using AUC (the Area under the Receiver Operating Characteristic Curve) and continuous Boyce indices. Optimal combinations of aggregation factor and regularisation value were chosen by inspecting plots of performance measures to identify the combination which maximised both measures and minimised the variance in replicate values of the measures, with weight given to identifying the minimum variance of the continuous Boyce measure. This last criterion focused on stability or reproducibility of the models under the chosen parameter values. Optimal model replicates where then projected on to the covariate data to produce raster maps which were then masked to remove areas where models were extrapolating beyond the range of covariates used to train the model. After masking of extrapolation, mean and standard deviation rasters were produced.

6.2.5.2 Simplified Maxent protocol

For taxa which could not pass through the bias-adjusted workflow, a simplified cross-validation method was used. Five-fold cross-validation was used to generate five sub-sampled occurrence sets. Each was fitted with Maxent models along a sequence of regularisation values from 1 to 10. Optimal values of regularisation were chosen by examining plots of AUC and continuous Boyce. For the optimal value, the five replicate models were projected on to the baseline covariate layers and masked to remove areas of extrapolation. Mean and standard deviation rasters were then produced.

Table 8. Summary of the number of occurrences and modelling approach for Maxent models of fauna species

Total records were the number of all occurrences obtained from the Atlas of Living Australia and the 1990s systematic surveys for each species. Filtered records (those used in models) were the number remaining after filtering to include only those occurrences within the combined RFA regions collected between 1991 and 1998, inclusive. Model type: FCV = modelling incorporated full cross-validation protocol detailed in Section 6.2.5.1; SCV = modelling incorporated the simplified cross-validation protocol detailed in Section 6.2.5.2; None = no model fitted due to insufficient records. Note that taxonomic names are supplied by the Australian Faunal Directory. There have been name changes since the mid 1990s, particularly for passerine birds and small reptiles. FMIP priority 1, species listed in Table 1; FMIP priority 2, species listed in Table 2

FMIP priority	Scientific name	Common name	Total records	Filtered records	Model type
	Acanthiza apicalis	Broad-tailed Thornbill	63,922	3	None
	Acanthiza chrysorrhoa	Yellow-rumped Thornbill	300,617	439	FCV
	Acanthiza lineata	Striated Thornbill	171,031	2,326	FCV
	Acanthiza nana	Yellow Thornbill	133,929	646	FCV
	Acanthiza pusilla	Brown Thornbill	406,894	3,408	FCV
1	*Acanthiza reguloides*	Buff-rumped Thornbill	83,242	113	FCV
	Acanthorhynchus tenuirostris	Eastern Spinebill	306,106	2,821	FCV
	Accipiter cirrocephalus	Collared Sparrowhawk	50,866	210	FCV
	Accipiter fasciatus	Brown Goshawk	113,036	170	FCV
1	*Accipiter novaehollandiae*	Grey Goshawk	22,994	319	FCV
	Acritoscincus platynotus	Red-throated Skink	2,285	180	FCV
1	*Acrobates pygmaeus*	Feathertail Glider	5,553	354	FCV
	Adelotus brevis	Tusked Frog	5,074	381	FCV
	Aegotheles cristatus	Australian Owlet-nightjar	54,856	2,334	FCV
1, 2	*Aepyprymnus rufescens*	Rufous Bettong	2,483	280	FCV
	Ailuroedus crassirostris	Green Catbird	28,683	651	FCV
	Alectura lathami	Australian Brush-turkey	101,735	534	FCV
1	*Alisterus scapularis*	Australian King-parrot	200,448	1,780	FCV
	Amalosia lesueurii	Lesueur's Velvet Gecko	4,146	413	FCV
	Amphibolurus muricatus	Jacky Lizard	7,326	466	FCV
	Anas castanea	Chestnut Teal	213,138	334	FCV
	Anas gracilis	Grey Teal	360,882	354	FCV
	Anas superciliosa	Pacific Black Duck	645,519	974	FCV
1	*Anepischetosia maccoyi*	Highlands Forest-skink	2,097	37	SCV
	Anilios nigrescens	Blackish Blind Snake	2,319	68	FCV
	Anilios proximus	Proximus Blind Snake	600	1	None
	Anomalopus leuckartii	Two-clawed Worm-skink	1,304	77	SCV
	Anomalopus swansoni	Punctate Worm-skink	387	86	None
	Anomalopus verreauxii	Three-clawed Worm-skink	733	8	SCV
	Antechinus flavipes	Yellow-footed Antechinus	11,254	275	FCV
	Antechinus stuartii	Brown Antechinus	29,376	1,696	FCV
	Antechinus swainsonii	Dusky Antechinus	4,516	40	FCV
	Anthochaera carunculata	Red Wattlebird	675,972	1,273	FCV
	Anthochaera chrysoptera	Little Wattlebird	52,235	641	FCV
	Anthochaera phrygia	Regent Honeyeater	7,425	81	FCV
	Anthus novaeseelandiae	Australasian Pipit	190,876	305	FCV
	Apus pacificus	Fork-tailed Swift	11,306	13	FCV
	Aquila audax	Wedge-tailed Eagle	184,276	462	FCV
	Ardea alba	Great Egret	163,697	419	FCV
	Ardenna pacifica	Wedge-tailed Shearwater	83,825	38	SCV
1	*Artamus cyanopterus*	Dusky Woodswallow	134,267	479	FCV
	Artamus leucorynchus	White-breasted Woodswallow	97,754	85	FCV

FMIP priority	Scientific name	Common name	Total records	Filtered records	Model type
	Artamus superciliosus	White-browed Woodswallow	52,290	33	FCV
1	*Assa darlingtoni*	Pouched Frog	1,362	154	FCV
1, 2	*Atrichornis rufescens*	Rufous Scrub-bird	2,839	95	FCV
	Austrelaps ramsayi	Highland Copperhead	1,775	12	SCV
	Austrelaps superbus	Lowland Copperhead	2,748	17	SCV
1	*Austronomus australis*	White-striped Freetail-bat	15,683	629	FCV
	Aviceda subcristata	Pacific Baza	21,330	277	FCV
1	*Bellatorias frerei*	Major Skink	589	7	SCV
	Bellatorias major	Land Mullet	1,413	313	FCV
	Boiga irregularis	Brown Tree Snake	2,644	11	FCV
	Bos taurus	European Cattle	14,235	252	FCV
1	*Burhinus grallarius*	Bush Stone-curlew	43,634	2	SCV
	Cacatua galerita	Sulphur-crested Cockatoo	577,201	1,112	FCV
	Cacomantis flabelliformis	Fan-tailed Cuckoo	156,157	1,666	FCV
	Cacomantis pallidus	Pallid Cuckoo	66,084	47	FCV
	Cacomantis variolosus	Brush Cuckoo	45,376	480	FCV
	Cacophis krefftii	Southern Dwarf Crowned Snake	784	23	FCV
1	*Cacophis squamulosus*	Golden-crowned Snake	2,272	1	FCV
	Calamanthus pyrrhopygius	Chestnut-rumped Heathwren	11,295	25	FCV
	Calidris acuminata	Sharp-tailed Sandpiper	80,804	146	FCV
	Caligavis chrysops	Yellow-faced Honeyeater	218,005	3,327	FCV
	Callocephalon fimbriatum	Gang-gang Cockatoo	97,853	694	FCV
	Calyptorhynchus banksii	Red-tailed Black Cockatoo	66,713	3,682	None
1	*Calyptorhynchus funereus*	Yellow-tailed Black-Cockatoo	148,455	1,405	FCV
1, 2	*Calyptorhynchus lathami*	Glossy Black-cockatoo	39,439	2,549	FCV
1	*Calyptotis ruficauda*	Red-tailed Calyptotis	1,142	310	FCV
1	*Calyptotis scutirostrum*	Scute-snouted Calyptotis	2,996	492	FCV
1	*Canis familiaris*	Dog/Dingo	13,383	6	None
1	*Capra hircus*	Goat	34,163	66	FCV
1	*Carinascincus coventryi*	Southern Forest Cool-skink	2,986	1	SCV
	Carlia tetradactyla	Southern Rainbow-skink	1,676	11	SCV
	Carlia vivax	Lively Rainbow Skink	1,739	15	FCV
	Carterornis leucotis	White-eared Monarch	5,015	203	FCV
	Centropus phasianinus	Pheasant Coucal	77,208	403	FCV
1	*Cercartetus nanus*	Eastern Pygmy-possum	3,814	15	FCV
	Ceyx azureus	Azure Kingfisher	43,296	317	FCV
	Chalcites basalis	Horsfield's Bronze-cuckoo	51,216	70	FCV
	Chalcites lucidus	Shining Bronze-cuckoo	38,474	800	FCV
	Chalcophaps indica	Emerald Dove	26,933	269	FCV
1, 2	*Chalinolobus dwyeri*	Large-eared Pied Bat	2,061	62	FCV
	Chalinolobus gouldii	Gould's Wattled Bat	37,579	611	FCV
	Chalinolobus morio	Chocolate Wattled Bat	22,303	854	FCV
	Chalinolobus nigrogriseus	Hoary Wattled Bat	1,046	33	FCV
	Chelodina longicollis	Eastern Long-necked Turtle	11,263	38	FCV
	Chenonetta jubata	Australian Wood Duck	423,844	616	FCV
	Cheramoeca leucosterna	White-backed Swallow	24,712	3	SCV
	Chloris chloris	Common Greenfinch	32,849	1,078	SCV
	Chroicocephalus novaehollandiae	Silver Gull	538,164	565	FCV
1	*Chthonicola sagittata*	Speckled Warbler	36,798	152	FCV
	Cincloramphus cruralis	Brown Songlark	44,360	12	SCV
1	*Cinclosoma punctatum*	Spotted Quail-thrush	13,380	596	FCV
	Cisticola exilis	Golden-headed Cisticola	120,609	184	FCV

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1	*Climacteris erythrops*	Red-browed Treecreeper	16,322	842	FCV
1, 2	*Climacteris picumnus*	Brown Treecreeper	124,850	296	FCV
1	*Coeranoscincus reticulatus*	Three-toed Snake-tooth Skink	319	4	SCV
	Colluricincla harmonica	Grey Shrike-thrush	580,729	3,547	FCV
	Colluricincla megarhyncha	Little Shrike-thrush	51,543	153	FCV
	Columba leucomela	White-headed Pigeon	35,806	608	FCV
	Concinnia brachysoma	Northern Barsided Skink	–	–	None
1	*Concinnia martini*	Dark Bar-sided Skink	1,019	35	FCV
1	*Concinnia tenuis*	Bar-sided Skink	1,660	165	FCV
	Coracina novaehollandiae	Black-faced Cuckoo-Shrike	530,521	2,076	FCV
	Coracina papuensis	White-bellied Cuckoo-Shrike	81,636	375	FCV
	Coracina tenuirostris	Cicadabird	11,132	36	SCV
	Corcorax melanorhamphos	White-winged Chough	163,741	478	FCV
	Cormobates leucophaea	White-throated Treecreeper	287,411	3,801	FCV
	Corvus coronoides	Australian Raven	550,169	1,428	FCV
	Corvus mellori	Little Raven	316,090	169	FCV
	Corvus orru	Torresian Crow	286,979	767	FCV
	Corvus tasmanicus	Forest Raven	57,824	248	FCV
	Coturnix pectoralis	Stubble Quail	38,845	8	SCV
	Coturnix ypsilophora	Brown Quail	40,322	35	SCV
	Cracticus nigrogularis	Pied Butcherbird	278,787	680	FCV
	Cracticus torquatus	Grey Butcherbird	430,968	1,699	FCV
	Crinia parinsignifera	Eastern Sign-bearing Froglet	9,961	223	FCV
	Crinia signifera	Common Eastern Froglet	68,496	1,752	FCV
	Crinia tinnula	Tinkling Froglet	2,760	286	FCV
1	*Cryptophis nigrescens*	Eastern Small-eyed Snake	2,852	12	FCV
	Ctenotus eurydice	Brown-backed Yellow-lined Ctenotus	68	9	SCV
	Ctenotus robustus	Robust Ctenotus	9,893	397	FCV
	Ctenotus taeniolatus	Copper-tailed Skink	8,033	450	FCV
	Cuculus optatus	Oriental Cuckoo	2,584	2	None
	Cyclodomorphus gerrardii	Pink-tongued Lizard	755	6	FCV
	Dacelo novaeguineae	Kookaburra	624,210	3,022	FCV
1	*Dama dama*	Fallow Deer	11,222	84	None
1, 2	*Daphoenositta chrysoptera*	Varied Sittella	76,792	686	FCV
1, 2	*Dasyurus maculatus*	Spotted-tailed Quoll	13,802	975	FCV
	Delma plebeia	Leaden Delma	256	3	None
	Demansia psammophis	Yellow-faced Whip Snake	3,888	61	FCV
1	*Dendrelaphis punctulatus*	Green Tree Snake	6,538	9	FCV
1	*Dicaeum hirundinaceum*	Mistletoebird	231,931	1,728	FCV
	Dicrurus bracteatus	Spangled Drongo	116,941	575	FCV
	Diplodactylus vittatus	Eastern Stone Gecko	5,070	3	SCV
	Diporiphora australis	Tommy Roundhead	1,718	14	None
	Diporiphora nobbi	Nobbi Dragon	3,889	84	FCV
1	*Egernia cunninghami*	Cunningham's Skink	3,574	12	FCV
1	*Egernia mcpheei*	Eastern Crevice Skink	515	7	FCV
1	*Egernia saxatilis*	Black Rock Skink	1,921	2	SCV
	Egernia striolata	Tree Skink	6,592	82	SCV
	Egretta novaehollandiae	White-faced Heron	491,036	882	FCV
	Elseyornis melanops	Black-fronted Dotterel	157,075	104	FCV
	Emydura macquarii macquarii	Macquarie River Turtle	971	32	FCV
	Entomyzon cyanotis	Blue-faced Honeyeater	145,058	254	FCV
	Eolophus roseicapilla	Galah	788,978	832	FCV

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	Eopsaltria australis	Eastern Yellow Robin	315,936	3,096	FCV
	Ephippiorhynchus asiaticus	Black-necked Stork	35,123	445	FCV
	Equus caballus	Brumby	6,563	73	FCV
	Eudynamys orientalis	Eastern Koel	90,961	755	FCV
1	*Eulamprus heatwolei*	Yellow-bellied Water-Skink	6,746	377	FCV
	Eulamprus kosciuskoi	Alpine Water-Skink	16,437	706	FCV
	Eulamprus quoyii	Eastern Water-skink	9,840	729	FCV
1	*Eurostopodus mystacalis*	White-throated Nightjar	8,532	670	FCV
	Eurystomus orientalis	Dollarbird	94,388	677	FCV
	Falco berigora	Brown Falcon	168,714	97	FCV
	Falco cenchroides	Nankeen Kestrel	236,837	256	FCV
	Falco hypoleucos	Grey Falcon	3,163	72	SCV
	Falco longipennis	Australian Hobby	68,559	181	FCV
	Falco peregrinus	Peregrine Falcon	46,154	180	FCV
1	*Falcunculus frontatus*	Crested Shrike-tit	62,093	637	FCV
1, 2	*Falsistrellus tasmaniensis*	Eastern False Pipistrelle	4,642	349	FCV
1	*Felis catus*	Cat	18,952	528	FCV
	Furina diadema	Red-naped Snake	1,758	5	SCV
	Gallinula tenebrosa	Dusky Moorhen	278,791	360	FCV
	Gallirallus philippensis	Buff-banded Rail	33,307	8	SCV
	Geopelia humeralis	Bar-shouldered Dove	205,480	484	FCV
	Geopelia striata	Peaceful Dove	249,622	354	FCV
	Gerygone mouki	Brown Gerygone	70,929	1,287	FCV
	Gerygone olivacea	White-throated Gerygone	80,876	779	FCV
	Gliciphila melanops	Tawny-crowned Honeyeater	19,450	32	FCV
	Glossopsitta concinna	Musk Lorikeet	123,142	366	FCV
	Grallina cyanoleuca	Magpie-lark	1,001,705	1,043	FCV
	Gymnorhina tibicen	Australian Magpie	1,296,411	2,225	FCV
	Haliaeetus leucogaster	White-Bellied Sea-Eagle	120,239	738	FCV
	Haliastur indus	Brahminy Kite	52,987	316	FCV
	Haliastur sphenurus	Whistling Kite	263,812	704	FCV
1	*Harrisoniascincus zia*	Rainforest Cool-skink	298	18	SCV
1	*Heleioporus australiacus*	Giant Burrowing Frog	1,491	2	FCV
	Hemiaspis signata	Black-Bellied Swamp Snake	1,901	69	FCV
	Hemiergis decresiensis	Three-toed Earless Skink	6,452	50	FCV
	Heteronotia binoei	Bynoe's Gecko	27,721	10	SCV
	Hieraaetus morphnoides	Little Eagle	51,171	171	FCV
	Hirundapus caudacutus	Spine-tailed Swift	42,014	558	FCV
	Hirundo neoxena	Welcome Swallow	770,301	1,230	FCV
1	*Hoplocephalus bitorquatus*	Pale-headed Snake	604	10	None
	Hoplocephalus bungaroides	Broad-headed Snake	614	3	SCV
1	*Hoplocephalus stephensii*	Stephens' Banded Snake	627	2	FCV
	Hydromys chrysogaster	Water-Rat	7,667	4	FCV
	Hydroprogne caspia	Caspian Tern	95,494	108	FCV
	Intellagama lesueurii	Eastern Water Dragon	14,345	795	FCV
1	*Isoodon macrourus*	Northern Brown Bandicoot	31,585	515	FCV
1, 2	*Isoodon obesulus*	Southern Brown Bandicoot	11,285	2	SCV
	Lalage leucomela	Varied Triller	64,812	241	FCV
	Lalage sueurii	White-winged Triller	88,581	24	FCV
	Lampropholis amicula	Friendly Sunskink	612	133	FCV
	Lampropholis caligula	Montane Sunskink	213	66	SCV
1	*Lampropholis delicata*	Dark-flecked Garden Sunskink	25,550	2,650	FCV

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	Lampropholis guichenoti	Pale-flecked Garden Sunskink	27,061	620	FCV
	Lathamus discolor	Swift Parrot	17,617	44	FCV
	Lechriodus fletcheri	Fletcher’s Frog	1,542	245	FCV
	Lepus capensis	Brown Hare	4,804	15	FCV
	Lerista bougainvillii	South-eastern Slider	5,813	22	SCV
	Lerista muelleri	Wood Mulch-slider	2,611	1	None
	Leucosarcia melanoleuca	Wonga Pigeon	58,373	1,214	FCV
	Lialis burtonis	Burton’s Snake-lizard	6,224	12	FCV
	Lichenostomus melanops	Yellow-tufted Honeyeater	67,663	286	FCV
	Lichmera indistincta	Brown Honeyeater	252,602	325	FCV
	Limnodynastes dumerilii	Eastern Banjo Frog	19,319	201	FCV
	Limnodynastes fletcheri	Barking Frog	5,164	2	None
	Limnodynastes peronii	Peron's Marsh Frog	31,205	899	FCV
	Limnodynastes tasmaniensis	Spotted Grass Frog	34,245	168	FCV
	Limnodynastes terraereginae	Northern Banjo Frog	1,693	80	FCV
	Limosa lapponica	Bar-tailed Godwit	68,526	224	FCV
	Liopholis modesta	Eastern Ranges Rock-Skink	769	16	SCV
	Liopholis whitii	White’s Skink	7,079	210	FCV
1	*Litoria booroolongensis*	Booroolong Frog	4,613	4	None
	Litoria brevipalmata	Green-thighed Frog	483	39	SCV
	Litoria caerulea	Green Tree Frog	10,095	124	FCV
	Litoria chloris	Red-eyed Tree Frog	1,631	61	FCV
1	*Litoria citropa*	Blue Mountains Tree Frog	1,807	8	FCV
1	*Litoria daviesae*	Davies’ Tree Frog	422	3	FCV
1	*Litoria dentata*	Bleating Tree Frog	5,232	25	FCV
	Litoria fallax	Eastern Dwarf Tree Frog	25,982	950	FCV
	Litoria freycineti	Freycinet's Frog	1,005	21	FCV
	Litoria gracilenta	Dainty Green Tree Frog	1,929	47	FCV
	Litoria jervisiensis	Jervis Bay Tree Frog	727	46	FCV
	Litoria latopalmata	Broad-palmed Frog	6,642	77	FCV
	Litoria lesueuri	Lesueur’s Frog	9,575	1,239	FCV
1	*Litoria littlejohni*	Heath Frog	2,672	1	None
	Litoria nasuta	Rocket Frog	4,880	42	FCV
1	*Litoria nudidigita*	Leaf Green River Tree Frog	1,269	10	None
1	*Litoria pearsoniana*	Pearson’s Frog	1,898	74	FCV
	Litoria peronii	Peron’s Tree Frog	31,509	716	FCV
1	*Litoria phyllochroa*	Green Stream Frog	5,256	313	FCV
	Litoria revelata	Revealed Frog	965	24	FCV
	Litoria rubella	Little Red Tree Frog	8,536	4	None
1	*Litoria subglandulosa*	Glandular Frog	587	6	SCV
	Litoria tyleri	Tyler’s Tree Frog	3,651	50	FCV
	Litoria verreauxii	Verreaux’s Frog	15,221	399	FCV
1	*Lophoictinia isura*	Square-tailed Kite	12,741	20	FCV
	Lopholaimus antarcticus	Topknot Pigeon	27,519	469	FCV
1	*Lophosaurus spinipes*	Southern Angle-headed Dragon	723	10	FCV
1	*Lygisaurus foliorum*	Tree-base Litter-skink	2,517	9	FCV
	Macropus giganteus	Eastern Grey Kangaroo	123,553	1,207	FCV
	Macropygia phasianella	Brown Cuckoo-dove	50,428	1,068	FCV
	Malurus cyaneus	Superb Fairy-wren	735,143	1,992	FCV
	Malurus lamberti	Variegated Fairy-wren	38,823	1,538	FCV
	Malurus melanocephalus	Red-backed Fairy-wren	92,008	297	FCV
1	*Manorina melanocephala*	Noisy Miner	568,624	1,032	FCV

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1, 2	*Manorina melanophrys*	Bell Miner	72,094	746	FCV
	Mastacomys fuscus	Broad-toothed Rat	1,439	22	FCV
	Megalurus timoriensis	Tawny Grassbird	8,216	1	None
	Melanodryas cucullata	Hooded Robin	53,468	78	FCV
	Meliphaga lewinii	Lewin's Honeyeater	244,788	2,643	FCV
	Melithreptus albogularis	White-throated Honeyeater	84,273	180	FCV
1	*Melithreptus brevirostris*	Brown-headed Honeyeater	111,924	342	FCV
	Melithreptus gularis	Black-chinned Honeyeater	29,595	25	FCV
1	*Melithreptus lunatus*	White-naped Honeyeater	146,515	1,514	FCV
	Melomys cervinipes	Fawn-footed Melomys	3,819	363	FCV
	Menetia greyii	Common Dwarf Skink	16,140	2	None
	Menura alberti	Albert's Lyrebird	6,217	177	FCV
1	*Menura novaehollandiae*	Superb Lyrebird	79,602	1,827	FCV
	Merops ornatus	Rainbow Bee-eater	230,914	517	FCV
	Microcarbo melanoleucos	Little Pied Cormorant	413,797	696	FCV
	Microeca fascinans	Jacky Winter	127,138	615	FCV
1, 2	*Micronomus norfolkensis*	Eastern Freetail-bat	2,375	106	FCV
1	*Miniopterus australis*	Little Bentwing-bat	6,131	540	FCV
1	*Miniopterus orianae*	Northern Bentwing-bat	10,525	423	FCV
1, 2	*Mixophyes balbus*	Stuttering Frog	2,532	205	FCV
	Mixophyes fasciolatus	Great Barred Frog	4,637	598	FCV
1	*Mixophyes fleayi*	Fleay's Barred Frog	2,705	2	None
1, 2	*Mixophyes iteratus*	Giant Barred Frog	4,890	169	FCV
	Monarcha melanopsis	Black-faced Monarch	44,638	1,294	FCV
1	*Morelia spilota*	Diamond/Carpet Python	7,059	633	FCV
	Morelia spilota mcdowelli	Carpet Python	1,252	22	FCV
	Morelia spilota spilota	Diamond Python	882	11	FCV
	Morethia boulengeri	Boulenger's Snake-eyed Skink	17,880	48	SCV
	Mus musculus	House Mouse	54,842	315	FCV
1	*Myiagra cyanoleuca*	Satin Flycatcher	19,411	221	FCV
	Myiagra inquieta	Restless Flycatcher	110,925	377	FCV
1	*Myiagra rubecula*	Leaden Flycatcher	92,368	1,036	FCV
1, 2	*Myotis macropus*	Large-footed Myotis	6,021	199	FCV
	Myzomela sanguinolenta	Scarlet Honeyeater	87,925	1,298	FCV
1	*Nebulifera robusta*	Robust Velvet Gecko	1,035	1	SCV
	Neochmia temporalis	Red-browed Finch	285,346	1,860	FCV
	Neophema pulchella	Turquoise Parrot	13,656	116	FCV
	Nesoptilotis leucotis	White-eared Honeyeater	145,401	877	FCV
1, 2	*Ninox connivens*	Barking Owl	14,281	160	FCV
1, 2	*Ninox novaeseelandiae*	Southern Boobook	101,171	2,886	FCV
1, 2	*Ninox strenua*	Powerful Owl	26,624	1,645	FCV
1	*Notamacropus dorsalis*	Black-striped Wallaby	19,300	40	SCV
1	*Notamacropus parma*	Parma Wallaby	2,213	409	FCV
	Notamacropus parryi	Whiptail Wallaby	1,550	130	FCV
1	*Notamacropus rufogriseus*	Red-necked Wallaby	56,982	1,442	FCV
	Notechis scutatus	Tiger Snake	5,814	14	FCV
	Numenius madagascariensis	Eastern Curlew	57,794	203	FCV
	Nycticorax caledonicus	Nankeen Night-heron	62,915	138	FCV
	Nyctophilus bifax	Eastern Long-eared Bat	876	88	FCV
1	*Nyctophilus geoffroyi*	Lesser Long-eared Bat	22,361	417	FCV
1	*Nyctophilus gouldi*	Gould's Long-eared Bat	12,970	891	FCV
	Oedura tryoni	Southern Spotted Velvet Gecko	1,713	139	SCV

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1	*Ophioscincus truncatus*	Short-limbed Snake-skink	665	18	FCV
	Origma solitaria	Rockwarbler	6,964	35	FCV
	Oriolus sagittatus	Olive-backed Oriole	156,602	1,294	FCV
1	*Ornithorhynchus anatinus*	Platypus	12,703	6	FCV
	Orthonyx temminckii	Australian Logrunner	15,683	467	FCV
1	*Oryctolagus cuniculus*	Rabbit	54,623	611	FCV
	Osphranter robustus	Common Wallaroo	47,431	38	FCV
	Ovis aries	Sheep	4,201	13	SCV
	Ozimops planiceps	South-eastern Free-tailed Bat	4,061	44	FCV
1	*Ozimops ridei*	Ride’s Free-tailed Bat	3,159	2	FCV
1	*Pachycephala olivacea*	Olive Whistler	16,088	199	FCV
	Pachycephala pectoralis	Golden Whistler	315,666	2,840	FCV
	Pachycephala rufiventris	Rufous Whistler	379,033	2,115	FCV
	Pardalotus punctatus	Spotted Pardalote	359,715	2,863	FCV
	Pardalotus striatus	Striated Pardalote	479,003	1,500	FCV
1	*Parvipsitta pusilla*	Little Lorikeet	47,441	589	FCV
	Pelecanus conspicillatus	Australian Pelican	350,889	594	FCV
1, 2	*Perameles nasuta*	Long-nosed Bandicoot	28,213	917	FCV
1, 2	*Petauroides volans*	Greater Glider	31,536	5,442	FCV
1, 2	*Petaurus australis*	Yellow-bellied Glider	25,108	2,781	FCV
1, 2	*Petaurus breviceps*	Sugar Glider	29,806	2,745	FCV
1, 2	*Petaurus norfolcensis*	Squirrel Glider	7,245	395	FCV
	Petrochelidon ariel	Fairy Martin	131,500	180	FCV
	Petrochelidon nigricans	Tree Martin	200,490	266	FCV
	Petrogale penicillata	Brush-tailed Rock-wallaby	5,198	72	FCV
1	*Petroica boodang*	Scarlet Robin	98,058	446	FCV
	Petroica goodenovii	Red-capped Robin	98,639	24	SCV
1	*Petroica phoenicea*	Flame Robin	66,812	426	FCV
	Petroica rosea	Rose Robin	39,176	794	FCV
	Phalacrocorax carbo	Great Cormorant	201,334	488	FCV
	Phalacrocorax sulcirostris	Little Black Cormorant	304,595	481	FCV
	Phalacrocorax varius	Pied Cormorant	173,327	336	FCV
	Phaps chalcoptera	Common Bronzewing	187,412	310	FCV
	Phaps elegans	Brush Bronzewing	24,349	43	FCV
1	*Phascogale tapoatafa*	Brush-tailed Phascogale	5,462	27	FCV
1, 2	*Phascolarctos cinereus*	Koala	127,145	4,147	FCV
	Philemon citreogularis	Little Friarbird	119,187	165	FCV
	Philemon corniculatus	Noisy Friarbird	223,486	2,050	FCV
1	*Philoria loveridgei*	Loveridge’s Frog	554	31	SCV
1	*Philoria sphagnicola*	Sphagnum Frog	983	100	FCV
1	*Phoniscus papuensis*	Golden-tipped Bat	1,423	177	FCV
	Phylidonyris niger	White-cheeked Honeyeater	62,500	739	FCV
	Phylidonyris novaehollandiae	New Holland Honeyeater	364,403	622	FCV
	Phylidonyris pyrrhoptera	Crescent Honeyeater	53,836	4	SCV
	Phyllurus platurus	Broad-tailed Gecko	1,972	26	FCV
	Pitta versicolor	Noisy Pitta	17,689	272	FCV
	Planigale maculata	Common Planigale	1,395	19	SCV
1	*Platycercus elegans*	Crimson Rosella	501,054	2,664	FCV
	Platycercus eximius	Eastern Rosella	140,154	1,077	FCV
	Platyplectrum ornatum	Ornate Burrowing Frog	8,852	109	FCV
	Plectorhyncha lanceolata	Striped Honeyeater	71,653	242	FCV
	Podargus ocellatus	Marbled Frogmouth	1,617	99	FCV

FMIP priority	Scientific name	Common name	Total records	Filtered records	Model type
	Podargus strigoides	Tawny Frogmouth	101,530	1,414	FCV
	Pogona barbata	Bearded Dragon	7,533	27	FCV
	Pomatostomus superciliosus	White-browed Babbler	95,564	4	SCV
1, 2	*Pomatostomus temporalis*	Grey-crowned Babbler	75,764	389	FCV
	Porphyrio porphyrio	Purple Swamphen	293,524	370	FCV
1, 2	*Potorous tridactylus*	Long-nosed Potoroo	8,758	188	FCV
	Pseudechis porphyriacus	Red-bellied Black Snake	17,221	170	FCV
	Pseudemoia entrecasteauxii	Southern Grass Skink	7,160	87	FCV
1	*Pseudemoia spenceri*	Trunk-climbing Cool-skink	2,048	35	SCV
1	*Pseudocheirus peregrinus*	Common Ringtail Possum	64,689	1,567	FCV
1	*Pseudomys fumeus*	Smokey Mouse	604	2	SCV
	Pseudomys gracilicaudatus	Eastern Chestnut Mouse	502	49	SCV
	Pseudomys novaehollandiae	New Holland Mouse	2,441	85	FCV
1	*Pseudomys oralis*	Hastings River Mouse	1,224	1	FCV
	Pseudonaja textilis	Common Brown Snake	11,365	36	FCV
1	*Pseudophryne australis*	Red-crowned Toadlet	3,330	2	FCV
	Pseudophryne bibronii	Bibron’s Toadlet	9,401	104	FCV
1	*Pseudophryne coriacea*	Red-backed Toadlet	6,961	1,073	FCV
	Psophodes olivaceus	Eastern Whipbird	207,161	2,667	FCV
	Pteropus alecto gouldii	Black Flying-fox	5,273	18	SCV
1, 2	*Pteropus poliocephalus*	Grey-headed Flying-fox	54,488	581	FCV
	Pteropus scapulatus	Little Red Flying-fox	3,058	353	FCV
1	*Ptilinopus magnificus*	Wompoo Fruit-dove	26,851	390	FCV
	Ptilinopus regina	Rose-crowned Fruit-dove	19,259	238	FCV
	Ptilinopus superbus	Superb Fruit-Dove	7,726	18	SCV
	Ptilonorhynchus violaceus	Satin Bowerbird	120,568	1,664	FCV
	Ptiloris paradiseus	Paradise Riflebird	8,167	306	FCV
	Ptilotula fusca	Fuscous Honeyeater	61,201	365	FCV
	Ptilotula penicillata	White-plumed Honeyeater	408,642	131	FCV
	Purnella albifrons	White-fronted Honeyeater	33,226	2	None
	Pycnoptilus floccosus	Pilotbird	9,601	169	FCV
	Pygopus lepidopodus	Common Scaly-foot	2,355	9	SCV
	Rankinia diemensis	Mountain Dragon	2,111	30	FCV
	Rattus fuscipes	Bush Rat	87,189	2,047	FCV
	Rattus lutreolus	Swamp Rat	12,147	397	FCV
	Rattus norvegicus	Brown Rat	1,183	8	None
	Rattus rattus	Black Rat	22,597	326	FCV
	Rattus tunneyi	Pale Field-rat	3,891	138	FCV
	Rhinella marina	Cane Toad	14,882	176	FCV
	Rhinolophus megaphyllus	Eastern Horseshoe-bat	5,617	510	FCV
	Rhipidura albiscapa	Grey Fantail	650,128	3,980	FCV
	Rhipidura leucophrys	Willie Wagtail	898,905	1,228	FCV
	Rhipidura rufifrons	Rufous Fantail	19,739	2,745	FCV
1, 2	*Saccolaimus flaviventris*	Yellow-Bellied Sheathtail-bat	3,628	55	FCV
1	*Saiphos equalis*	Three-toed Skink	6,314	845	FCV
	Saltuarius cornutus	Northern Leaf-tailed Gecko	338	4	SCV
1	*Saltuarius swaini*	Southern Leaf-tailed Gecko	595	13	FCV
	Saproscincus challengeri	Orange-tailed Shadeskink	1,578	311	FCV
1	*Saproscincus mustelinus*	Weasel Skink	5,938	351	FCV
1	*Saproscincus rosei*	Highland Forest Skink	1,261	233	FCV
	Saproscincus spectabilis	Gully Skink	543	168	SCV
1, 2	*Scoteanax rueppellii*	Greater Broad-nosed Bat	2,265	291	FCV

FMIP priority	Scientific name	Common name	Total records	Filtered records	Model type
	Scotorepens balstoni	Inland Broad-nosed Bat	3,987	9	None
	Scotorepens greyii	Little Broad-nosed Bat	3,545	13	SCV
1	*Scotorepens orion*	Eastern Broad-nosed Bat	3,137	393	FCV
	Scythrops novaehollandiae	Channel-billed Cuckoo	56,930	502	FCV
	Sericornis citreogularis	Yellow-throated Scrubwren	27,990	618	FCV
	Sericornis frontalis	White-browed Scrubwren	373,554	2,758	FCV
	Sericornis magnirostra	Large-billed Scrubwren	43,146	592	FCV
	Sericulus chrysocephalus	Regent Bowerbird	17,225	298	FCV
1	*Silvascincus murrayi*	Murray's Skink	2,005	489	FCV
	Smicrornis brevirostris	Weebill	260,001	41	FCV
	Sminthopsis crassicaudata	Fat-tailed Dunnart	8,624	2,522	None
	Sminthopsis murina	Common Dunnart	4,563	87	FCV
	Sphecotheres vieilloti	Australasian Figbird	176,146	511	FCV
	Stagonopleura bella	Beautiful Firetail	12,378	89	SCV
	Stipiturus malachurus	Southern Emu-wren	21,591	195	FCV
	Stizoptera bichenovii	Double-Barred Finch	96,337	64	FCV
	Strepera graculina	Pied Currawong	512,919	3,425	FCV
	Strepera versicolor	Grey Currawong	131,609	174	FCV
1	*Sus scrofa*	Pig	17,136	177	FCV
	Syconycteris australis	Common Blossom-Bat	2,595	42	FCV
	Symposiachrus trivirgatus	Spectacled Monarch	25,114	331	FCV
	Tachybaptus novaehollandiae	Australasian Grebe	251,979	292	FCV
1	*Tachyglossus aculeatus*	Short-beaked Echidna	41,014	776	FCV
1	*Thylogale stigmatica*	Red-legged Pademelon	4,966	3	FCV
1	*Thylogale thetis*	Red-necked Pademelon	11,105	642	FCV
	Tiliqua scincoides	Eastern Blue-Tongue	25,062	88	FCV
	Todiramphus macleayii	Forest Kingfisher	59,579	135	FCV
	Todiramphus sanctus	Sacred Kingfisher	203,763	1,118	FCV
1	*Tregellasia capito*	Pale-yellow Robin	20,291	256	FCV
	Trichoglossus chlorolepidotus	Scaly-Breasted Lorikeet	103,690	536	FCV
	Trichoglossus haematodus	Rainbow Lorikeet	295,079	1,339	FCV
1	*Trichosurus caninus*	Northern Mountain Brushtail Possum	9,553	671	FCV
1	*Trichosurus cunninghami*	Southern Mountain Brushtail Possum	9,742	35	FCV
1	*Trichosurus vulpecula*	Common Brushtail Possum	155,228	1,974	FCV
	Tringa nebularia	Common Greenshank	60,951	142	FCV
	Tropidechis carinatus	Rough-Scaled Snake	691	20	FCV
	Turdus merula	Blackbird	376,896	107	FCV
	Turnix melanogaster	Black-Breasted Button-Quail	951	17	None
	Turnix varius	Painted Button-Quail	15,586	57	FCV
	Tyto alba	Barn Owl	13,679	15	FCV
	Tyto longimembris	Eastern Grass Owl	1,062	1	None
1, 2	*Tyto novaehollandiae*	Masked Owl	8,489	841	FCV
1, 2	*Tyto tenebricosa*	Sooty Owl	10,761	1,263	FCV
	Underwoodisaurus milii	Barking Gecko	5,598	2	SCV
	Uperoleia fusca	Dusky Toadlet	2,456	139	FCV
	Uperoleia laevigata	Smooth Toadlet	4,099	330	FCV
	Uperoleia tyleri	Tyler's Toadlet	447	19	SCV
	Uvidicolus sphyrurus	Border Thick-Tailed Gecko	177	3	SCV
	Vanellus miles	Masked Lapwing	609,844	1,017	FCV
	Varanus gouldii	Gould's Goanna	7,013	4	FCV
1	*Varanus rosenbergi*	Heath Monitor	1,746	4	SCV
1	*Varanus varius*	Lace Monitor	14,740	1,432	FCV

FMIP priority	Scientific name	Common name	Total records	Filtered records	Model type
	Vermicella annulata	Bandy-Bandy	1,870	5	FCV
1	*Vespadelus darlingtoni*	Large Forest Bat	15,513	809	FCV
1	*Vespadelus pumilus*	Eastern Forest Bat	6,975	770	FCV
1	*Vespadelus regulus*	Southern Forest Bat	13,343	579	FCV
1	*Vespadelus troughtoni*	Eastern Cave Bat	970	9	SCV
	Vespadelus vulturnus	Little Forest Bat	41,342	978	FCV
1, 2	*Vombatus ursinus*	Bare-nosed Wombat	81,393	1,286	FCV
1	*Vulpes vulpes*	Fox	79,142	1,173	FCV
	Wallabia bicolor	Swamp Wallaby	404,107	3,517	FCV
	Zoothera heinei	Russet-Tailed Thrush	4,515	34	SCV
	Zoothera lunulata	Bassian Thrush	23,378	200	FCV
	Zosterops lateralis	Silvereye	568,782	2,322	FCV

6.2.5.3 Covariates used

A panel of prospective covariates were used to fit fauna ENMs (Table 6). The selected covariates were chosen based on a combination of experience in fitting ENMs and consideration of the likely ecological drivers for the taxa to be modelled. A fire impact covariate was evaluated during preliminary model fits but was found to cause frequent software failure due to the limited number of categories covered by occurrence records that remained after applying the project's spatio-temporal occurrence filter.

Given the diverse array of taxa and a corresponding diversity of environments with which each taxon may be associated, the final panel of covariates was a compromise between detailed representation of presumed environmental drivers and compactness. All covariate layers were on a 90-m raster.

6.2.5.4 Spatio-temporal occurrence filtering

A critical factor determining the outcome of Maxent models is the nature of the occurrence data used to fit a model. The objective in preparing occurrence data for use in ENMs is to ensure that the occurrence records represent a least-biased sample of the full range of environments in which the taxon is known to occur. Unfortunately, the requirements of the FMIP Baseline Project 2 necessitated the application of a defined spatial and temporal filter on occurrence data available for fitting fauna ENMs. A demonstration of the implications of this impact on ENM outputs is provided in Appendix 4.

The overall implications of the current project's spatio-temporal filter for fauna ENMs can be quantified in two ways. First, we can see the reduction in the number of records available for ENM fitting at three filter stages: no filter (i.e. the full assembled and cleaned body of occurrence records for a taxon), spatial filter (i.e. the number of occurrence records that fall within the combined RFA regions, which geographically define the FMIP Baseline Project 2 modelling domain), and the combined spatial and temporal filter (i.e. the number of records falling within the study domain and collected between 1991 to 1998, inclusive). A table was generated storing the proportion of the full occurrence set for each taxon after application of the spatial filter and the final spatio-temporal filter. These data were then plotted to graphically portray the impact of the filters.

A second way of understanding the impact of the FMIP Baseline Project 2 filtering process is to consider the changes in environmental coverage of occurrence records available at each of the three filter levels. This was assessed by performing a Principal Component Analysis on the table of covariate values for the full occurrence data set for a taxon. Three convex hulls were fitted to the projection of the PCA onto principal components 1 and 2. The first was the convex hull around all points. The area of this hull was used as a measure of environmental coverage of the full occurrence set. The second was a convex hull around records in the spatially filtered set whose area was used as a measure of environmental coverage by occurrences in that subset of records. Finally, a convex hull was fitted to the records remaining in the spatio-temporal filtered set. A table was compiled of the proportion of the full convex hull area encompassed by each filter, and the data plotted to provide a graphical representation of the trend in environmental coverage.

6.2.6 Boosted regression trees

Also referred to as Gradient Boosted Models (GBMs), Boosted Regression Tree models use a machine learning technique which builds models from an ensemble of small regression models fitted to a sub-range of covariate values (Hastie *et al.* 2009). Optimisation algorithms are used to find the best performing combination of fitted regression sub-models with the sequence of decisions used to select amongst alternate sub-models arranged in a tree-like data structure. One very efficient method for seeking optimum tree structures is the gradient boosting method which gives rise to the alternate name (GBM) for this type of model. Elith *et al.* (2008) provided a comprehensive guide to the application of BRTs to niche modelling.

Because the sub-models within a Boosted Regression Tree model are linear models (regressions), they can be fitted using either presence–absence data or presence-only data. We applied BRT modelling to a selection of taxa for which we were able to extract sufficient presence–absence records from the available systematic survey data sets. Models were fitted using an adaptation of the approach described by Elith *et al.* (2008) and implemented in the R-package dismo (https://CRAN.R-project.org/package=dismo).

Following Elith *et al.* (2008) the values of two primary parameters were varied to find an optimal model: tree complexity and learning rate. Tree complexity was stepped from 3 to 5 in integer values. For each value tree complexity, cross-validated BRT models were fitted. To make further allowance for the stochastic nature of the tree-building process, the search for an optimal combination of parameters was replicated five times. The combination of tree complexity and learning rate that gave the highest value of Test AUC was recorded as the optimum combination. The optimum parameter values were used to fit a model to all the data (i.e. without cross-validation) with the fitted model then used to produce a geographical projection of the model (Elith *et al.* 2008).

A table of species detections for each of the six survey methods was extracted from the fauna data sets. Data from the four RFA regions covered by the current project were pooled when it was understood that the survey protocols were sufficiently similar to reduce the confounding influence of differences in detectability. From the combined survey data, a single file for each identified combination of taxon and sampling method was extracted and used as input to the BRT models.

BRT models were attempted for a total of 427 taxa using data collected by six survey methods. Table 9 summarises the number of taxa for which BRT fitting was attempted across the six methods. The same panel of environmental covariates used in Maxent model fitting was used for the BRT models.

6.2.7 Maxent flora modelling

For the flora models, we used 17 spatial covariates (Table 6) for all species, provided there was minimal correlation (Pearson correlation coefficient, $r < 0.7$) among covariates. Otherwise one of each correlated pair of covariates was dropped from the analysis. All spatial layers were prepared in ArcGIS using ArcMap version 10.7.1 to a uniform spatial resolution of 90-m raster, the geographic coordinate system (GDS 1984) in decimal degrees, FIMP project boundary extent, and asci file type. The number of occurrences varied with species (Table 10), being a combination of data derived from corporate systematic surveys (1987–2000; Section 6.1.2) and ALA (Atlas of Living Australia, 1991–1998), especially for species selected as responsive to COG (noting the significant limitations with this dataset as an indicator of actual old-growth forest), fire history and climate change. For some weeds and species susceptible to Myrtle Rust and Phytophthora, there were no records from systematic surveys; hence, only ALA occurrences were used (Table 10). We selected ALA records with coordinate uncertainty ≤ 1000 m.

Table 9. Summary of number of fauna species recorded by each survey method in 1990s systematic surveys

Cross-tabulation of taxa and survey methods; many taxa were detected by multiple survey methods. The number of unique taxa detected across all survey methods was 427

Survey method	**Number of taxa encountered**
Diurnal Bird Surveys	224
Diurnal Herpetofauna Surveys	137
Transect Spotlighting	154
Harp Trapping	5
Hair Tubes	39
Nocturnal Owl Call Playback	131
Total unique taxa	**427**

We used the java version (with Graphic User Interface) of the Maxent program version 3.4.4 (Phillips *et al.* 2021), which had the option to choose various output formats and to select or deselect 'threshold' (T) and 'hinge' (H) features in addition to previously available 'linear' (L), 'quadratic' (Q), and 'product' (P) features. For all species, we chose LPQ features and the default 'cloglog' output format. We ran ten cross-validations for all species using the 'random seed' option to use different sets of occurrence points for model training and testing; we used 10,000 background points to which all occurrence samples were added. Especially for those species with presence records < 50, we additionally added all samples to background. By selecting the option 'remove duplicate presence records', we eliminated presence records that were either spatially coincident (overlapping) or occurring within the same grid cells of covariate layers (Phillips 2017). Because of this feature, the total number of presence points used in modelling was less than all of the input data (Table 10).

We also used the default settings of 500 maximum iterations, a 0.00001 convergence threshold, 0 adjust sample radius, and a 0.5 default prevalence. Furthermore, in order to appropriately control for model overfitting, we used the recommended regularisation multipliers for LPQ features: 0.05 for occurrence points ≥ 100; 0.25 for 30–99 points; 0.9 for 17–29 points; and 1.6 for 10–16 points (Philips and Dudík 2008). Model outputs were yielded in 'asci' format which were subsequently converted to 'tiff' format in ArcMap.

6.2.8 Resolution of environmental covariates for analysis

DPIE covariate layers are typically available at one arc-second or three arc-second resolution (~30 m and 90 m, respectively). However, for many of the source datasets (geology, soil, vegetation), as well as the applied surface modelling, an implied accuracy of 30 m can give a false sense of precision, so the covariate data were standardised at three arc-seconds (~90 m), which also enabled more realistic computing times for surface prediction. The 30-m data were retained so that fine-grained modelling could be undertaken if warranted for topographically constrained species.

Table 10. Number of occurrence points used for modelling priority flora species with Maxent

Number of occurrence points from corporate systematic surveys and ALA used for modelling habitat suitability of priority flora species with Maxent. Reason for priority status: C = climate change; F = fire; M = Myrtle Rust; O = old growth; P = Phytophthora, and W = weed.

Species	Priority	Data source			Total points used in modelling
		Systematic	ALA	Total	
Acacia concurrens	C	144	181	325	181
Acacia dealbata	C F	390	611	1,001	791
Acacia irrorata	F	449	675	1,124	741
Acacia mearnsii	C	237	419	656	512
Acacia melanoxylon	F	722	1,199	1,921	1,309
Acacia obtusifolia	F O	325	326	651	502
Acacia terminalis	C	243	528	771	607
Ackama paniculosa	F O	356	734	1,090	749
Acmena smithii	F O	478	1,016	1,494	1,091
Acrothamnus hookeri	C	119	169	288	189
Adiantum hispidulum	O	251	541	792	561
Alectryon subcinereus	O	250	517	767	531
Alpinia caerulea	C	245	528	773	513
Angophora costata	C	176	532	708	584
Angophora subvelutina	C	171	350	521	346
Angophora woodsiana	C	95	139	234	139
Anredera cordifolia	W	1	15	16	14
Archirhodomyrtus beckleri	F M	250	426	676	435
Archontophoenix cunninghamiana	F	196	556	752	545
Aristida ramosa	C	127	467	594	491
Asparagus aethiopicus	W	4	44	48	44
Asparagus asparagoides	W	2	21	23	19
Asperula scoparia	C	284	395	679	468
Asplenium australasicum	F	316	810	1,126	817
Astroloma humifusum	P	93	176	269	223
Backhousia leptopetala	M	0	38	38	36
Banksia oblongifolia	C	116	339	455	345
Banksia spinulosa	F O	315	598	913	723
Bedfordia arborescens	C	139	283	422	317
Blechnum cartilagineum	F	849	1,310	2,159	1,477
Boronia parviflora	P	8	54	62	54
Bossiaea cinerea	P	Insufficient records (4 only)			
Bossiaea neo-anglica	C	84	167	251	162
Brunoniella pumilio	C	102	102	204	144
Cassinia aculeata	F O	287	366	653	557
Cassinia trinerva	C	115	157	272	183
Ceratopetalum apetalum	F O	136	348	484	365
Chrysanthemoides monilifera subsp. *monilifera*	W	Insufficient records (1 only)			
Chrysanthemoides monilifera subsp. *rotundata*	W	30	177	207	187
Chrysocephalum apiculatum	C	173	734	907	752
Cissus hypoglauca	F	891	1,464	2,355	1,601
Coprosma hirtella	C	122	194	316	240
Correa lawrenceana	P	Insufficient records (6 only)			
Correa reflexa	C	162	477	639	544
Corymbia maculata	O	408	733	1,141	869
Croton verreauxii	C	133	350	483	344
Cyathea australis	F O	562	825	1,387	965
Cytisus scoparius	W	12	42	54	47

Species	Priority	Data source			Total points used in modelling
		Systematic	ALA	Total	
Daviesia wyattiana	P	13	42	55	35
Decaspermum humile	M	5	61	66	60
Dendrobium pugioniforme	O	110	439	549	332
Denhamia bilocularis	C	170	270	440	269
Dillwynia glaberrima	P	29	71	100	91
Dillwynia sericea	P	43	139	182	162
Dodonaea triquetra	C	142	524	666	537
Dolichandra unguis-cati	W	Insufficient records (4 only)			
Echinopogon ovatus	F O	531	744	1,275	940
Embelia australiana	F O	184	441	625	445
Epacris impressa	C P	207	325	532	397
Epacris paludosa	P	20	40	60	50
Eragrostis leptostachya	C	191	340	531	372
Eremophila debilis	C	104	217	321	218
Eucalyptus agglomerata	C	211	388	599	462
Eucalyptus biturbinata	C	146	684	830	666
Eucalyptus brunnea	C	89	246	335	248
Eucalyptus caliginosa	C	139	502	641	499
Eucalyptus cameronii	C	187	342	529	343
Eucalyptus campanulata	C	484	903	1,387	910
Eucalyptus cypellocarpa	C	364	660	1,024	737
Eucalyptus dalrympleana	C	265	606	871	619
Eucalyptus elata	C	135	273	408	299
Eucalyptus fastigata	C O P	268	254	522	368
Eucalyptus fraxinoides	P	54	55	109	81
Eucalyptus imlayensis	P	Insufficient records (5 only)			
Eucalyptus laevopinea	C	212	443	655	442
Eucalyptus longifolia	C	77	115	192	172
Eucalyptus macrorhyncha	C	171	471	642	535
Eucalyptus melliodora	C	141	538	679	573
Eucalyptus moluccana	C	125	347	472	350
Eucalyptus muelleriana	C	247	342	589	432
Eucalyptus obliqua	C	364	696	1,060	745
Eucalyptus paniculata	C	110	229	339	293
Eucalyptus pauciflora	C	240	539	779	592
Eucalyptus pilularis	O	452	832	1,284	886
Eucalyptus planchoniana	C	81	135	216	134
Eucalyptus propinqua	C F	312	541	853	534
Eucalyptus radiata	C	318	807	1,125	841
Eucalyptus robertsonii	C O	124	285	409	288
Eucalyptus saligna	F	553	914	1,467	976
Eucalyptus sieberi	C F O	449	398	847	721
Eucalyptus smithii	C P	77	162	239	157
Eucalyptus viminalis	C	209	408	617	471
Euroschinus falcatus var. *falcatus*	C	143	387	530	385
Genista monspessulana	W	0	19	19	16
Glochidion ferdinandi	C	285	715	1,000	717
Gompholobium latifolium	C	131	252	383	307
Gompholobium pinnatum	C	101	227	328	225
Goodenia ovata	F O	256	334	590	515
Goodenia rotundifolia	C	135	277	412	283
Goodia lotifolia	F	153	233	386	314
Gossia acmenoides	M	7	46	53	46
Gossia fragrantissima	M	0	54	54	52
Gossia hillii	M	7	29	36	29

Species	Priority	Data source			Total points used in modelling
		Systematic	ALA	Total	
Grevillea irrasa subsp. *irrasa*	P	0	14	14	10
Grevillea obtusiflora	P	Insufficient records (none)			
Grevillea victoriae	P	24	61	85	72
Haloragodendron lucasii	P	Insufficient records (none)			
Hibbertia calycina	P	7	15	22	21
Hibbertia circinata	P	Insufficient records (2 only)			
Hibbertia vestita	C	125	275	400	273
Hibbertia virgata	P	Insufficient records (4 only)			
Hierochloe rariflora	C	200	341	541	373
Hybanthus stellarioides	C	207	339	546	338
Imperata cylindrica	F	1,484	2,322	3,806	2,431
Lantana camara	W	509	1,155	1,664	1,136
Lenwebbia prominens	M	2	18	20	18
Lepidosperma urophorum	C	229	293	522	379
Leptinella filicula	C	73	89	162	107
Leptospermum trinervium	M	261	699	960	748
Leucopogon ericoides	P	54	165	219	176
Lomandra spicata	F O	276	515	791	533
Lomatia ilicifolia	C O F	247	181	428	358
Lophostemon suaveolens	C	87	180	267	180
Macrozamia communis	C F	153	350	503	433
Mallotus philippensis	C	140	408	548	397
Melaleuca nodosa	M	60	211	271	214
Melaleuca quinquenervia	M	59	259	318	254
Melaleuca squamea	M	Insufficient records (7 only)			
Melichrus procumbens	C	83	243	326	239
Monotoca glauca	P	Insufficient records (none)			
Nematolepis rhytidophylla	P	Insufficient records (none)			
Nematolepis squamea	P	55	0	55	50
Notelaea venosa	O	366	408	774	609
Olearia argophylla	C	117	189	306	220
Oreomyrrhis eriopoda	C	158	296	454	332
Orites excelsus	F O	147	414	561	421
Oxylobium ellipticum	P	36	58	94	73
Ozothamnus argophyllus	C	84	165	249	197
Ozothamnus cuneifolius	C	80	86	166	140
Panicum effusum	C	174	371	545	403
Parsonsia straminea	F	470	927	1,397	989
Pereskia aculeata	W	Insufficient records (none)			
Persoonia chamaepeuce	C	98	155	253	191
Persoonia cornifolia	P	77	328	405	319
Persoonia oleoides	C	111	243	354	245
Persoonia silvatica	C P	90	112	202	142
Persoonia stradbrokensis	C	209	353	562	351
Pimelea axiflora	C	108	264	372	256
Platycerium bifurcatum	F	310	752	1,062	762
Platylobium formosum	C P	246	336	582	433
Platysace ericoides	C	151	445	596	450
Poa ensiformis	C	121	85	206	173
Poa meionectes	C	640	959	1,599	1,171
Pomaderris aspera	C	166	370	536	396
Prostanthera lasianthos	C	106	226	332	241
Psychotria daphnoides	C P	81	136	217	131
Pultenaea altissima	P	4	18	22	18
Pultenaea baeuerlenii	P	Insufficient records (2 only)			

Species	Priority	Data source			Total points used in modelling
		Systematic	ALA	Total	
Pultenaea benthamii	P	18	31	49	25
Pultenaea daphnoides	C P	128	289	417	320
Pultenaea juniperina	P	31	43	74	51
Pultenaea paleacea	P	Insufficient records (9 only)			
Pultenaea parrisiae	P	Insufficient records (1 only)			
Pultenaea villosa	C	111	282	393	284
Pyrrosia rupestris	F	328	743	1,071	801
Rhodamnia argentea	M	12	66	78	65
Rhodamnia maideniana	M	0	40	40	38
Rhodamnia rubescens	F M O	375	726	1,101	747
Rhodamnia whiteana	M	Insufficient records (6 only)			
Rhodomyrtus psidioides	M	38	134	172	133
Rubus fruticosus aggregate	W	167	122	289	271
Rubus moluccanus	O	325	576	901	613
Sarcochilus falcatus	F O	113	269	382	283
Scleria mackaviensis	C	73	130	203	131
Solanum hapalum	F O	295	6	301	300
Solanum pungetium	F O	135	155	290	204
Sorghum leiocladum	C	281	498	779	499
Sprengelia incarnata	P	3	48	51	46
Stephania japonica	F O	332	401	733	596
Syzygium anisatum	M	0	16	16	16
Syzygium hodgkinsoniae	M	2	211	213	196
Tasmannia purpurascens	P	24	56	80	59
Tetrarrhena juncea	C F	189	152	341	319
Tetratheca bauerifolia	C	77	132	209	159
Tetratheca subaphylla	P	5	8	13	13
Themeda triandra	F	1,478	2,840	4,318	3,032
Trochocarpa laurina	F	693	1,166	1,859	1,209
Ulex europaeus	W	Insufficient records (9 only)			
Xanthorrhoea australis	P	50	100	150	100
Xanthorrhoea concava	F	102	50	152	112
Xanthorrhoea glauca	P	44	144	188	158
Xanthorrhoea latifolia	C F	117	301	418	301

6.1 Flora species prioritisation

Flora species prioritisation in this project was driven by the main drivers of forest ecosystem change, and focused on species thought to be reactive or sensitive to: (1) harvest forest operations, (2) fire, (3) climate change, (4) weeds, (5) Phytophthora (*Phytophthora cinnamomi*), and (6) Myrtle Rust (*Austropuccinia psidii*). Section 5 described our rationale and approach in broad terms. In this section, we detail how flora species were selected in relation to each of the above criteria.

6.1.1 Candidate old growth and fire

Pickett and White (1985) offer a useful working definition of disturbance, as 'any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment'. A forest harvest operation is clearly a disturbance, but should be seen in the context of the range of natural disturbances that affect any plant community, including fire, drought, flood, pest and disease outbreaks, windstorms and natural treefalls.

Attributes that determine a plant species response to natural disturbances are also relevant to its response to forest harvest operations, although there are potentially important differences in temporal and spatial scale. There is a paucity of information on the response of plant species to disturbance by forest harvest operations and conversely, on plant species requirements for old-growth attributes. However, a general conceptual framework may be developed. Species which are favoured by forest harvest operations (relative increase in abundance or extent) are those which can exploit the changes. For understorey species, which comprise most of the plant species diversity in eucalypt forests, these changes include the short-term increase in available resources (especially water, mineral nutrients and light) and the increased availability of substrates for germination. In the medium term, the availability of resources to understorey plants is likely to decline as regenerating eucalypts increasingly compete for those resources. Species that favour old-growth forests (and thus may experience a relative decrease in abundance or extent following harvesting operations) are those which require long stable periods to persist or regenerate. Notable examples are epiphytes which require trees to reach adequate size to provide suitable substrates and which often also require shady or humid conditions, which are only achieved during stable periods.

Fire is also a disturbance event, but we treat it separately because it has a different management context, in the sense that a single fire may be a natural event but aspects of the fire regime (especially season, frequency and intensity) are often deliberately manipulated to achieve particular objectives. There is a substantial literature on plant species responses to fire and attempts are frequently made to explain or predict changes in plant populations based on life-history attributes or growth characteristics such as regeneration strategy, resilience or sensitivity to damage by heat and longevity. This approach has been useful for developing fire management guidelines. However, it has several limitations for our purpose: (1) responses are often based on experimental data from one or a few sites and may not necessarily describe responses elsewhere or under other conditions; (2) data are often based on one or a few aspects of a particular fire regime; (3) it is difficult in practice to extrapolate response at one or a few sites to landscape-scale changes, particularly in the context of spatial patterns of plant community distribution.

For both COG and Fire History, we chose to use empirical analysis of the survey data described in Section 6.1.2, with respect to mapped COG (see Box: Old-growth forests and mapping in NSW) and fire history data, to indicate broad-scale plant species responses to these factors and to prioritise species as described in Section **Error! Reference source not found.**. In the case of COG, this was due to the lack of data on response to forest harvest operations for most species. In the case of fire, it was due to the difficulty of extrapolating available data to the landscape scale under a wide variety of fire regimes. However, we recognise that our approach also has limitations, notably: (1) mapped COG and fire history data is likely to vary in accuracy due to variation in the known limitations and reliability (a) of API to map COG, and (b) historical fire records, respectively; (2) there may be a mismatch in scale of survey plots compared to mapped data, particularly for fire history, so that mapped data may not accurately represent disturbance at the scale of the survey plot; (3) there are interactions between disturbance and other environmental factors (e.g. timber harvesting is more likely to occur in particular types of environments that are more productive), which constrain attempts at balanced survey design and confound interpretation of observed responses.

For our empirical analyses, the variables used to characterise disturbance and fire history of the survey plots are listed in Table 11. Rainforest vegetation had not been consistently assessed for candidate old growth so plots in rainforest were excluded from analyses involving the variable, COG01.

Box: Old-growth forests and mapping in NSW

The Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-Committee (JANIS) defines old-growth forest as '*Ecologically mature forest where the effects of disturbances are now negligible.*'[1] This definition is an agreed national operational interpretation of the definition from the National Forest Policy Statement and used in NSW RFAs and other supporting instruments. The JANIS definition provides that old growth forests should demonstrate characteristics of mature age and evidence of disturbance below a set threshold. Given the history of human interaction with forests in NSW, it is likely that a number of forests that display structural traits of old growth have been previously disturbed.

In 1995–96, the *Broad Old-growth Mapping Project* identified old-growth forests in the Upper and Lower North East regions of NSW for the Interim Forest Assessment.[2] Following this, between 1997 and 1999, the CRAFTI project updated the *Old Growth Mapping Project* as part of the RFA's CRA process. This process identified 'candidate' old growth (COG) forests, which the project's expert panel considered to represent a greater area than actual old-growth extent.[3] Further work has since occurred including intersecting habitat modelling to develop a HCVOG layer subset and additional supplementary areas from candidate old-growth forests that were not already intersected by the HCVOG data layer.

A pre-exisiting COG layer was not available for the Eden and Southern RFA regions, so the Project Team used the forest growth-stage mapping to create this layer. We did this by identifying the categories which included >10% senescent trees in the forest canopy but with less than 10% regrowth forest in the canopy. Using these growth-stage thresholds in the two northern RFA regions provided a close match to the existing COG layer for the two northern regions. This process provided a measure of understanding as to how the existing COG layer had been derived in the northern regions and this rule-set was repeated for the two southern regions to derive the COG layer that we used in the modelling in the Eden and Southern regions.

NSW's old-growth mapping products have significant limitations. A 1999 expert review found that the old-growth maps derived in the CRAFTI project were inaccurate, and recommended the data layer be continually reviewed and improved, including through field checking.[4] For example, the expert panel emphasised that the old-growth forest identified by the CRAFTI mapping project is only a 'candidate' for listing as old-growth forest. It is highly likely that the candidate old-growth layer – and subsequently the HCVOG layer – also contain significant areas that are not old growth.

At the request of the NSW Government in 2018, the Natural Resources Commission confirmed there were significant errors in old-growth forest mapping on state forests based on a pilot area in northern NSW.[5]

Old-growth forest are conserved and managed by a range of NSW and Commonwealth regulations and arrangements. These include the CAR reserve system and targets, the Coastal IFOA and Forest Management Zones under the *Forestry Act 2012* (NSW), and the State Heritage Register.

Researchers in this current project have used the COG spatial layer as surrogate for disturbance, namely timber harvesting. However, interpretation of results derived from this dataset should be used with caution given its known limitations and errors.

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1 JANIS (1997) *Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia*, p. 14. Available at: http://www.agriculture.gov.au/SiteCollectionDocuments/rfa/publications/nat_nac.pdf.

2 NPWS (1999) *Old-growth Forest Related Projects – UNE/LNE Regions, part of CRA, project number NA 28/EH*. Available at: http://www.agriculture.gov.au/SiteCollectionDocuments/rfa/regions/nsw-north-east/enviroment/nsw_ne_na28eh.pdf.

3 *Ibid.*

4 *Ibid.*

5 https://www.nrc.nsw.gov.au/completed/old-growth-remapping

Table 11. Disturbance or management variables used for GAM analyses to select priority flora species

Refer to Section 6.1.4 for details

Variable	Definition
COG01	Candidate Old Growth (COG) Forest mapped within 100 m of plot location, coded as COG = 0 if mapped COG was absent and COG = 1 if present
YearsSinceFire	Integer number of years between the most recent fire mapped at the plot location and the date of floristic survey. For analysis, grouped into classes of 1–4 years, 5–15 years, 16–30 years, > 30 years
FireCount	Number of fires recorded at the plot location up to the date of floristic survey. For analysis, grouped into classes of 0 fires, 1 fire, 2 fires, ≥3 fires
Burnt01	Burnt or unburnt, coded as Burnt01 = 1 (burnt) if YearsSinceFire ≤ 30 years and Burnt01 = 0 (unburnt) if YearsSinceFire > 30 years

Analyses were done for each RFA region separately. Within each region, separate analyses were done for each Vegetation Formation (Keith 2004), which had adequate sample size (minimum of 100 plots) and for all forested vegetation formations combined. Plots were assigned to vegetation formations based on the current plot assignments in the PCT module of BioNet.

For each of the two binary variables (COG01 and Burnt01), we calculated frequency and difference in frequency between the occurrence of each species in each category. In each case we calculated a series of binomial confidence intervals, using function binom.test in R, in probability classes of 90%, 95% and 99%, for the observed frequencies. Then for each species and treatment pair we calculated the difference between the lower confidence limit of the higher frequency and the upper confidence limit of the lower frequency to determine the maximum class at which these limits did not overlap (i.e. broadest confidence interval at which the frequencies could be considered different). This gave a pairwise measure of the degree of confidence that the observed differences had not arisen from chance alone. We used these measures in a relative sense to rank species according to observed response.

For all factors in Table 11, we used generalised additive models with a binomial response and logit link function (Venables and Ripley 1997) to detect differences in occupancy after accounting for effects of other physical environmental variables. Preliminary testing of models using a few species indicated that one or more of eight variables (Table 12) were either likely to be related to patterns of distribution for many species, were correlated with disturbance variables, or both. For each species with ≥ 50 records in an RFA region, we developed a base model using these variables and contrasted the base model with models in which COG01, Burnt01, YearsSinceFire and FireCount were each added separately. Data values for the latter two variables were unevenly distributed, which may have been partly an artefact of the history of record-keeping. Values for these variables were grouped into classes and treated as factors for GAM analyses, as indicated in Table 11. For each RFA region, GAM results were used to rank each species in classes of response to management or disturbance factors, based on the predicted difference in occupancy and probability class (> 0.1, < 0.1, < 0.05 or < 0.01) at which the addition of the management term to the base model was significant. The predicted difference in occupancy was calculated using the models, which included physical environmental factors plus each of the management factors as predictors. For COG, if p0 was the vector of predicted occupancy assuming all plots had COG01 = 0 and p1 was the vector of predicted occupancy assuming all plots had COG01 = 1, the difference in occupancy was calculated as the mean of p1 – p0, as a percentage of the overall mean occupancy. In the case of each of the three fire factors, the differences were similarly calculated, as differences between each level and the unburnt class.

Table 12. Environmental variables used in GAM analyses to select COG and fire-responsive priority flora species Refer to Section 6.1.4 for details.

Variable	Code	Description
rad	ce_radhp_f	Highest Period Radiation (bio21)
rainann	cw_precipann_f	Annual Precipitation (bio12)
dcoast	d_coast_disa_f	Distance from NSW East Coast (Euclidean)
flood	d_flooded	Distance (Euclidean) from seasonally flooded water bodies
dem	lf_dems1s_f	Elevation from 1 sec SRTM smoothed DEM (DEM-S)
exp	lf_exp315_f	Exposure to the NW (low = exposed (drier forests); high = sheltered (moister forests)).
rough500	lf_rough0500_f	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 500-m neighbourhood. Derived from DEM-S
cti	lf_cti_f	Compound topographic index or CTI also known as wetness index, topographic wetness index. Based on DEM-H (for flow direction and accumulation)
silic	silica index	Class of proportion of silica in substrate, as one of Ultramafic, Mafic, Intermediate, SilicLower, SilicMid, SilicUpper

In selecting priority flora species using differences in occupancy among COG and fire history classes, GAM results were used rather than simple binomial proportions because they were potentially less likely to indicate a response where the observed occupancy was confounded by interactions with environment. For example, in UNE and LNE, relatively undisturbed plots (with COG01 = 1) were more likely to occur in rougher topography in cooler sites at higher elevations away from the coast. This type of confounding is unavoidable in retrospective analysis of the type done here, but the effects may be minimised to the extent that models can incorporate variation due to confounding factors. Priority species were selected by initially filtering using combined thresholds of minimum naïve occupancy of 0.05 in at least one RFA region, predicted difference between COG or fire history classes of at least 30% and a GAM probability threshold of maximum 0.05. Species were then subjectively selected from this filtered list based on growth form, distribution and an assessment of the extent to which results were affected by interaction with environment based on the distribution of a species among vegetation formations and habitat types. Species were selected to provide a wide range of plant growth forms and patterns of distribution. The 49 species selected are listed in Table 3, with brief notes on characteristics and reasons for final selection.

6.1.2 Climate change

For 933 taxa recorded at 25 or more plots across all regions, climatic or other relevant data were summarised for all the plot points at which the species was recorded. The data summaries were used to prioritise flora species with respect to climate. The variables used are listed in Table 13. For each of these variables, the median and interdecile range was calculated for each species, using the values for plots at which the species was recorded. For each variable, the lowest 5-percentile, lowest decile of the interdecile range, lowest decile, first and third quartiles, and highest decile of the median were recorded across all species and were used as thresholds with which to compare values for individual species. Two sets of criteria were used to select species as potential priority species with respect to climate. Firstly, species with a value for a variable below the lowest 5-percentile of the interdecile range for that variable and either above or below the lowest and highest deciles were selected if the number of records was at least 70. Secondly, species with a value for a variable below the first decile of the interdecile range for that variable and either above or below the quartiles for the median were selected if the number of records for the species was at least 100.

Table 13. Variables used to prioritise flora species with respect to climate change and number of flora species meeting selection criteria

Refer to Section 6.1.4 for further details about variables

Variable	Code	Definition	No. of species with values in upper quartile	No. of species with values in lower quartile
tempann	ct_tempann_f	Annual Mean Temperature (bio1)	11	0
tempc	ct_tempmtcp_f	Min Temperature of Coldest Period (bio6)	1	22
tempw	ct_tempmtwp_f	Max Temperature of Warmest Period (bio5)	4	12
dem	lf_dems1s_f	Elevation from 1 sec SRTM smoothed DEM (DEM-S)	2	20
rainann	cw_precipann_f	Annual Precipitation (bio12)	2	14
rainsw	cw_rain_sumwin_f	Average Rainfall – Summer Winter Ratio	2	18
raind	cw_precipdp_f	Precipitation of Driest Period (bio14)	0	17
lat	Lat	Latitude	9	12

Ninety species met these criteria and are listed in Appendix 6b, as well as with brief notes on their occurrence in Table 3. Eighty-one of these putatively most climate-sensitive species were chosen for preliminary climate projection modelling, as described in Section 6.4, and reported in Appendix 11b. Table 13 summarises the number of species that met the criteria for each climate variable. The total in Table 13 exceeds 90 because many species met the criteria for more than one variable. Many more species are restricted to areas of lower temperature or higher elevation and which may thus decrease with a trend of increasing temperature, compared to those with a range limited to high-temperature areas. Many more species are restricted by low rainfall than high rainfall. Of the species that are latitudinally restricted to either the extreme north or extreme south of NSW, all except three also meet climate thresholds.

6.1.3 Weed species

A weed is 'a plant that requires some form of action to reduce its negative effects on the economy, the environment and human health or amenity' (IPAC 2016). About 500 introduced species and genera of weed are declared noxious or are under some form of regulatory control in Australia. Weeds can affect the structure, function and dynamics of forest ecosystems, and impact negatively on native fauna and flora, in several ways, by: (1) displacing native plant and animal species and harbouring pests and diseases; (2) increasing fuel loads, leading to more intense bushfires and changing the composition and structure of native vegetation, and (3) threatening the habitat suitability or integrity of nationally and globally significant sites, species and ecological communities on all tenures. Effective monitoring of weeds is important, because if permitted to spread to their full potential, most weed species can impact extensive areas of land in multiple jurisdictions, often multiple industries and a range of significant environmental assets. The extent, persistence and impacts of weeds are a challenge for Australia and require an ongoing strategic response (IPAC 2016).

The Weeds of National Significance (WoNS) are priority weeds either currently or that pose a future threat, and are recognised by Australian governments based on an agreed assessment framework (IPAC 2016). There are currently 32 species of WoNS requiring coordinated and strategic monitoring and management in different parts of the nation (see the CISS 2021 website, *Weeds Australia*). The national list of WoNS was filtered to produce a list of weed species with the potential to affect ecosystem dynamics and recovery of eastern NSW forests after disturbance and deflect or arrest natural successional trajectories, resulting in undesirable states of forest composition and structure, or threatening the integrity of native vegetation (e.g. a risk to threatened populations, species or ecological communities). The resulting list of 12 taxa (11 species) contained six shrubs (*Chrysanthemoides monilifera* subsp. *monilifera*, *Chrysanthemoides monilifera* subsp. *rotundata*, *Cytisus scoparius*, *Genista monspessulana*, *Lantana camara*, *Ulex europaeus*), three vines (*Anredera cordifolia*, *Dolichandra unguis-cati*, *Pereskia aculeata*), two scrambling perennial herbs (*Asparagus asparagoides* and *A. aethiopicus*) and one bramble (*Rubus fruticosus* aggregate). Table 14 lists these taxa and the threat that each poses to eastern NSW forests.

6.1.4 Root-rot Fungus (*Phytophthora cinnamomi*)

The root-rot fungus, Phytophthora (*P. cinnamomi*), is a soil-borne pathogen belonging to the water mould group, Oomycetes, and is widespread in coastal forests as well as some higher elevation forests (e.g. Barrington Tops) in NSW (NSW Threatened Species Scientific Committee 2019). The pathogen infects a large range of native flora species and can kill plants. Reproduction and infection occur entirely within soil or plant roots under warm, moist conditions. Susceptible species display a range of symptoms and in some species, the response varies among individuals: some individuals and species are killed, some are damaged but endure, and some show no apparent symptoms. *P. cinnamomi* can also contribute to plant death when other stresses are present (e.g. waterlogging, drought, and perhaps wildfire).

Infection of native plants by *P. cinnamomi* has been identified as a threat to seven flora species and two animal species listed as threatened under the *Biodiversity Conservation Act 2016* (NSW), as a result of the death of plants as well as the loss of habitat and reduced habitat complexity (NSW Threatened Species Scientific Committee 2019). In addition, 68 threatened plant taxa (species and subspecies), four threatened fauna species and four threatened ecological communities occur in the vicinity of known *P. cinnamomi* infestations or in habitat that may be vulnerable to *P. cinnamomi* infestation. Many other native plant species are susceptible to *P. cinnamomi*.

O'Gara *et al.* (2005) compiled a list of Australian plant responses to *P. cinnamomi* from the literature and unpublished records and observations of researchers. The 27 NSW species that were listed as highly susceptible to *P. cinnamomi* by O'Gara *et al.* (2005) were included in our priority flora list of species for forest monitoring. This list was supplemented with an updated list of 19 species in south-eastern NSW identified by Dr Keith McDougall (pers. comm., 8 June 2021) as highly susceptible to *P. cinnamomi* infection under most conditions. Four species were common to both lists, and the total list of 42 priority flora species highly susceptible to *P. cinnamomi* infection according to these criteria is presented in Table 15.

6.1.5 Myrtle Rust (*Austropuccinia psidii*)

Myrtle Rust (*Austropuccinia psidii*) is a fungal disease that infects the foliage, flowers and fruits of plants in the Myrtaceae. Myrtle Rust was first detected in NSW on the Central Coast in April 2010. Initial attempts to eradicate it were unsuccessful because the spores are so easily dispersed by wind. It has subsequently spread up and down the eastern Australian coastline landscape in moist environments in forest, bushland, gardens and amenity settings such as parks and street plantings, and is now found in NSW, Victoria, Queensland, Tasmania and the Tiwi Islands in the Northern Territory.

Table 14. List of priority weeds for forest monitoring in eastern NSW forests

Weeds of National Significance with the potential to invade native vegetation, reduce native species diversity or change ecosystem dynamics, including deflecting or arresting native forest succession and affecting threatened flora and fauna and ecological communities in eastern NSW forests (Weeds Australia).

No.	Species name	Common name	Habit	Notes
1	*Asparagus aethiopicus*	Asparagus Fern	Perennial herb	Scrambling herb confined to warm temperate woodlands, littoral rainforest, rainforest gullies, riverbanks, moist gullies and shady roadsides with rainfall of 500 to 1500 mm per year. Forms dense impenetrable thickets that smother and suppress other ground flora, also impacting native animals
2	*Chrysanthemoides monilifera* subsp. *rotundata*	Bitou Bush	Shrub	Fast growing, aggressive invader of cool temperate to subtropical coastal dune vegetation, forming dense thickets that can out-compete and often eliminate native flora, also spreading into the understorey of adjacent undisturbed sclerophyll forest and woodland
3	*Rubus fruticosus* aggregate	European Blackberry	Shrub (bramble)	Long-lived, sprawling, mound forming, fast growing shrub to 2–3 m, forming dense stands in native bush, forestry and production areas in wetter cool to warm temperate areas where rainfall exceeds 700 mm, often in disturbed areas. Thickets can restrict movement of people and machinery
4	*Chrysanthemoides monilifera* subsp. *monilifera*	Boneseed	Shrub	Aggressive invader of a range of environments including intact undisturbed native woodland and open forest. Tolerant of shade, salinity, strong wind, windblown sand and water, drought, low nutrients and, to some extent, disturbances such as fire
5	*Asparagus asparagoides*	Bridal Creeper	Perennial herb	Long-lived highly invasive scrambling herb that invades dry sclerophyll forest and woodland, damp sclerophyll forest, riparian vegetation and warm temperate rainforest, forming dense impenetrable thickets that smother other plants, and becoming the dominant plant species over time
6	*Cytisus scoparius*	English Broom	Shrub	Highly invasive in cooler, wetter areas regions of NSW south from Glen Innes, including the Northern Tablelands and Southern Tablelands, invading heathy and grassy woodlands, dry sclerophyll forest, wet sclerophyll forest, and alpine and subalpine areas. An estimated 10,000 ha has been invaded in the Barrington Tops, endangering several orchid species and a daisy shrub
7	*Dolichandra unguis-cati*	Cat's Claw Creeper	Vine	Long-lived woody climber or creeper, particularly aggressive in riparian vegetation and disturbed rainforest plant communities in SE Qld and NE NSW, smothering native vegetation, by growing up over tall trees or forming a thick carpet of stems and leaves as a ground cover over forest floor
8	*Ulex europaeus*	Gorse	Shrub	Highly invasive shrub, 1–3 m tall, in cool to warm temperate woodlands, dry sclerophyll forest, damp sclerophyll forest and riparian vegetation with rainfall from 450–2400 mm, forming dense impenetrable thickets that exclude native flora and domestic and native

No.	Species name	Common name	Habit	Notes
				animals, and providing cover for feral animals such as rabbits and foxes. A major problem in national parks and reserves in SE NSW and Barrington Tops National Park
9	*Lantana camara*	Lantana	Shrub	Erect sprawling or scandent shrub to 6 m, invading disturbed native woodland, forest and rainforest in E NSW (except cool temperate areas) and forming dense impenetrable thickets, reducing seedling germination, exacerbating fire in dry rainforest through fuel-load accumulation, and threatening many endangered plants, animals and ecological communities
10	*Pereskia aculeata*	Leaf Cactus	Vine	Grows vigorously, forming large inpenetrable thickets in subtropical eucalypt communities in SE Qld and N NSW, is drought tolerant and prefers light shade, favouring well-drained nutrient-rich sites and occurring in riparian vegetation. Currently relatively localised to just a few areas in NSW
11	*Anredera cordifolia*	Madeira Vine	Vine	An aggressive long-lived scandent woody vine that smothers other trees and shrubs, causing structural damage or collapse of the canopy, in subtropical and warm to cool-temperate forest in higher rainfall or riparian sites
12	*Genista monspessulana*	Cape Broom	Shrub	Highly invasive shrub to 3–5 m forming dense inpenetrable thickets in disturbed temperate woodland and open forest in eastern NSW, tolerating warmer and drier environments than *Cytisus scoparius* (Scotch Broom). Excludes most other vegetation increasing fuel-loads, changing vegetation structure, out-competing native plants and discouraging their regeneration by shading understorey species and (being a legume) increasing soil fertility, and increasing soil erosion by excluding grasses and forbs, thereby increasing amount of bare ground. Fires and soil disturbance in infested areas usually lead to mass germination

Table 15. Native flora species chosen for priority monitoring due to high susceptibility to P. cinnamomi *infection*

Source: Pc, O'Gara et al. *(2005); Pc*, K. McDougall (pers. comm.); Pc**, both sources. O'Gara* et al. *(2005) defined 'highly susceptible' as 'species that are frequently and consistently killed in the wild following infection by* P. cinnamomi*, and/or appear to decline or be rare on infested sites'.*

No.	Species	Source	No.	Species	Source
1	*Astroloma humifusum*	Pc	22	*Melaleuca squamea*	Pc
2	*Boronia parviflora*	Pc	23	*Monotoca elliptica*	Pc
3	*Bossiaea cinerea*	Pc	24	*Monotoca glauca*	Pc*
4	*Correa lawrenceana*	Pc*	25	*Nematolepis rhytidophylla*	Pc*
5	*Daviesia wyattiana*	Pc**	26	*Nematolepis squamea*	Pc
6	*Dillwynia glaberrima*	Pc	27	*Oxylobium ellipticum*	Pc
7	*Dillwynia sericea*	Pc	28	*Persoonia cornifolia*	Pc
8	*Epacris impressa*	Pc*	29	*Persoonia silvatica*	Pc*
9	*Epacris paludosa*	Pc	30	*Platylobium formosum*	Pc
10	*Eucalyptus fastigata*	Pc	31	*Pultenaea altissima*	Pc*
11	*Eucalyptus fraxinoides*	Pc	32	*Pultenaea baeuerlenii*	Pc*
12	*Eucalyptus imlayensis*	Pc	33	*Pultenaea benthamii*	Pc*
13	*Eucalyptus smithii*	Pc	34	*Pultenaea daphnoides*	Pc*
14	*Grevillea irrasa*	Pc**	35	*Pultenaea juniperina*	Pc
15	*Grevillea obtusiflora*	Pc*	36	*Pultenaea paleacea*	Pc
16	*Grevillea victoriae*	Pc*	37	*Pultenaea parrisiae*	Pc*
17	*Haloragodendron lucasii*	Pc*	38	*Sprengelia incarnata*	Pc*
18	*Hibbertia calycina*	Pc	39	*Tasmannia purpurascens*	Pc
19	*Hibbertia circinata*	Pc*	40	*Tetratheca subaphylla*	Pc**
20	*Hibbertia virgata*	Pc	41	*Xanthorrhoea australis*	Pc**
21	*Leucopogon ericoides*	Pc	42	*Xanthorrhoea glauca*	Pc

Repeated infection of adult plants of highly susceptible species can lead to defoliation, loss of reproductive capacity, and death. Some 382 native Australian plant species or subspecies (17% of the 2,253 known native Myrtaceae) had been recorded as infected by *A. psidii* to 2020, and this 'host range' is expected to expand further if the geographical range of Myrtle Rust in Australia increases. Some 43 species (11% of known hosts) are known or suspected to be severely affected, and serious declines towards extinction are underway in some of these species. Loss of Myrtaceae species habitat may also affect some animal species, human economic, social and cultural values and amenity, as well as ecosystem integrity. Only about 3% of native species screened for susceptibility so far have failed to develop infection.

The *Myrtle Rust National Action Plan* (Makinson *et al.* 2020) listed 43 native species of Myrtaceae as either of emergency, high or medium priority for management action. They were categorised according to their known or suspected level of decline due to Myrtle Rust either regionally or over their total range). The key determinants were (1) known high to extreme susceptibility to infection, (2) the estimated degree of exposure of a species to Myrtle Rust inoculum over its geographic range, and (3) (where data were available) observations of severe impact and/or population decline in the wild or in open-cultivation. Of these species, 17 occur in eastern NSW, and were selected as priority species for future forest monitoring in this state. They are listed in Table 16.

Table 16. Priority flora species susceptible to Myrtle Rust in NSW

These species of Myrtaceae are recommended for management action (field survey, monitoring and germplasm capture), according to their known or suspected level of decline due to Myrtle Rust (Makinson et al. *2020). Species were listed as either (1) emergency (E) priority – species undergoing extremely strong decline are recommended for emergency-level action to secure germplasm; (2) very high (VH) priority – species known or strongly suspected to be in serious decline on a total or regional basis, and recommended for the most urgent conservation action, or (3) medium (M) priority – known or suspected high susceptibility, and suspected decline but for which there are fewer observations of impact.*

No.	Species	Priority	No.	Species	Priority
1	*Archirhodomyrtus beckleri*	VH	10	*Melaleuca quinquenervia*	M
2	*Backhousia leptopetala*	M	11	*Rhodamnia argentea*	M
3	*Decaspermum humile*	VH	12	*Rhodamnia maideniana*	E
4	*Gossia acmenoides*	M	13	*Rhodamnia rubescens*	E
5	*Gossia fragrantissima*	VH	14	*Rhodamnia whiteana*	M
6	*Gossia hillii*	VH	15	*Rhodomyrtus psidioides*	E
7	*Lenwebbia prominens*	M	16	*Syzygium anisatum*	VH
8	*Leptospermum trinervium*	M	17	*Syzygium hodgkinsoniae*	VH
9	*Melaleuca nodosa*	VH			

6.2 Climate projections

Modelling into future climates is a complicated task involving multiple portrayals of each species model (multiple climate projections, multiple time-steps, and inclusion or exclusion of anthropogenic disturbance). An added constraint to climate projections of species models is that to avoid the computational burden of additional modelling streams, only covariates that are not themselves subject to climate change can be used, that is, although climatic covariates are allowed to be dynamic, all other covariates must be plausibly static. Therefore, for example, we use topography and substrate covariates and not vegetation type as covariates. This has consequences for the quality of the model to accurately predict distributions, but this limitation is acceptable within the context of the large uncertainties associated with future predictions generally.

A resilience approach is generally applied in climate impact research whereby high uncertainty is accepted as innate, so an ensemble of projections is examined with the objective of assessing outcomes in terms of how values (e.g. forest species) are maintained at acceptable levels given a range of plausible outcomes (Peterson *et al.* 2003). In this current baseline assessment climate impacts were examined using the NSW and ACT Regional Climate Modelling (NARCliM) ensemble that was developed for eastern Australia, covering all of NSW, Victoria, and roughly a third of Queensland and South Australia (Evans *et al.* 2012a, b). The fauna assessment was able to leverage off a concurrent study using all 12 NARCliM projections; however, for flora it has only been feasible to use a single projection, to date.

6.2.1 Flora ENM models

NARCliM provides high-resolution climate change projections across NSW, which can be used to plan for the range of likely future changes in climate (DPIE 2021a). Layers were downscaled from global climate models (GCMs) and Regional Climate Models (RCMs), coded and described (Macadam 2018) following the nomenclature of Xu and Hutchinson (2011). In all, 12 NARCliM surfaces are available (Section 6.2.2.2). Following the meta-analysis of Evans and Ji (2012a, b), the most independent of the four equally likely and best-performing GCMs, MIROC3.2 (Evans and Ji 2012a), was chosen for analysis. Of the three best-performing RCMs in the NARCLiM suite, the first and most independent, RCM1 (Evans and Ji 2012b), was chosen. The relative temperature–precipitation space occupied by MIROC3.2 is shown in Figure 10. MIROC predicts a warmer wetter climate, whereas the other three equally likely GCMs in the NARCliM suite predict hotter, or drier, or both hotter and drier (i.e. more extreme) climates by 2070. MIROC3.2 represents perhaps the best-case scenario for the impact of future climate on native flora and fauna in NSW with regards to increasing heat and drought, compared to the three other equally likely climate futures.

Eighty-one putatively climate-sensitive flora species were selected as described in Section 6.3.2 for climate projection using Maxent and NARCliM in conjunction with 15 spatial covariates (Table 6) with a nine arc-second (~250-m) spatial resolution for base layers. The NARCliM climate variables reflected three time periods: base (2000), and two projections, 2030 (near future) and 2070 (far future). We used the same input species occurrence datasets (1990s baseline) and Maxent model parameterisations as for flora distribution modelling (Section 6.2.7), with the following additional settings: 'write clamp grid when projecting', 'Do MESS analysis when projecting', 'extrapolate', and 'do clamping'.

Baseline (1990s) models of mean habitat suitability using the 2000 NARCliM climate variables and the corresponding 2030 and 2070 projections for each species were assessed visually. The extent of medium (0.45) or greater habitat suitability in each pair of models (baseline vs projection) was compared, and the difference in mean habitat suitability between 2000 and 2030 or 2070 rated as no change (< 10% change), minor change (10–50% reduction or increase compared to 2000 benchmark), or marked change (> 50% reduction or increase).

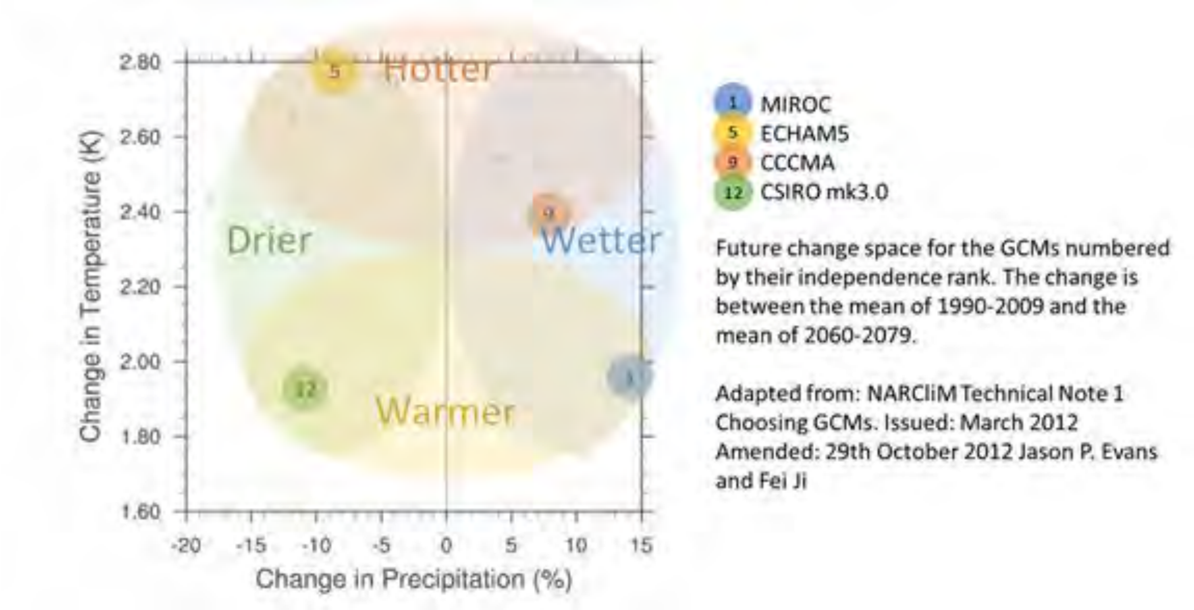


Figure 10. GCMs in precipitation–temperature space

6.2.2 Fauna ENM and REMP models

In order to avoid duplication of the complicated process of projecting fauna species models (which was not feasible in the current project), 78 projected fauna models were adopted from ongoing work in the Persistence in the Landscape Project (PLP), undertaken concurrently with FMIP Baseline Project 2 for the Saving Our Species (SoS) program. There are approximately a further 20 landscape-managed species in the SoS program, which were not modelled as part of the PLP at this stage. Of particular interest to the current project is the Yellow-bellied Glider, which anecdotally is currently suffering range contraction at low elevations. The Greater Glider, which was not part of the PLP as it is not currently listed as threatened in NSW, was developed and included due to its relevance to forest monitoring.

Of the species for which PLP models have been prepared, 14 were also on the priority list for this baseline assessment. Of these, seven were considered of sufficient quality (at the time of drafting this report, version 2 models) to be adopted as a focus the current baseline assessment (Table 17). Results for the full set of 78 PLP species are presented in aggregated form only. Koala was modelled as part of a separate project for the Koala Strategy, but so far only for inland areas, beyond the study region of the current project. Synergies between the PLP and the current project allow for interim results for these seven PLP species to be reported here as an example of how priority forest species can be assessed in terms of climate change trajectories. Detailed methods for the PLP models are scheduled to become available in June 2022 (Drielsma *et al.* in prep.).

PLP ENMs for 2000 used filtered species records up to 2020 (including records pre-1990s). These models are therefore baselines for the PLP climate projections (but a different context to the 1990s baselines developed for the current project and spanning a longer temporal scale), using 2000 climate, and disturbance data proximal to that date in terms of the climate change time-scale (centred on 2013). In terms of climate change, the PLP baseline models can be considered good approximations of baseline conditions prior to the instigation of major climatic disturbance within NSW forest, which can be considered beginning with the 2017–2019 drought and associated 2019–2020 bushfires.

The measure employed for reporting in the PLP is potential occupancy or *Pi* (Drielsma and Love 2021; Drielsma and Ferrier 2009). *Pi*, referred to here as landscape capacity, is an estimate of the occupancy that can theoretically be supported based on the ecological niche and the condition (clearing and disturbance) at each location, as well as the amount and connectivity of habitat in relation to the species' needs and movement abilities. *Pi* estimates the proportion of time each location could be occupied; it does not estimate abundance. *Pi* is summed across the regions for the purpose of region-wide or, in this case, RFA-wide reporting.

The realised niche for any species in the future will depend on a range of factors. Notably, it will depend on suitable resources (e.g. vegetation, or other species upon which a species of interest depends) establishing in a timely fashion as the species' climate envelope shifts spatially. In the PLP process either the ENM or a REMP (Section 6.2.2.3) model is used to represent landscape capacity. REMP is used to consider whether there is sufficient habitat at each location to support a population, and is calculated separately from the Maxent modelling (ENM) process (i.e. by summing the amount of connected habitat predicted in the ENM to each location). In either case (ENM or REMP), landscape capacity is represented spatially for each 90-m pixel[6] across NSW and can be summed across regions to represent the region's capacity to support a species across epochs. The models are produced for the NARCliM extent, but for the current project, the data were clipped to and reported for NSW.

[6] ENMs were produced at 250-m resolution. However, condition was included at the spatial resolution of 90 m, making the final models 90-m resolution.

Table 17. Species models from the PLP project relevant to the current project

Expert-derived landscape species variables are shown in the five right columns. However, of the seven species, REMP was only found to be beneficial to the *Aepyprymnus rufescens* model

PLP_ ID	Species	Common name	Minimum viable habitat area (ha)	Home range movement min. (m)	Home range movement max. (m)	Dispersal movement min. (m)	Dispersal movement max. (m)
71	*Aepyprymnus rufescens*	Rufous Bettong	500	400	1,300	1,200	6,500
11	*Atrichornis rufescens*	Rufous Scrub-bird	600	250	1,000	300	20,000
78	*Mixophyes balbus*	Stuttering Frog	190	13	30	2,300	3,594
21	*Ninox connivens*	Barking Owl	100,000	2,000	4,000	10,000	20,000
68	*Ninox strenua*	Powerful Owl	-	-	-	-	-
88	*Petauroides volans*	Greater Glider	1,500	150	200	500	3,500
8	*Tyto tenebricosa*	Sooty owl	37,500	500	5,000	25,000	75,000

6.2.2.1 Limitations of the PLP models

The version 2 PLP database was developed rapidly for the purpose of providing landscape scale prioritisation across multiple species for the SoS program. The version 2 models were generally suitable inputs into aggregated products, where multiple species and time-series models are overlaid to find common or 'combined' climate refugia. Thus, any weakness in the individual models do not unduly influence the aggregated products. In practice, these aggregated results tend to show clear patterns with respect to multi-species climate refugia and can therefore be used for that purpose with some confidence. Review of the version 2 PLP models by species experts led to refined version 3 models, which are more suited as stand-alone products. Due to the late timing of the refinements, projections of version 3 models were prioritised and reported here, but only for the seven species selected earlier in this baseline project.

A preliminary investigation by the current project team (RK) identified a number of weaknesses in respect to the version 2 iterations of the 14 PLP relevant models. Potential under-prediction in some models was likely resulting from how the REMP model filters out suitable habitat that may not be sufficiently connected to support high levels of occupancy. It is possible in some instances that the model is excluding areas with recorded sightings, but which the REMP model appears to be finding (if REMP is configured correctly) to be unviable in the long term (i.e. the extinction debt is still playing out). The seven species models that are included in this current assessment (Table 17) were considered of sufficient quality in their preliminary form (version 2) to provide NRC with examples of the potential of this approach to the FMIP and Coastal IFOA monitoring program going forward.

Transition from version 2 to version 3 involved expert review of each baseline model, followed by model refinement, where required. Refinements comprised, according to individual model need:

- refitting maxent models with improved occurrence data (sourcing additional records and removal of spurious records)
- applying spatial masks and water proximity modifiers
- whereas all preliminary models were modified by applying an ecological condition multiplier, in some cases this was either removed, or replaced with a binary native/non-native vegetation mask
- and removing the REMP stage for models where it was found to not improve alignment with expert knowledge

Validated PLP 2000 baseline models were projected into future climates with some confidence, but the projected models cannot themselves be validated in the normal way.

6.2.2.2 Projecting into future climates

The PLP modelling process was designed to keep all inputs other than climatic covariates constant across epochs. Baseline climatic covariates are replaced with projected versions for modelling of future epochs. ENMs were developed using filtered species records up to 2020, and a common set of ANUCLIM climatic (for each epoch), substrate and topographic covariates. The climate change predictors used in the PLP ENM modelling were derived using ANUCLIM covariate data, based on simulations performed under the NARCliM climate projections (Evans *et al.* 2014). The NARCliM climate data consists of climate projections using four Global Climate Models (GCMs) – CSIRO-Mk3.0, ECHAM5, MIROC3.2 and CCCMA3.1 – and three different configurations of the Weather Research and Forecasting (WRF) Regional Climate Models (RCM): R1, R2 and R3, starting with the year 2000 as a baseline and projected to 2030 and 2070.

The process initially resulted in 25 ENMs at 250-m spatial resolution for each individual species (1 × baseline; plus 12 GCM/RCM combinations times two projected epochs). The baseline represents the epoch 1990–2009, centred on 2000. The projected epochs were 2020–2039, centred on 2030; and 2060–2079, centred on 2070. For each combination of species, epoch and GCM, RCMs were averaged early in the process resulting in nine ENMs per species (one each for the 2000 baseline, and four GCMs for 2030 and four for 2070). Grids of standard deviation were produced for each instance of species x GCM x epoch.

The averaged ENMs for each GCM were used for REMP modelling, and then the preferred GCM models (ENM or REMP) were averaged for each species/epoch combination. The averaged models produced at this point are used to represent the unmodified (reconstructed) prediction of species habitat suitability (i.e. in the absence of any clearing or anthropogenic disturbance since circa 1750, and what could theoretically be conserved or reconstructed in the current and future epochs). The current Ecological Condition layer, centred on 2013, was developed for the NSW Biodiversity Indicator Program (Love *et al.* 2020a) and represents the naturalness and intactness of native vegetation at each 90 × 90-m pixel across NSW, proximal to 2013. It has a continuous value range of 0–1, where 0 represents cleared of all native vegetation and habitat features and loss of regenerative capacity, and 1 represents an undisturbed, pristine state, which is associated with the assumed state circa 1750 in Australia (or pre-industrial state). In version 2, this layer was multiplied to all unmodified models to create a set of 'modified' models to represent the environmental niche at each 90-m pixel of habitat once clearing and disturbance is considered (in version 3, this process was modified for each species, case by case). Native vegetation extent or ecological condition, when included, was assumed to remain constant into future epochs; that is, no further clearing, degradation or re-vegetation, change in land use or other management or disturbance was forecast. Only modified models were used for subsequent assessment in the baseline project.

The Ecological Condition layer available at the time of modelling overly relied on tenure to infer the ground cover component. Better ground cover is assumed within national parks and reserves, as this attribute could not feasibly be measured using remote sensing. This limitation was found to introduce error to some models in some locations. However, this limitation has greater consequence in non-forested than forested areas, as ecological condition in forests is more dependent on relative canopy cover, which can be more reliably estimated from satellite imagery. FMIP Baseline Project 1 has now produced a replacement layer for Ecological Condition which is better in this respect. Going forward, the models could also be improved by crafting condition (or include disturbance covariates) to reflect the needs of individual species (e.g. some species prefer a level of the 'right sort' of disturbance).

6.2.2.3 ENM and REMP baselines and projections

For the purpose of running Rapid Evaluation of Metapopulation Persistence (REMP) (Drielsma and Ferrier 2009; Drielsma and Love 2021) for selected species, species landscape parameters (area of habitat needed to support a population for at least 100 years, and home range and dispersal movement abilities) were sourced from previous projects (Dept Environment Climate Change and Water 2009; Taylor *et al.* 2016) or elicited from expert ecologists (Drielsma *et al.* in prep.).

Of the seven focus species, only one of the seven species, Rufous Bettong (*Aepyprymnus rufescens*), was ultimately found suited to REMP modelling. Powerful Owl, for example, was found to be unsuitable as it is a species of extremely high mobility, and in the study region is theoretically able to reach almost any suitable habitat present. Thus, for Powerful Owl, the ENM became the preferred model of landscape capacity; for Rufous Bettong, species landscape parameters variables were used to further refine the ENM model within REMP.

6.2.2.4 Reporting results using the common reporting framework

Results of summed landscape capacity (summed *Pi*) were derived by RFA region using a common reporting framework that was developed as part of FMIP Baseline Project 1 for reporting on forest condition and fragmentation. The framework can extract statistics for any number of nested reporting units and make them readily available within a pivot table in Microsoft Excel. The framework will also be integrated into the Biodiversity Indicator Program and will be useful more generically (e.g. for local government and NPWS business purposes). In the current project, the approach was used to report on landscape trajectories by species and RFA region.

6.3 Species trend analyses

Compared to the comprehensive and extensive corporate fauna and flora datasets that were collected during the 1990s and that were available for analysis to provide baselines in this project, there have been relatively few datasets covering the 2000s and 2010s from which recent trends in species distribution and abundance (or occupancy) can be determined. Most of those that are available were limited in spatial coverage to less than one region and to a limited range of species. Other datasets were limited in duration (e.g. surveys) or used methodology unsuited to the purposes of the present study (e.g. no repeat surveys). The most suitable data available for species trend analyses were usually those curated by individual researchers as part of their long-term research programs. The main addition to these long-term research datasets were the results of the first 5 years of the NSW National Parks and Wildlife Service 'WildCount' species monitoring program (Mills 2019).

A dynamic occupancy modelling framework was used to estimate trends in occupancy for selected species where sufficient data were available. A hierarchical approach was taken to modelling in order to reduce the total number of candidate models. We first modelled detection probability (p) to account for imperfect detection associated with surveys and held initial occupancy ($\pi 1$), colonisation (γ) and extinction (ε) constant. Detection probability was allowed to vary with survey-specific covariates or season of survey or held constant (null model) among all 'visits' to a site. The top model for p was carried forward to model $\pi 1$.

Initial occupancy was modelled while holding γ and ε constant, which is the standard approach used for dynamic occupancy modelling. Where sufficient sample sizes were available, site-based variables were included as covariates for occupancy as well as a null model that held initial occupancy constant across sites.

Two parameters, γ (colonisation, or proportion of unoccupied sites where the species was detected in the following season) and ε (extinction, or proportion of occupied sites where the species was not detected in the following season), were then modelled using the top model for initial occupancy. A null model where these parameters were held constant was also included. The influence (direction and magnitude) of covariates on parameters of supported models was assessed by plotting relationships while holding all other supported covariates at the median value or mode for categorical variables. Prior to analysis, covariates were examined for collinearity. None of the covariates considered were highly correlated ($r > 0.7$).

For other datasets, other metrics were used to assess trends (e.g. abundance, activity). These are described in more detail in Section 0 where relevant.

WildCount camera data from 2012–2016 were reanalysed by Dr Doug Mills (NSW NPWS) for this project. This consisted of firstly partitioning the approximately 200 monitoring sites into those occurring within forest vegetation types, and those occurring within the two northern RFA regions (n = 95 sites) and those occurring within the two southern RFA regions (n = 60 sites). Species detectability models and species occupancy models were then constructed (without the use of climate and environmental covariates) for 24 (17 native and seven introduced) species, principally mammals and birds, being the most frequently recorded species in each combined region (Appendix 9). Species detectability was calculated using the results of 14 consecutive 'visits' (camera days) per year.

Temporal data from the following sources were accessed for trend analysis:

- Owls, gliders and possums (data source: Kavanagh)
- Koalas (data source: NSW DPI)
- Southern Brown Bandicoot (data source: Forestry Corporation of NSW)
- Yellow-bellied Gliders at Bago-Maragle State Forests (data source: Forestry Corporation of NSW)
- Bats (data source: NSW DPI)
- Fauna in eucalypt plantations (data source: NSW DPI)
- Frogs in Chaelundi State Forest (data source: Forestry Corporation of NSW)
- WildCount camera data (data source: NSW National Parks and Wildlife Service)

Results of trend analyses are presented in Section 7.4.

7. Results

7.1 Baseline datasets

7.1.1 Survey gap analysis

The SGA has quantified how well each RFA region and each tenure was sampled in the 1990s and by WildCount more recently. Global P-Median (an estimate of the summed environmental distances between each part of the region to its environmentally closest survey site) results for the three surveys are presented in Table 18. The global P-Median values for fauna and flora are lower (6,688 and 5,787, respectively) than for WildCount (10,116), indicating poorer coverage of the (same) environmental space by WildCount. In Table 18, the change in global P-Median is the reduction in P-Median achieved by adding a single new survey site at the location with the highest local P-Median.

Iterative reduction in global P-Median for the three surveys is presented in Figure 11. At each iteration, the next-best (highest local P-Median) survey site is added to the survey sites after re-calculation of the SGA. For 1990s fauna, there is a 4.0% reduction in global P-Median with the addition of a single survey site, 9.3% with five sites and 11.8% with seven sites. 1990s flora shows a 4.5% reduction with the addition of one site, 8.2% with five sites and 10.2% with seven sites. WildCount shows greatest capacity for improvement, with a 6.4% reduction with the addition of one site, 12.6% with five sites and 15.4% with seven sites. The analysis demonstrates that global P-Median would have been reduced considerably by better sampling the full forested extent across all tenures, but with diminishing returns with each added next-best survey site.

The mapped local P-Median results are presented below for 1990s fauna (Figure 12A), 1990s flora (Figure 12B) and for WildCount (Figure 12C).

Table 18. Global P-Median and change in P-Median (Δ P-Median) resulting from adding the one next-best site for the 1990s fauna, 1990s flora, and WildCount systematic surveys

Survey	**Global P-Median**	**Δ global P-Median (adding next-best site)**	**Percent Δ global P-Median (adding next-best site, %)**
Combined 1990s fauna	6,688	266	−3.97
Combined 1990s flora	5787	261	−4.50
WildCount	10,116	460	−6.47

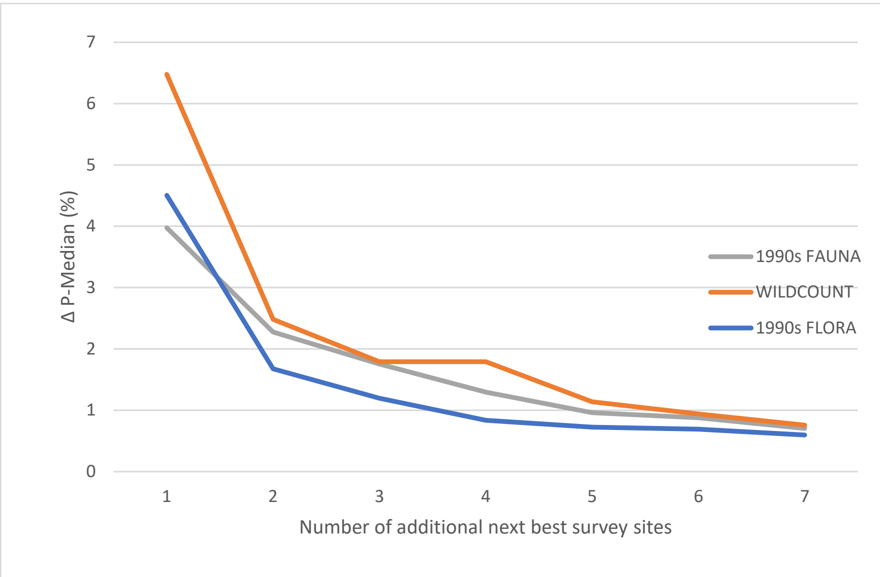
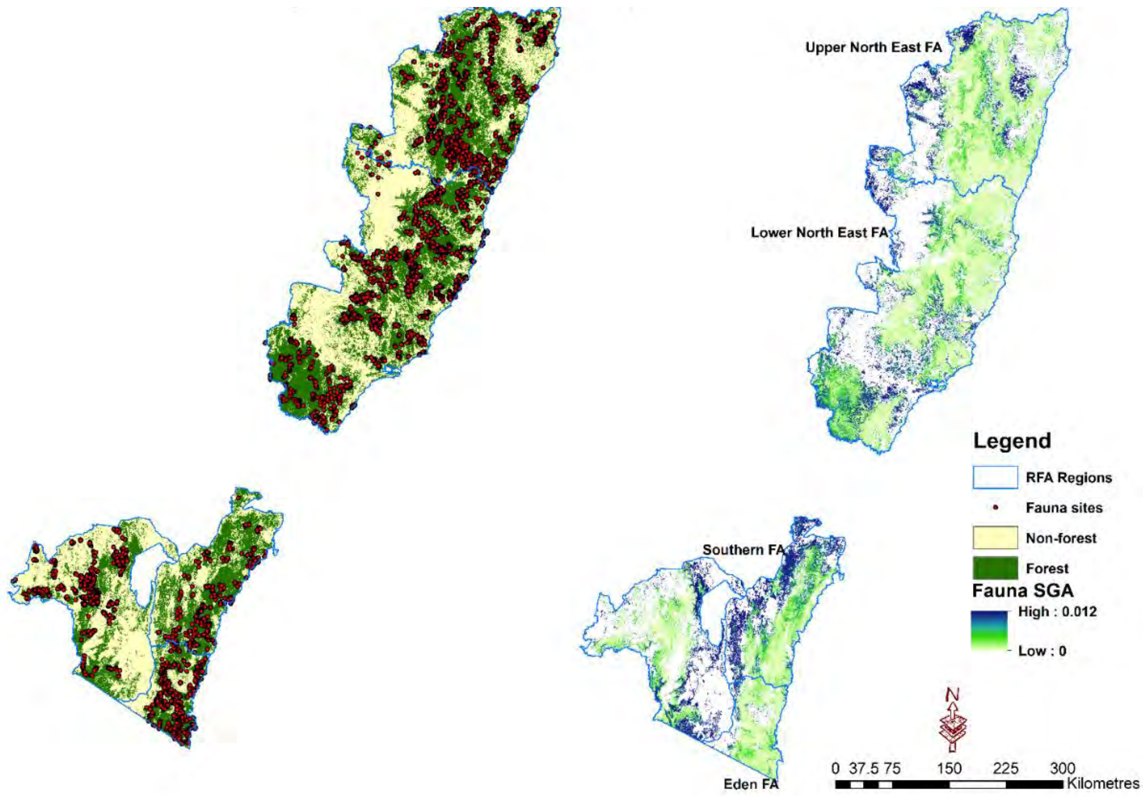
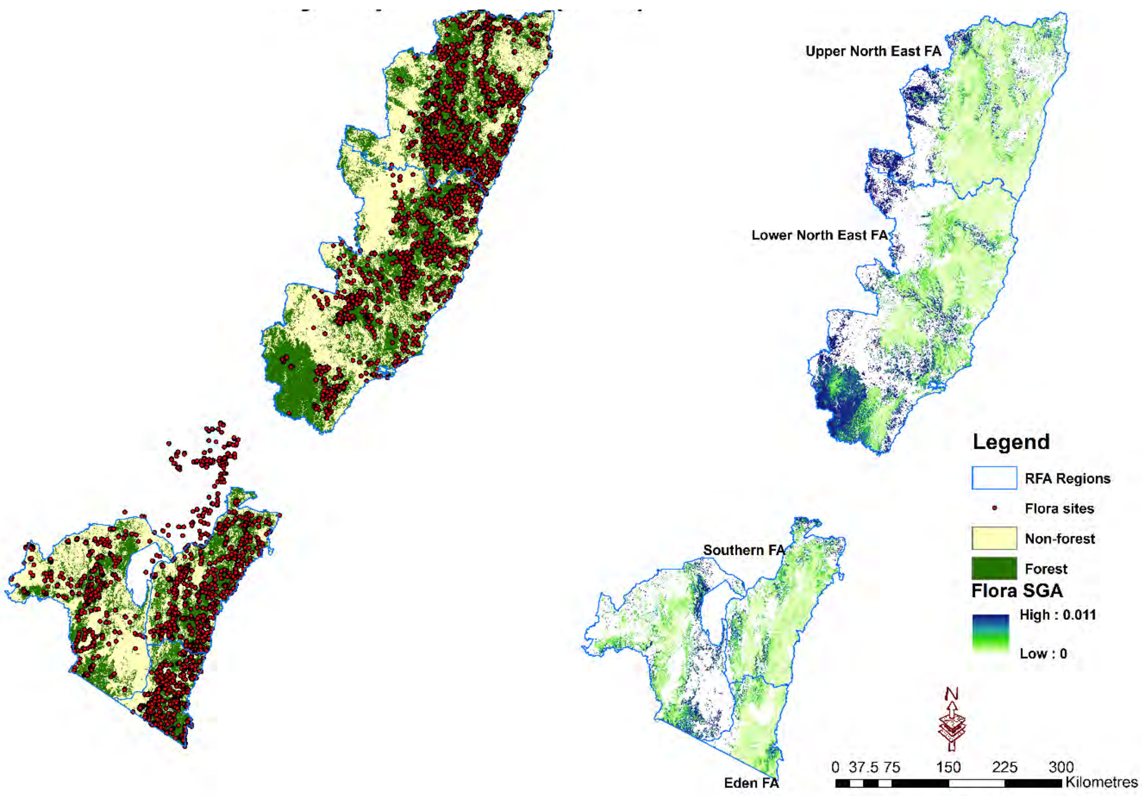


Figure 11. Reduction in global P-Median with seven additional 'next-best' survey sites for the three surveys.

(A)


Upper North East FA
Lower North East FA
Southern FA
Eden FA
Legend
RFA Regions
Fauna sites
Non-forest
Forest
Fauna SGA
High : 0.012
Low : 0
N
0 37.5 75 150 225 300
Kilometres

(B)


Upper North East FA
Lower North East FA
Southern FA
Eden FA
Legend
RFA Regions
Flora sites
Non-forest
Forest
Flora SGA
High : 0.011
Low : 0
N
0 37.5 75 150 225 300
Kilometres

(C)

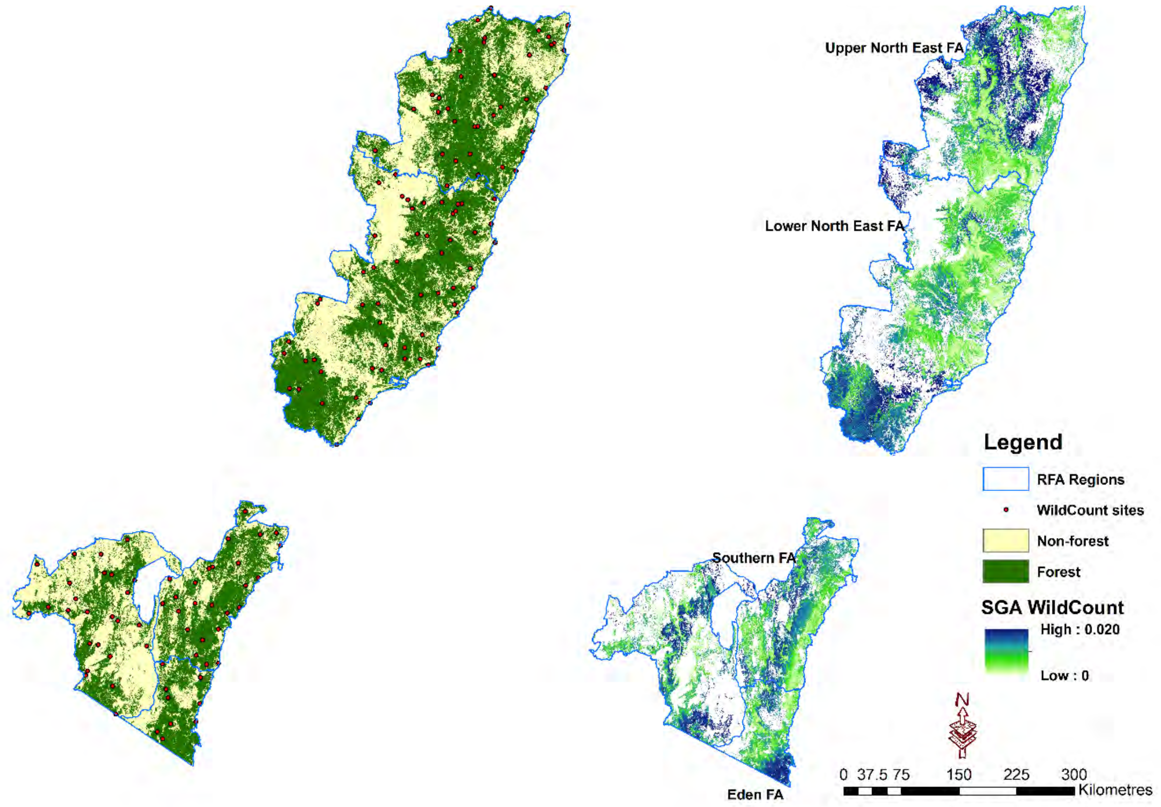


Figure 12. P-Median surfaces from Survey Gap Analysis for the (A) 1990s fauna survey sites; (B) 1990s flora survey sites, and (C) the contemporary WildCount survey program

The left map shows site locations (red circles) in relation to forest extent (green). The right map shows the P-Median surface. High values are under-surveyed

The maps of local P-Median indicate clear geographic differences in P-Median (Figures 12A–C). They show that for each of the three datasets, concentrations of relatively high Local P-Median tend to occur outside of the best sampled areas in the NEFBS and CRA surveys and are mostly on the periphery of large blocks of contiguous forest or in smaller fragments, and are found mostly outside reserves and state forest. An exception to this, in relation to the flora surveys and WildCount, is the area of high P-Median in the south-west corner of the Lower North East RFA region, which includes large parts of Wollemi and Goulburn River National Parks. WildCount also appears to undersample the south-east corner of Eden RFA, including Nadgee Nature Reserve. Other examples can be identified at finer scales.

The mean local P-Median and other statistics, by RFA region and by tenure, are presented in the following zonal statistics tables and charts. These tables and charts show the mean local P-Median for each of the four RFA regions and each of eight tenure classes[7] for: (1) 1990s fauna surveys (Table 19); (2) 1990s flora surveys (Table 20), and for (3) WildCount (Table 21). These data reflect the relative survey coverage of the environmental space of NSW for the three surveys across these

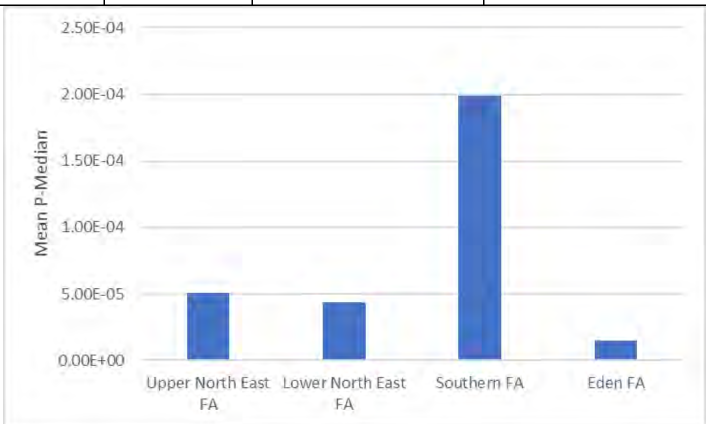
[7] Unresolved tenure is a category in the corporate tenure layer held by DPIE. It represents just over 0.007% of the RFA regions

domains. Higher P-Median values indicate lower coverage (i.e. local P-Median reflects how much the site in a survey would improve, by reducing, the global P-Median for the North East, Southern and Eden RFA regions). For example, for the 1990s fauna surveys, the survey coverage of the Upper and Lower North East RFA regions (mean P-Medians of 5.05 x 10^{-5} and 4.41 x 10^{-5}, respectively) was better (lower) than for the Southern RFA (mean P-Median of 1.99 x 10^{-4}). Eden RFA was the most comprehensively surveyed (mean local P-Median = 1.50 x 10^{-5}).

Table 19. Zonal statistic table (top) and charts (below) for 1990s fauna surveys

P-median values by RFA and by tenure. SD = standard deviation

RFA Area	**Area (ha)**	**Max. P-Median**	**Mean P-Median**	**SD P-Median**
Upper North East RFA	2,307,942	4.85E-03	5.05E-05	1.51E-04
Lower North East RFA	3,116,491	2.42E-03	4.41E-05	1.27E-04
Southern RFA	2,054,917	1.18E-02	1.99E-04	5.54E-04
Eden RFA	516,979	5.35E-04	1.50E-05	4.30E-05
Tenure				
National park	3,047,671	4.72E-03	4.04E-05	1.64E-04
Crown land – Other	133,063	8.93E-03	1.38E-04	3.79E-04
Crown land – Leasehold	83,162	9.65E-03	1.96E-04	4.25E-04
Private	3,428,810	1.18E-02	1.44E-04	4.27E-04
Unresolved tenure	568	4.39E-03	3.26E-04	6.16E-04
State forest	1,302,311	1.77E-03	1.40E-05	5.58E-05
Indigenous owned	470	1.49E-04	3.08E-05	3.42E-05
Other	266	1.35E-04	2.61E-05	3.61E-05



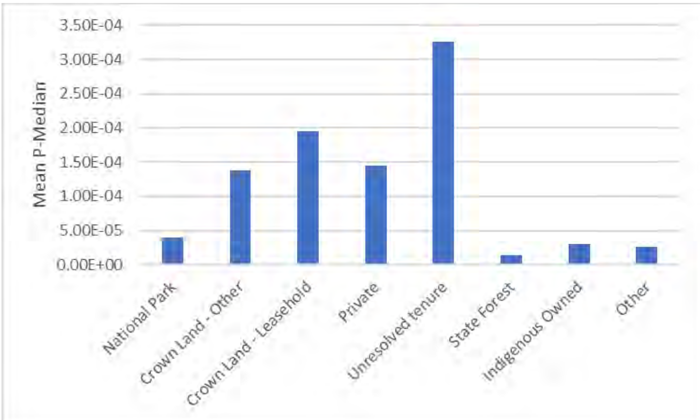
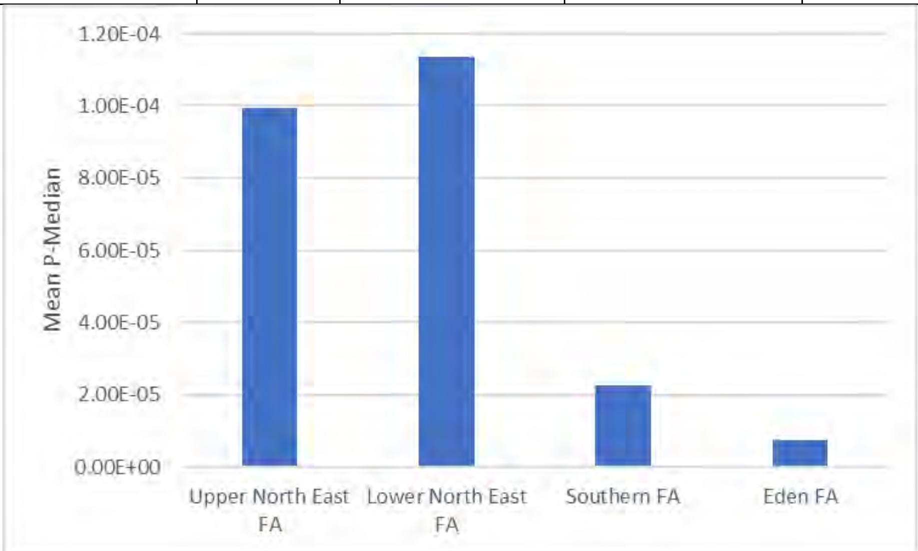


Table 20. Zonal statistics (in tabular form, top, and charts, below) for the 1990s flora surveys

P-median values by RFA and by tenure. SD = standard deviation

RFA Area	Area (ha)	Max. P-Median	Mean P-Median	SD P-Median
Upper North East RFA	2,307,942	1.13E-02	9.94E-05	4.67E-04
Lower North East RFA	3,116,491	7.25E-03	1.13E-04	4.88E-04
Southern RFA	2,054,917	1.19E-03	2.25E-05	4.76E-05
Eden RFA	516,979	2.92E-04	7.59E-06	1.32E-05
Tenure				
National park	3,047,671	6.14E-03	3.00E-05	1.11E-04
Crown land – Other	133,063	1.03E-02	1.64E-04	6.06E-04
Crown land – Leasehold	83,162	1.09E-02	1.72E-04	5.28E-04
Private	3,428,810	1.13E-02	1.45E-04	5.71E-04
Unresolved tenure	568	1.07E-02	4.95E-04	1.76E-03
State forest	1,302,311	2.92E-03	6.80E-06	2.67E-05
Indigenous owned	470	8.63E-05	1.49E-05	1.72E-05
Other	266	1.08E-04	2.93E-05	3.06E-05



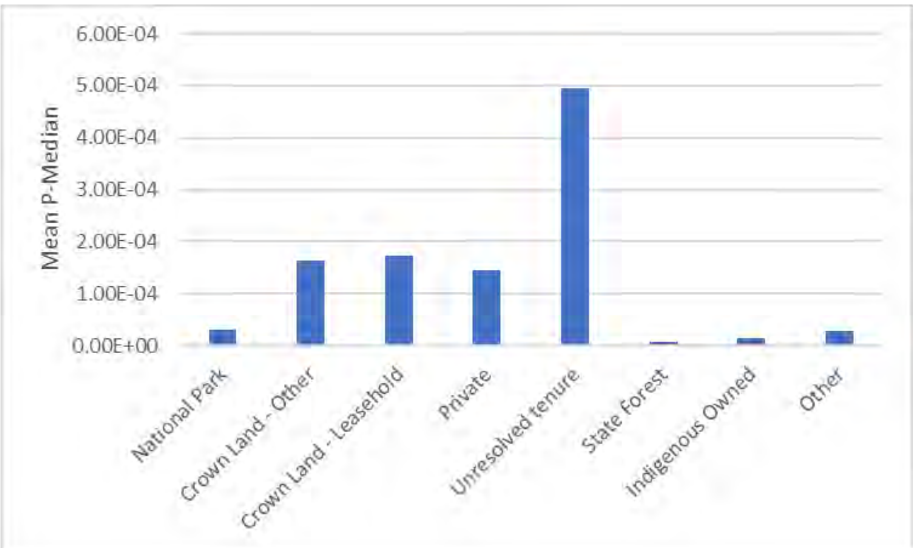
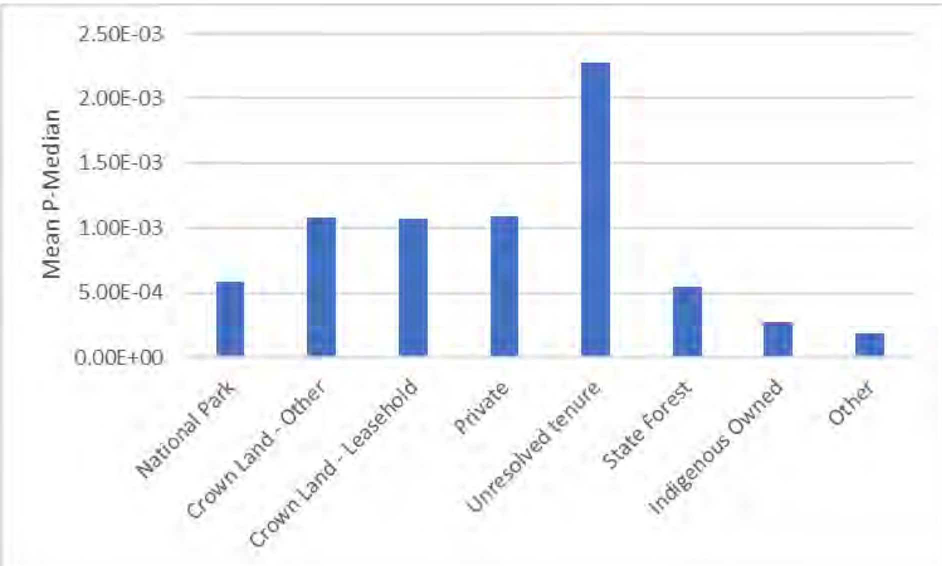


Table 21. Zonal statistic table (top) and charts (below) for the WildCount program P-median values by RFA and by tenure. SD = standard deviation

RFA Area	Area (ha)	Max. P-median	Mean P-Median	SD P-Median
Upper North East RFA	2,307,942	2.00E-02	1.09E-03	1.68E-03
Lower North East RFA	3,116,491	1.33E-02	7.26E-04	1.24E-03
Southern RFA	2,054,917	1.58E-02	6.71E-04	7.33E-04
Eden RFA	516,978	2.51E-03	6.22E-04	5.71E-04
Tenure				
National park	3,047,671	1.58E-02	5.89E-04	7.05E-04
Crown land – Other	133,063	1.68E-02	1.08E-03	1.63E-03
Crown land – Leasehold	83,162	1.90E-02	1.07E-03	1.58E-03
Private	3,428,810	2.00E-02	1.09E-03	1.67E-03
Unresolved tenure	568	1.80E-02	2.28E-03	3.56E-03
State forest	1,302,311	7.67E-03	5.49E-04	7.20E-04
Indigenous owned	470	1.65E-03	2.77E-04	2.88E-04
Other	266	5.56E-04	1.87E-04	1.33E-04



The zonal statistics analysis of local P-Median shows that the environmental space present in national parks and state forests were better sampled than those in private native forests (PNF) and Crown forest lands (CFL), and that PNF and CFL are therefore likely to include some environmental space that is poorly sampled (under-represented). State forests are better sampled than all other tenures, except in the case of WildCount where indigenous lands and 'other' were better sampled.

The relative sampling across RFA regions varied by survey. For fauna, the Eden RFA region was the best sampled and the Southern RFA was by far the least sampled. For flora, the Eden RFA again was the best sampled, but Southern was much better sampled than UNE and LNE. For WildCount, survey sites are more evenly spread geographically, except that UNE is significantly less well sampled than the other three regions.

The geographical differences in local P-Median mean it is possible that species that naturally occur in the less sampled areas have been missed or under-sampled in the 1990s surveys. The full geographic range of other species may not have been fully represented in spatial models either; for example, if high precipitation areas have been oversampled, ENM models may overly associate some species distributions with high values for the precipitation covariates.

Note that global P-Median values are a consideration separate from the number of sites needed to achieve sufficient statistical power for estimating species status and trends. Results could change in future recalculations of the SGA with the inclusion of improved input data, including: a more nuanced GDM, where environmental space could be represented at higher granularity; and using the newly developed forest extent layer, delivered by FMIP Baseline Project 1. Using the reporting framework in that project, local P-Median could also be reported by other domains such as land use and vegetation class.

7.1.2 Naïve occupancy

Naïve occupancy (NO) is a simple measure (proportion) of species presence in the landscape, based on the number of sites where a species was detected by a particular survey method, divided by the total number of sites surveyed by that method. For example, if a species was detected at ten sites by a spotlighting survey over 100 sites, the species' naïve occupancy would be 0.1.

Different survey methods will produce different NO for a species, based on the efficacy of that method in detecting the species. Species occupancy modelling provides an improved estimate of occupancy because it takes species detectability into account when appropriate survey methods are used (i.e. when the method includes repeat samples or visits to the same sites). However, not all survey methods used during the 1990s included repeat visits and so NO is the best estimate that is available for many species. The species NO derived from each survey method provides a guide as to the most appropriate survey data sets to use in modelling species occupancy and distribution, such as SOM or ENM.

Fauna species naïve occupancy using the 'best' survey method for each species in each RFA region is presented in Table 22. Note, the best survey method – as determined by the maximum levels of naïve occupancy returned – is relative among the range of survey methods that were used in the 1990s and the manner in which they were implemented (i.e. whether repeat surveys were included as part of the survey method). These data show that NO varies widely between species, and between regions, using the same survey method. It should also be noted that the fauna species naïve occupancy data reported in Table 22 may be quite different (lower) than the modelled occupancy estimates for the same species after detectability is accounted for. For example, modelled occupancy estimates for the Greater Glider were 0.52 and 0.62 in the combined northern and combined southern regions, and for the Powerful Owl were 0.56 and 0.58, respectively (Section 7.2.1).

Fauna species naïve occupancy for each region for each survey method used in the 1990s surveys is provided in the electronic files package of deliverables for the project. Comparable data showing how modelled species occupancy, where detectability is considered, varies widely depending on the survey method used is given in Einoder *et al*. (2018). In contrast to fauna surveys, the flora survey for this report's species compilation was based on a single method: the 20 m × 20 m plot. Flora species naïve occupancy for each region is provided in Appendix 5.

7.1.2.1 Fauna

A total of 520 native fauna species, and 11 species of introduced mammals, were recorded during the 1990s systematic surveys (Table 23). Species richness was greater in north-eastern NSW than in south-eastern NSW, although twice as many sites were surveyed there (ratio 68:32 sites; Table 4). More species of introduced mammals were also recorded in north-eastern NSW. The largest number of native species was recorded in the LNE region (Table 23).

7.1.2.2 Fauna survey method comparisons

Species baselines for fauna are relative to the survey methods and the sampling designs used to derive the information. Therefore, species baselines need to be defined in these terms. Important factors for consideration are:

- survey technique (noting that species can often be detected using more than one method; however, some techniques provide more reliable data than others) (Einoder *et al*. 2018);
- experience of the observers;
- number of visits or sampling repeats to each survey site during the sampling period;
- the number of survey (or monitoring) sites;
- the stratification used to allocate sites (preferably, species baselines are calculated from sites which fully represent the available environmental space in the region of interest), and
- the independence of these sites from each other (so that species records obtained at one site are not unduly affected by the presence of those species at other nearby sites).

A range of survey techniques was applied across each of the main datasets used in this project in north-eastern NSW (i.e. the EIS surveys, NEFBS surveys, CRA surveys, Debus surveys and Kavanagh surveys) and in southern NSW (i.e. EIS surveys, CRA surveys, and Kavanagh surveys). The survey methods used in each dataset are summarised in the previous section and are provided in more detail in Appendix 3.

Appendix 3 presents the various methods used in the 1990s fauna surveys, which can be used to select the method best suited for estimating occupancy for each species – as determined by the maximum levels of naïve occupancy (Table 22). The range in values for naïve occupancy for a particular survey method is due to the different results that were returned for the same species in each of the datasets and regions.

It should be noted that the survey method abbreviations used in Table 22 and Appendix 3 may require further explanation. For example, the Greater Glider was primarily detected using the spotlighting method (which could have been undertaken along a walked or driven spotlighting transect) or secondarily using the nocturnal call-playback technique from a fixed point; however, it is important to understand that the latter survey method incorporates a short period of spotlighting when this (non-vocal) species was recorded.

Table 22. Naïve occupancy for fauna species according to the 'best' survey method in each RFA region

Survey methods are described in Appendix 3. Data are drawn from multiple regional datasets (EIS surveys, NEFBS surveys, CRA surveys, Debus surveys, Kavanagh surveys). See Notes below Table for codes and futher information

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Adelotus brevis	Tusked Frog	Amphibia	Nocturnal herpets	0.054	0.131		
Assa darlingtoni	Pouched Frog	Amphibia	Nocturnal herpets	0.018			
Crinia parinsignifera	Eastern Sign-bearing Froglet	Amphibia	Nocturnal herpets	0.114	0.028		
Crinia parinsignifera	Eastern Sign-bearing Froglet	Amphibia	Nocturnal streamside			0.021	
Crinia signifera	Common Eastern Froglet	Amphibia	Nocturnal streamside			0.563	0.571
Crinia signifera	Common Eastern Froglet	Amphibia	Nocturnal herpets	0.211	0.254		
Crinia tinnula	Wallum Froglet	Amphibia	Diurnal herpets	0.003	0.001		
Geocrinia victoriana	Eastern Smooth Frog	Amphibia	Nocturnal streamside				0.033
Heleioporus australiacus	Giant Burrowing Frog	Amphibia	Nocturnal herpets		0.005		
Heleioporus australiacus	Giant Burrowing Frog	Amphibia	Nocturnal streamside			0.021	
Lechriodus fletcheri	Fletcher's Frog	Amphibia	Nocturnal herpets	0.012	0.009		
Limnodynastes dumerilii	Eastern Banjo Frog	Amphibia	Nocturnal streamside			0.125	0.063
Limnodynastes dumerilii	Eastern Banjo Frog	Amphibia	Nocturnal herpets	0.036	0.042		
Limnodynastes fletcheri	Long-thumbed Frog	Amphibia	Nocturnal herpets	0.006			
Limnodynastes peronii	Brown-striped Frog	Amphibia	Nocturnal streamside			0.104	0.273
Limnodynastes peronii	Brown-striped Frog	Amphibia	Nocturnal herpets	0.072	0.113		
Limnodynastes tasmaniensis	Spotted Grass Frog	Amphibia	Nocturnal herpets	0.048	0.028		
Limnodynastes tasmaniensis	Spotted Grass Frog	Amphibia	Nocturnal streamside			0.042	
Limnodynastes terraereginae	Northern Banjo Frog	Amphibia	Nocturnal herpets	0.006			
Litoria brevipalmata	Green-thighed Frog	Amphibia	Nocturnal herpets	0.018			
Litoria caerulea	Green Tree Frog	Amphibia	Nocturnal herpets	0.018	0.009		
Litoria chloris	Red-eyed Tree Frog	Amphibia	Nocturnal herpets	0.054	0.042		
Litoria citropa	Blue Mountains Tree Frog	Amphibia	Nocturnal streamside			0.104	0.088
Litoria citropa	Blue Mountains Tree Frog	Amphibia	Nocturnal herpets		0.005		
Litoria dentata	Bleating Tree Frog	Amphibia	Nocturnal herpets	0.030	0.028		
Litoria ewingii	Brown Tree Frog	Amphibia	Nocturnal streamside			0.042	0.029
Litoria fallax	Eastern Dwarf Tree Frog	Amphibia	Nocturnal herpets	0.139	0.183		
Litoria freycineti	Freycinet's Frog	Amphibia	Nocturnal herpets		0.019		

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Litoria freycineti	Freycinet's Frog	Amphibia	Nocturnal streamside			0.042	
Litoria gracilenta	Dainty Green Tree Frog	Amphibia	Nocturnal herpets	0.060	0.005		
Litoria jervisiensis	Jervis Bay Tree Frog	Amphibia	Nocturnal herpets		0.014		
Litoria jervisiensis	Jervis Bay Tree Frog	Amphibia	Nocturnal streamside			0.042	
Litoria latopalmata	Broad-palmed Frog	Amphibia	Nocturnal herpets	0.127	0.075		
Litoria lesueuri	Lesueur's Frog	Amphibia	Nocturnal streamside			0.250	0.222
Litoria lesueuri	Lesueur's Frog	Amphibia	Nocturnal herpets	0.301	0.239		
Litoria littlejohni	Littlejohn's Tree Frog	Amphibia	Nocturnal streamside			0.021	
Litoria nasuta	Rocket Frog	Amphibia	Nocturnal herpets	0.048	0.009		
Litoria pearsoniana	Pearson's Green Tree Frog	Amphibia	Diurnal herpets	0.001	0.001		
Litoria pearsoniana/phyllochroa/barringtonensis	Leaf Green Tree Frog species complex	Amphibia	Nocturnal herpets	0.120	0.249		
Litoria peronii	Peron's Tree Frog	Amphibia	Nocturnal streamside			0.146	0.027
Litoria peronii	Peron's Tree Frog	Amphibia	Nocturnal herpets	0.114	0.131		
Litoria phyllochroa	Leaf-green Tree Frog	Amphibia	Nocturnal streamside			0.250	0.079
Litoria phyllochroa	Leaf-green Tree Frog	Amphibia	Diurnal herpets		0.001		
Litoria revelata	Revealed Frog	Amphibia	Nocturnal herpets	0.006	0.014		
Litoria rubella	Desert Tree Frog	Amphibia	Diurnal herpets		0.001		
Litoria subglandulosa	Glandular Frog	Amphibia	Nocturnal herpets	0.018	0.042		
Litoria tyleri	Tyler's Tree Frog	Amphibia	Nocturnal herpets	0.024	0.052		
Litoria verreauxii	Verreaux's Frog	Amphibia	Nocturnal streamside			0.021	0.026
Litoria verreauxii	Verreaux's Frog	Amphibia	Nocturnal herpets	0.066	0.061		
Litoria verreauxii alpina	Alpine Tree Frog	Amphibia	Nocturnal streamside			0.021	
Mixophyes fasciolatus	Great Barred Frog	Amphibia	Nocturnal herpets	0.139	0.070		
Mixophyes iteratus	Giant Barred Frog	Amphibia	Nocturnal herpets	0.036	0.005		
Paracrinia haswelli	Haswell's Froglet	Amphibia	Nocturnal streamside			0.021	
Philoria sphagnicola	Sphagnum Frog	Amphibia	Diurnal herpets		0.001		
Platyplectrum ornatum	Ornate Burrowing Frog	Amphibia	Nocturnal herpets	0.048	0.014		
Pseudophryne australis	Red-crowned Toadlet	Amphibia	Nocturnal herpets		0.052		
Pseudophryne bibronii	Bibron's Toadlet	Amphibia	Nocturnal herpets	0.006	0.038		
Pseudophryne bibronii	Bibron's Toadlet	Amphibia	Nocturnal streamside			0.063	
Pseudophryne coriacea	Red-backed Toadlet	Amphibia	Nocturnal herpets	0.229	0.192		
Pseudophryne coriacea	Red-backed Toadlet	Amphibia	Diurnal herpets	0.077			

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Pseudophryne corroboree	Southern Corroboree Frog	Amphibia	Diurnal herpets			0.005	
Pseudophryne dendyi	Southern Toadlet	Amphibia	Nocturnal streamside			0.188	0.125
Uperoleia fusca	Dusky Toadlet	Amphibia	Nocturnal herpets	0.012	0.047		
Uperoleia laevigata	Smooth Toadlet	Amphibia	Nocturnal herpets	0.036	0.028		
Uperoleia tyleri	Tyler’s Toadlet	Amphibia	Diurnal herpets		0.001		
Acanthiza apicalis	Inland Thornbill	Aves	Diurnal bird		0.001		
Acanthiza chrysorrhoa	Yellow-rumped Thornbill	Aves	Diurnal bird	0.001	0.003	0.004	
Acanthiza lineata	Striated Thornbill	Aves	Diurnal bird	0.591	0.569	0.512	0.424
Acanthiza nana	Yellow Thornbill	Aves	Diurnal bird	0.037	0.085	0.004	0.019
Acanthiza pusilla	Brown Thornbill	Aves	Diurnal bird	0.762	0.745	0.479	0.703
Acanthiza reguloides	Buff-rumped Thornbill	Aves	Diurnal bird	0.214	0.132	0.062	0.013
Acanthorhynchus tenuirostris	Eastern Spinebill	Aves	Diurnal bird	0.603	0.659	0.424	0.411
Accipiter cirrocephalus	Collared Sparrowhawk	Aves	Diurnal bird	0.020	0.022		0.006
Accipiter fasciatus	Brown Goshawk	Aves	Diurnal bird	0.027	0.032	0.014	0.006
Accipiter novaehollandiae	Grey Goshawk	Aves	Diurnal bird	0.040	0.017	0.004	0.006
Aegotheles cristatus	Australian Owlet-nightjar	Aves	Nocturnal call-playback	0.297	0.305	0.285	0.420
Aerodramus terraereginae	Australian Swiftlet	Aves	Diurnal bird			0.004	
Ailuroedus crassirostris	Green Catbird	Aves	Diurnal bird	0.221	0.150		
Alectura lathami	Australian Brush-turkey	Aves	Diurnal bird	0.052	0.044		
Alisterus scapularis	Australian King-Parrot	Aves	Diurnal bird	0.475	0.383	0.068	0.082
Anas castanea	Chestnut Teal	Aves	Diurnal bird		0.001		
Anas gracilis	Grey Teal	Aves	Diurnal bird		0.001		
Anas platyrhynchos	Mallard	Aves	Diurnal bird			0.009	
Anas superciliosa	Pacific Black Duck	Aves	Diurnal bird	0.009	0.011	0.014	0.019
Anthochaera carunculata	Red Wattlebird	Aves	Diurnal bird	0.210	0.185	0.292	0.209
Anthochaera chrysoptera	Little Wattlebird	Aves	Diurnal bird	0.030	0.059	0.019	0.044
Anthochaera phrygia	Regent Honeyeater	Aves	Diurnal bird		0.001	0.004	
Anthus novaeseelandiae	Australian Pipit	Aves	Diurnal bird	0.004	0.003	0.012	
Apus pacificus	Fork-tailed Swift	Aves	Diurnal bird	0.003	0.002		0.006
Aquila audax	Wedge-tailed Eagle	Aves	Diurnal bird	0.058	0.052	0.037	0.006
Ardenna pacifica	Wedge-tailed Shearwater	Aves	Diurnal bird	0.001		0.004	
Artamus cyanopterus	Dusky Woodswallow	Aves	Diurnal bird	0.027	0.024	0.051	0.051
Artamus leucorynchus	White-Breasted Woodswallow	Aves	Diurnal bird	0.001	0.007	0.004	

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Artamus personatus	Masked Woodswallow	Aves	Diurnal bird			0.004	
Artamus superciliosus	White-browed Woodswallow	Aves	Diurnal bird		0.003	0.043	
Atrichornis rufescens	Rufous Scrub-bird	Aves	Diurnal bird	0.003	0.010		
Aviceda subcristata	Pacific Baza	Aves	Diurnal bird	0.017	0.010	0.004	
Butorides striatus	Striated Heron	Aves	Diurnal bird	0.001			
Cacatua galerita	Sulphur-crested Cockatoo	Aves	Diurnal bird	0.116	0.133	0.156	0.070
Cacomantis flabelliformis	Fan-tailed Cuckoo	Aves	Diurnal bird	0.399	0.348	0.198	0.057
Cacomantis variolosus	Brush Cuckoo	Aves	Diurnal bird	0.153	0.107	0.027	
Calidris acuminata	Sharp-tailed Sandpiper	Aves	Diurnal bird		0.001		
Caligavis chrysops	Yellow-faced Honeyeater	Aves	Diurnal bird	0.722	0.672	0.615	0.418
Callocephalon fimbriatum	Gang-gang Cockatoo	Aves	Diurnal bird		0.036	0.249	0.190
Calyptorhynchus lathami	Glossy Black-Cockatoo	Aves	Diurnal bird	0.156	0.097	0.021	0.038
Carduelis carduelis	Goldfinch	Aves	Diurnal bird				0.006
Carterornis leucotis	White-eared Monarch	Aves	Diurnal bird	0.014			
Casmerodius modesta	Great Egret	Aves	Diurnal bird		0.001		
Centropus phasianinus	Pheasant Coucal	Aves	Diurnal bird	0.038	0.027		
Ceyx azureus	Azure Kingfisher	Aves	Diurnal bird	0.011	0.012	0.017	
Chalcites basalis	Horsfield's Bronze-Cuckoo	Aves	Diurnal bird	0.009	0.003	0.004	
Chalcites lucidus	Shining Bronze-Cuckoo	Aves	Diurnal bird	0.241	0.206	0.101	
Chalcophaps indica	Emerald Dove	Aves	Diurnal bird	0.074	0.016		
Chenonetta jubata	Australian Wood Duck	Aves	Diurnal bird	0.009	0.004		
Chenonetta jubata	Australian Wood Duck	Aves	Site spotlighting			0.006	0.011
Cheramoeca leucosterna	White-backed Swallow	Aves	Diurnal bird		0.003		
Chloris chloris	European Greenfinch	Aves	Diurnal bird	0.001			
Chroicocephalus novaehollandiae	Silver Gull	Aves	Diurnal bird		0.002		
Cincloramphus cruralis	Brown Songlark	Aves	Diurnal bird	0.001			
Cincloramphus mathewsi	Rufous Songlark	Aves	Diurnal bird	0.001	0.001	0.008	
Cincloramphus timoriensis	Tawny Grassbird	Aves	Diurnal bird		0.002		
Cinclosoma punctatum	Spotted Quail-thrush	Aves	Diurnal bird	0.054	0.050	0.051	0.032
Cisticola exilis	Golden-headed Cisticola	Aves	Diurnal bird		0.005		
Climacteris erythrops	Red-browed Treecreeper	Aves	Diurnal bird	0.325	0.288	0.132	0.063
Climacteris picumnus	Brown Treecreeper	Aves	Diurnal bird	0.024	0.020	0.041	0.019
Colluricincla harmonica	Grey Shrike-thrush	Aves	Diurnal bird	0.887	0.738	0.564	0.525

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Colluricincla megarhyncha	Little Shrike-thrush	Aves	Diurnal bird	0.072	0.001		
Columba leucomela	White-headed Pigeon	Aves	Diurnal bird	0.160	0.051	0.008	
Coracina novaehollandiae	Black-faced Cuckoo-shrike	Aves	Diurnal bird	0.367	0.267	0.117	0.095
Coracina papuensis	White-bellied Cuckoo-shrike	Aves	Diurnal bird	0.101	0.035	0.014	0.019
Corcorax melanorhamphos	White-winged Chough	Aves	Diurnal bird	0.035	0.025	0.035	
Cormobates leucophaea	White-throated Treecreeper	Aves	Diurnal bird	0.922	0.834	0.708	0.829
Corvus coronoides	Australian Raven	Aves	Diurnal bird	0.119	0.171	0.146	0.101
Corvus mellori	Little Raven	Aves	Diurnal bird		0.009	0.045	0.019
Corvus orru	Torresian Crow	Aves	Diurnal bird	0.152	0.023		
Corvus tasmanicus	Forest Raven	Aves	Diurnal bird	0.062	0.103		
Coturnix pectoralis	Stubble Quail	Aves	Diurnal bird	0.001	0.001		
Cracticus nigrogularis	Pied Butcherbird	Aves	Diurnal bird	0.061	0.018		
Cracticus torquatus	Grey Butcherbird	Aves	Diurnal bird	0.295	0.223	0.128	0.316
Cuculus optatus	Oriental Cuckoo	Aves	Diurnal bird	0.001			
Cyclopsitta diophthalma	Coxen's Fig-Parrot	Aves	Diurnal bird	0.001			
Cygnus atratus	Black Swan	Aves	Diurnal bird			0.004	
Dacelo novaeguineae	Laughing Kookaburra	Aves	Diurnal bird	0.586	0.455	0.292	0.209
Daphoenositta chrysoptera	Varied Sittella	Aves	Diurnal bird	0.220	0.113	0.049	0.025
Dasyornis brachypterus	Eastern Bristlebird	Aves	Diurnal bird			0.008	
Dicaeum hirundinaceum	Mistletoebird	Aves	Diurnal bird	0.492	0.374	0.084	0.133
Dicrurus bracteatus	Spangled Drongo	Aves	Diurnal bird	0.201	0.023		
Dromaius novaehollandiae	Emu	Aves	Diurnal bird			0.017	
Edolisoma tenuirostris	Cicadabird	Aves	Diurnal bird	0.414	0.294	0.051	0.057
Egretta novaehollandiae	White-faced Heron	Aves	Diurnal bird	0.004	0.007		
Elanus axillaris	Black-shouldered Kite	Aves	Diurnal bird			0.004	
Elseyornis melanops	Black-Fronted Dotterel	Aves	Diurnal bird	0.001	0.001		
Entomyzon cyanotis	Blue-faced Honeyeater	Aves	Diurnal bird	0.030	0.001		
Eolophus roseicapilla	Galah	Aves	Diurnal bird	0.004	0.009	0.012	0.019
Eopsaltria australis	Eastern Yellow Robin	Aves	Diurnal bird	0.688	0.641	0.496	0.709
Ephippiorhynchus asiaticus	Black-necked Stork	Aves	Diurnal bird		0.001		
Eudynamys orientalis	Eastern Koel	Aves	Diurnal bird	0.058	0.039		
Eurostopodus mystacalis	White-throated Nightjar	Aves	Nocturnal call-playback	0.040	0.022	0.066	0.049

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Eurystomus orientalis	Dollarbird	Aves	Diurnal bird	0.041	0.033	0.017	
Falco berigora	Brown Falcon	Aves	Diurnal bird	0.010	0.005	0.012	
Falco cenchroides	Nankeen Kestrel	Aves	Diurnal bird	0.003	0.002	0.004	
Falco hypoleucos	Grey Falcon	Aves	Diurnal bird	0.023			
Falco longipennis	Australian Hobby	Aves	Diurnal bird	0.003	0.002	0.013	
Falco peregrinus	Peregrine Falcon	Aves	Diurnal bird	0.006	0.002	0.004	
Falcunculus frontatus	Eastern Shrike-tit	Aves	Diurnal bird	0.149	0.156	0.066	0.044
Fulica atra	Eurasian Coot	Aves	Diurnal bird			0.004	
Gallinula tenebrosa	Dusky Moorhen	Aves	Diurnal bird	0.001			
Gallinula tenebrosa	Dusky Moorhen	Aves	Nocturnal call-playback		0.003		
Geopelia humeralis	Bar-shouldered Dove	Aves	Diurnal bird	0.014	0.017		
Geopelia placida	Peaceful Dove	Aves	Diurnal bird	0.033	0.013	0.019	
Gerygone fusca	Western Gerygone	Aves	Diurnal bird		0.001	0.009	
Gerygone mouki	Brown Gerygone	Aves	Diurnal bird	0.434	0.415	0.066	0.019
Gerygone olivacea	White-throated Gerygone	Aves	Diurnal bird	0.155	0.066	0.068	0.019
Gliciphila melanops	Tawny-Crowned Honeyeater	Aves	Diurnal bird		0.004		0.006
Glossopsitta concinna	Musk Lorikeet	Aves	Diurnal bird	0.089	0.011	0.039	0.032
Grallina cyanoleuca	Magpie-lark	Aves	Diurnal bird	0.004	0.012	0.006	0.019
Gymnorhina tibicen	Australian Magpie	Aves	Diurnal bird	0.220	0.215	0.115	0.120
Haliaeetus leucogaster	White-bellied Sea-Eagle	Aves	Diurnal bird	0.003	0.004		
Haliastur indus	Brahminy Kite	Aves	Diurnal bird		0.001		
Haliastur sphenurus	Whistling Kite	Aves	Diurnal bird	0.001	0.001	0.004	0.006
Heteroscenes pallidus	Pallid Cuckoo	Aves	Diurnal bird	0.026	0.008	0.021	
Hieraaetus morphnoides	Little Eagle	Aves	Diurnal bird	0.003	0.002	0.004	
Hirundapus caudacutus	White-throated Needletail	Aves	Diurnal bird	0.062	0.084	0.067	0.032
Hirundo neoxena	Welcome Swallow	Aves	Diurnal bird	0.026	0.028	0.019	0.019
Hydroprogne caspia	Caspian Tern	Aves	Diurnal bird		0.001		
Hylacola pyrrhopygia	Chestnut-rumped Heathwren	Aves	Diurnal bird	0.006	0.016	0.006	
Hypotaenidia philippensis	Buff-banded Rail	Aves	Diurnal bird	0.001	0.001		
Lalage leucomela	Varied Triller	Aves	Diurnal bird	0.038	0.005		
Lalage tricolor	White-winged Triller	Aves	Diurnal bird	0.006	0.001	0.006	
Lathamus discolor	Swift Parrot	Aves	Diurnal bird	0.001			
Leucosarcia melanoleuca	Wonga Pigeon	Aves	Diurnal bird	0.247	0.234	0.091	0.082

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Lichenostomus melanops	Yellow-tufted Honeyeater	Aves	Diurnal bird	0.027	0.049	0.031	
Lichmera indistincta	Brown Honeyeater	Aves	Diurnal bird	0.007	0.001		
Limosa lapponica	Bar-tailed Godwit	Aves	Diurnal bird		0.001		
Lophoictinia isura	Square-tailed Kite	Aves	Diurnal bird	0.003			
Lopholaimus antarcticus	Topknot Pigeon	Aves	Diurnal bird	0.096	0.054		
Macropygia phasianella	Brown Cuckoo-Dove	Aves	Diurnal bird	0.342	0.274	0.024	
Malurus cyaneus	Superb Fairy-wren	Aves	Diurnal bird	0.149	0.153	0.173	0.158
Malurus lamberti	Variegated Fairy-wren	Aves	Diurnal bird	0.304	0.222	0.048	
Malurus melanocephalus	Red-backed Fairy-wren	Aves	Diurnal bird	0.043	0.005		
Manorina melanocephala	Noisy Miner	Aves	Diurnal bird	0.071	0.029		0.013
Manorina melanophrys	Bell Miner	Aves	Diurnal bird	0.099	0.153	0.041	0.184
Melanodryas cucullata	Hooded Robin	Aves	Diurnal bird		0.001	0.004	
Meliphaga lewinii	Lewin’s Honeyeater	Aves	Diurnal bird	0.604	0.583	0.181	0.101
Melithreptus albogularis	White-throated Honeyeater	Aves	Diurnal bird	0.064	0.001		0.006
Melithreptus brevirostris	Brown-headed Honeyeater	Aves	Diurnal bird	0.018	0.041	0.080	0.070
Melithreptus gularis	Black-chinned Honeyeater	Aves	Diurnal bird	0.017	0.001		
Melithreptus lunatus	White-naped Honeyeater	Aves	Diurnal bird	0.373	0.410	0.348	0.329
Menura alberti	Albert’s Lyrebird	Aves	Diurnal bird	0.088			
Menura novaehollandiae	Superb Lyrebird	Aves	Diurnal bird	0.233	0.487	0.372	0.437
Merops ornatus	Rainbow Bee-eater	Aves	Diurnal bird	0.028	0.025	0.004	
Microcarbo melanoleucos	Little Pied Cormorant	Aves	Diurnal bird	0.003	0.002		0.006
Microeca fascinans	Jacky Winter	Aves	Diurnal bird	0.075	0.027	0.043	
Monarcha melanopsis	Black-faced Monarch	Aves	Diurnal bird	0.376	0.440	0.113	0.070
Myiagra cyanoleuca	Satin Flycatcher	Aves	Diurnal bird	0.070	0.049	0.094	0.044
Myiagra inquieta	Restless Flycatcher	Aves	Diurnal bird	0.035	0.009	0.033	0.019
Myiagra rubecula	Leaden Flycatcher	Aves	Diurnal bird	0.323	0.217	0.019	0.019
Myzomela sanguinolenta	Scarlet Honeyeater	Aves	Diurnal bird	0.406	0.231	0.027	
Neochmia temporalis	Red-browed Finch	Aves	Diurnal bird	0.328	0.277	0.086	0.108
Neophema pulchella	Turquoise Parrot	Aves	Diurnal bird		0.004	0.034	
Neosericornis citreogularis	Yellow-throated Scrubwren	Aves	Diurnal bird	0.190	0.225	0.004	
Nesoptilotis leucotis	White-eared Honeyeater	Aves	Diurnal bird	0.098	0.139	0.296	0.139
Ninox connivens	Barking Owl	Aves	Nocturnal call-playback	0.007	0.012		
Ninox novaeseelandiae	Southern Boobook	Aves	Nocturnal call-playback	0.386	0.315	0.432	0.321

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Ninox strenua	Powerful Owl	Aves	Nocturnal call-playback	0.190	0.123	0.090	0.144
Numenius madagascariensis	Eastern Curlew	Aves	Diurnal bird		0.001		
Nycticorax caledonicus	Nankeen Night Heron	Aves	Diurnal bird	0.001	0.001		
Ocyphaps lophotes	Crested Pigeon	Aves	Diurnal bird		0.001		
Origma solitaria	Rockwarbler	Aves	Diurnal bird		0.022	0.008	
Oriolus sagittatus	Olive-backed Oriole	Aves	Diurnal bird	0.315	0.194	0.072	0.013
Orthonyx temminckii	Australian Logrunner	Aves	Diurnal bird	0.238	0.123		
Pachycephala inornata	Gilbert's Whistler	Aves	Diurnal bird			0.004	
Pachycephala olivacea	Olive Whistler	Aves	Diurnal bird		0.021	0.045	0.006
Pachycephala pectoralis	Golden Whistler	Aves	Diurnal bird	0.556	0.644	0.453	0.392
Pachycephala rufiventris	Rufous Whistler	Aves	Diurnal bird	0.458	0.339	0.288	0.177
Pardalotus punctatus	Spotted Pardalote	Aves	Diurnal bird	0.657	0.644	0.521	0.291
Pardalotus striatus	Striated Pardalote	Aves	Diurnal bird	0.173	0.170	0.311	0.082
Parvipsitta pusilla	Little Lorikeet	Aves	Diurnal bird	0.182	0.045	0.071	0.019
Pelecanus conspicillatus	Australian Pelican	Aves	Diurnal bird		0.002		
Petrochelidon ariel	Fairy Martin	Aves	Diurnal bird	0.001			
Petrochelidon nigricans	Tree Martin	Aves	Diurnal bird	0.009	0.014	0.028	0.019
Petroica boodang	Scarlet Robin	Aves	Diurnal bird	0.092	0.089	0.068	0.070
Petroica goodenovii	Red-capped Robin	Aves	Diurnal bird	0.001		0.030	
Petroica phoenicea	Flame Robin	Aves	Diurnal bird	0.018	0.077	0.218	0.032
Petroica rodinogaster	Pink Robin	Aves	Diurnal bird			0.009	
Petroica rosea	Rose Robin	Aves	Diurnal bird	0.169	0.244	0.080	0.114
Phalacrocorax carbo	Great Cormorant	Aves	Diurnal bird	0.001	0.001		
Phalacrocorax sulcirostris	Little Black Cormorant	Aves	Diurnal bird	0.004	0.001		
Phalacrocorax varius	Pied Cormorant	Aves	Diurnal bird	0.003	0.002		
Phaps chalcoptera	Common Bronzewing	Aves	Diurnal bird	0.017	0.017	0.031	0.006
Phaps elegans	Brush Bronzewing	Aves	Diurnal bird		0.003	0.019	0.006
Philemon citreogularis	Little Friarbird	Aves	Diurnal bird	0.023	0.009		
Philemon corniculatus	Noisy Friarbird	Aves	Diurnal bird	0.485	0.301	0.138	0.019
Phylidonyris niger	White-cheeked Honeyeater	Aves	Diurnal bird	0.038	0.074	0.008	
Phylidonyris novaehollandiae	New Holland Honeyeater	Aves	Diurnal bird	0.077	0.061	0.142	0.127
Phylidonyris pyrrhopterus	Crescent Honeyeater	Aves	Diurnal bird		0.014	0.091	0.190
Pitta versicolor	Noisy Pitta	Aves	Diurnal bird	0.104	0.010		

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Platycercus elegans	Crimson Rosella	Aves	Diurnal bird	0.607	0.561	0.564	0.500
Platycercus eximius	Eastern Rosella	Aves	Diurnal bird	0.021	0.040	0.014	0.019
Plectorhyncha lanceolata	Striped Honeyeater	Aves	Diurnal bird	0.003	0.011		
Podargus ocellatus	Marbled Frogmouth	Aves	Nocturnal call-playback	0.007			
Podargus strigoides	Tawny Frogmouth	Aves	Nocturnal call-playback	0.101	0.077	0.037	0.064
Pomatostomus superciliosus	White-browed Babbler	Aves	Diurnal bird	0.001	0.003	0.004	
Pomatostomus temporalis	Grey-crowned Babbler	Aves	Diurnal bird	0.016			
Porphyrio porphyrio	Purple Swamphen	Aves	Diurnal bird	0.001	0.004		
Psephotus haematonotus	Red-rumped Parrot	Aves	Diurnal bird			0.004	
Psophodes olivaceus	Eastern Whipbird	Aves	Diurnal bird	0.556	0.569	0.315	0.297
Ptilinopus magnificus	Wompoo Fruit-Dove	Aves	Diurnal bird	0.129	0.023	0.004	
Ptilinopus regina	Rose-crowned Fruit-Dove	Aves	Diurnal bird	0.084	0.008		
Ptilinopus superbus	Superb Fruit-Dove	Aves	Diurnal bird	0.007			
Ptilonorhynchus violaceus	Satin Bowerbird	Aves	Diurnal bird	0.414	0.400	0.169	0.070
Ptiloris paradiseus	Paradise Riflebird	Aves	Diurnal bird	0.179	0.050		
Ptilotula fusca	Fuscous Honeyeater	Aves	Diurnal bird	0.043	0.013	0.035	
Ptilotula penicillata	White-plumed Honeyeater	Aves	Diurnal bird	0.001	0.004		
Purnella albifrons	White-fronted Honeyeater	Aves	Diurnal bird	0.001			
Pycnoptilus floccosus	Pilotbird	Aves	Diurnal bird		0.009	0.152	0.165
Pyrrholaemus sagittatus	Speckled Warbler	Aves	Diurnal bird	0.004	0.017	0.006	
Ramsayornis fasciatus	Bar-breasted Honeyeater	Aves	Diurnal bird		0.002		
Rhipidura albiscapa	Grey Fantail	Aves	Diurnal bird	0.790	0.776	0.642	0.734
Rhipidura leucophrys	Willie Wagtail	Aves	Diurnal bird	0.050	0.026	0.047	0.019
Rhipidura rufifrons	Rufous Fantail	Aves	Diurnal bird	0.362	0.425	0.084	0.114
Scythrops novaehollandiae	Channel-billed Cuckoo	Aves	Diurnal bird	0.108	0.038	0.004	
Sericornis frontalis	White-browed Scrubwren	Aves	Diurnal bird	0.579	0.617	0.500	0.544
Sericornis magnirostra	Large-billed Scrubwren	Aves	Diurnal bird	0.251	0.169	0.016	0.006
Sericulus chrysocephalus	Regent Bowerbird	Aves	Diurnal bird	0.061	0.018	0.004	
Smicrornis brevirostris	Weebill	Aves	Diurnal bird	0.004	0.023	0.004	0.006
Sphecotheres vieilloti	Australasian Figbird	Aves	Diurnal bird	0.055	0.005		
Stagonopleura bella	Beautiful Firetail	Aves	Diurnal bird		0.001		
Stagonopleura guttata	Diamond Firetail	Aves	Diurnal bird			0.004	
Stipiturus malachurus	Southern Emu-wren	Aves	Diurnal bird	0.003	0.007	0.004	

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Stizoptera bichenovii	Double-Barred Finch	Aves	Diurnal bird	0.001	0.005		
Strepera graculina	Pied Currawong	Aves	Diurnal bird	0.806	0.679	0.473	0.380
Strepera versicolor	Grey Currawong	Aves	Diurnal bird		0.001	0.130	0.108
Sturnus vulgaris	Common Starling	Aves	Diurnal bird		0.001	0.004	0.006
Symposiachrus trivirgatus	Spectacled Monarch	Aves	Diurnal bird	0.133	0.065		
Synoicus chinensis	King Quail	Aves	Diurnal bird		0.001		
Synoicus ypsilophora	Brown Quail	Aves	Diurnal bird				0.006
Tachybaptus novaehollandiae	Australasian Grebe	Aves	Diurnal bird	0.001			
Todiramphus macleayii	Forest Kingfisher	Aves	Diurnal bird	0.003			
Todiramphus sanctus	Sacred Kingfisher	Aves	Diurnal bird	0.170	0.112	0.062	0.006
Tregellasia capito	Pale-yellow Robin	Aves	Diurnal bird	0.129	0.044		
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet	Aves	Diurnal bird	0.128	0.022		
Trichoglossus haematodus	Rainbow Lorikeet	Aves	Diurnal bird	0.443	0.106	0.036	0.209
Tringa nebularia	Common Greenshank	Aves	Diurnal bird		0.001		
Turdus merula	Eurasian Blackbird	Aves	Diurnal bird		0.002	0.021	0.013
Turnix melanogaster	Black-breasted Button-quail	Aves	Diurnal bird	0.003			
Turnix pyrrhothorax	Red-chested Button-quail	Aves	Diurnal bird			0.004	
Turnix varius	Painted Button-quail	Aves	Diurnal bird	0.024	0.011	0.004	
Tyto alba	Eastern Barn Owl	Aves	Diurnal bird	0.001			
Tyto alba	Eastern Barn Owl	Aves	Site spotlighting			0.015	
Tyto alba	Eastern Barn Owl	Aves	Nocturnal call-playback		0.002		
Tyto longimembris	Eastern Grass Owl	Aves	Nocturnal call-playback		0.002		
Tyto novaehollandiae	Masked Owl	Aves	Nocturnal call-playback	0.073	0.055	0.147	0.058
Tyto tenebricosa	Sooty Owl	Aves	Nocturnal call-playback	0.116	0.108	0.103	0.099
Vanellus miles	Masked Lapwing	Aves	Diurnal bird	0.009	0.010	0.013	
Vanellus miles	Masked Lapwing	Aves	Site spotlighting				0.018
Zanda funerea	Yellow-tailed Black-cockatoo	Aves	Diurnal bird	0.170	0.220	0.047	0.177
Zoothera heinei	Russet-tailed Thrush	Aves	Diurnal bird	0.028	0.001		
Zoothera lunulata	Bassian Thrush	Aves	Diurnal bird	0.014	0.012	0.006	
Zosterops lateralis	Silvereye	Aves	Diurnal bird	0.409	0.472	0.230	0.165
Acrobates pygmaeus	Feathertail Glider	Mammalia	Nocturnal call-playback	0.011	0.010		
Acrobates pygmaeus	Feathertail Glider	Mammalia	Site spotlighting			0.055	0.072
Aepyprymnus rufescens	Rufous Bettong	Mammalia	Nocturnal call-playback	0.007			

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Antechinus flavipes	Yellow-footed Antechinus	Mammalia	Elliott trap	0.042	0.012		
Antechinus mimetes	Tasman Peninsula Dusky Antechinus	Mammalia	Elliott trap			0.092	0.200
Antechinus stuartii	Brown Antechinus	Mammalia	Elliott trap	0.634	0.639	0.673	0.800
Antechinus swainsonii	Dusky Antechinus	Mammalia	Elliott trap		0.002		
Austronomus australis	White-striped Freetail-bat	Mammalia	Harp trap	0.003	0.025	0.019	
Austronomus australis	White-striped Freetail-bat	Mammalia	Bat ultrasound			0.234	0.112
Bos taurus	European Cattle	Mammalia	Nocturnal call-playback	0.003	0.008		
Canis familiaris	Dog	Mammalia	Nocturnal call-playback	0.011	0.021	0.015	
Cercartetus nanus	Eastern Pygmy-possum	Mammalia	Diurnal herpets	0.001			
Cercartetus nanus	Eastern Pygmy-possum	Mammalia	Elliott trap		0.002	0.010	
Cercartetus nanus	Eastern Pygmy-possum	Mammalia	Site spotlighting				0.023
Chalinolobus dwyeri	Large-eared Pied Bat	Mammalia	Harp trap		0.015	0.019	
Chalinolobus dwyeri	Large-eared Pied Bat	Mammalia	Bat ultrasound			0.042	
Chalinolobus gouldii	Gould’s Wattled Bat	Mammalia	Harp trap	0.084	0.118	0.153	0.084
Chalinolobus gouldii	Gould’s Wattled Bat	Mammalia	Bat ultrasound			0.476	
Chalinolobus morio	Chocolate Wattled Bat	Mammalia	Harp trap	0.280	0.307	0.701	0.598
Chalinolobus morio	Chocolate Wattled Bat	Mammalia	Bat ultrasound			0.667	0.135
Chalinolobus nigrogriseus	Hoary Wattled Bat	Mammalia	Harp trap	0.012			
Dasyurus maculatus	Spotted-tailed Quoll	Mammalia	Elliott trap	0.025	0.042	0.041	
Equus caballus	Horse	Mammalia	Nocturnal call-playback	0.001			
Equus caballus	Horse	Mammalia	Site spotlighting			0.006	
Falsistrellus tasmaniensis	Eastern False Pipistrelle	Mammalia	Harp trap	0.090	0.101	0.165	0.140
Falsistrellus tasmaniensis	Eastern False Pipistrelle	Mammalia	Bat ultrasound			0.214	0.101
Felis catus	Cat	Mammalia	Transect cage	0.005			
Felis catus	Cat	Mammalia	Site spotlighting			0.006	
Felis catus	Cat	Mammalia	Elliott trap		0.017		
Hydromys chrysogaster	Water-rat	Mammalia	Elliott trap	0.008			
Hydromys chrysogaster	Water-rat	Mammalia	Transect cage		0.003		
Isoodon macrourus	Northern Brown Bandicoot	Mammalia	Elliott trap	0.038	0.035		
Lepus capensis	Brown Hare	Mammalia	Site spotlighting			0.006	
Macropus giganteus	Eastern Grey Kangaroo	Mammalia	Nocturnal call-playback	0.004	0.005		
Macropus giganteus	Eastern Grey Kangaroo	Mammalia	Site spotlighting			0.036	0.010
Mastacomys fuscus	Broad-toothed Rat	Mammalia	Elliott trap		0.002		

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Melomys cervinipes	Fawn-footed Melomys	Mammalia	Elliott trap	0.202	0.112		
Microchiroptera (suborder)	Unidentified microbat	Mammalia	Nocturnal call-playback	0.002	0.010		
Micronomus norfolkensis	Eastern Freetail-bat	Mammalia	Bat ultrasound			0.103	0.067
Micronomus norfolkensis	Eastern Freetail-bat	Mammalia	Harp trap		0.005		
Miniopterus australis	Little Bentwing-bat	Mammalia	Harp trap	0.087	0.078		
Miniopterus orianae oceanensis	Eastern Bent-winged Bat	Mammalia	Harp trap	0.044	0.083	0.013	0.084
Miniopterus orianae oceanensis	Eastern Bent-winged Bat	Mammalia	Bat ultrasound			0.490	0.494
Mormopterus loriae	Little Mastiff-bat	Mammalia	Harp trap		0.015		
Mormopterus norfolkensis/planiceps	Unidentified Free-tailed Bat	Mammalia	Bat ultrasound			0.007	
Mormopterus sp.	Unidentified Freetailed-bat	Mammalia	Harp trap	0.003			
Mus musculus	House Mouse	Mammalia	Elliott trap	0.059	0.035		
Myotis macropus	Southern Myotis	Mammalia	Harp trap	0.031	0.025	0.025	0.056
Myotis macropus	Southern Myotis	Mammalia	Bat ultrasound			0.013	0.101
Notamacropus parma	Parma Wallaby	Mammalia	Nocturnal call-playback	0.002	0.002		
Notamacropus parryi	Whiptail Wallaby	Mammalia	Nocturnal call-playback	0.001			
Notamacropus rufogriseus	Red-necked Wallaby	Mammalia	Nocturnal call-playback	0.004	0.009		
Notamacropus rufogriseus	Red-necked Wallaby	Mammalia	Site spotlighting			0.012	
Nyctophilus bifax	Eastern Long-eared Bat	Mammalia	Harp trap	0.025	0.003		
Nyctophilus corbeni	Corben’s Long-eared Bat	Mammalia	Harp trap		0.008		0.009
Nyctophilus geoffroyi	Lesser Long-eared Bat	Mammalia	Harp trap	0.093	0.149	0.312	0.439
Nyctophilus gouldi	Gould’s Long-eared Bat	Mammalia	Harp trap	0.383	0.446	0.395	0.346
Nyctophilus sp.	Unidentified Long-eared bat	Mammalia	Harp trap	0.006			
Ornithorhynchus anatinus	Platypus	Mammalia	Nocturnal streamside			0.021	
Ornithorhynchus anatinus	Platypus	Mammalia	Nocturnal call-playback		0.002		
Oryctolagus cuniculus	Rabbit	Mammalia	Nocturnal call-playback	0.002	0.002		
Oryctolagus cuniculus	Rabbit	Mammalia	Site spotlighting			0.024	0.030
Ozimops planiceps	Little Mastiff-bat	Mammalia	Harp trap		0.003		
Ozimops ridei	Ride’s Free-tailed Bat	Mammalia	Harp trap			0.006	
Ozimops ridei	Ride’s Free-tailed Bat	Mammalia	Bat ultrasound			0.093	0.101
Perameles nasuta	Long-nosed Bandicoot	Mammalia	Site spotlighting			0.048	0.020
Perameles nasuta	Long-nosed Bandicoot	Mammalia	Nocturnal call-playback	0.127	0.035		
Petauroides volans	Greater Glider	Mammalia	Nocturnal call-playback	0.405	0.319	0.059	0.152
Petaurus australis	Yellow-bellied Glider	Mammalia	Nocturnal call-playback	0.146	0.107	0.154	0.272

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Petaurus breviceps	Sugar Glider	Mammalia	Nocturnal call-playback	0.227	0.196		0.428
Petaurus breviceps	Sugar Glider	Mammalia	Site spotlighting			0.434	
Petaurus norfolcensis	Squirrel Glider	Mammalia	Nocturnal call-playback	0.004	0.002		
Petaurus norfolcensis	Squirrel Glider	Mammalia	Site spotlighting			0.018	
Phascogale tapoatafa	Brush-tailed Phascogale	Mammalia	Elliott trap	0.004			
Phascogale tapoatafa	Brush-tailed Phascogale	Mammalia	Transect cage		0.003		
Phascolarctos cinereus	Koala	Mammalia	Nocturnal call-playback	0.048	0.023		0.021
Phoniscus papuensis	Golden-tipped Bat	Mammalia	Harp trap	0.056	0.033	0.006	0.009
Phoniscus papuensis	Golden-tipped Bat	Mammalia	Bat ultrasound				0.022
Planigale maculata	Common Planigale	Mammalia	Elliott trap	0.004			
Potorous tridactylus	Long-nosed Potoroo	Mammalia	Elliott trap		0.002	0.020	
Pseudocheirus peregrinus	Common Ringtail Possum	Mammalia	Nocturnal call-playback	0.084	0.078		
Pseudocheirus peregrinus	Common Ringtail Possum	Mammalia	Site spotlighting			0.174	0.290
Pseudomys gracilicaudatus	Eastern Chestnut Mouse	Mammalia	Elliott trap	0.025	0.002		
Pseudomys novaehollandiae	New Holland Mouse	Mammalia	Elliott trap	0.021	0.010		
Pseudomys oralis	Hastings River Mouse	Mammalia	Elliott trap	0.046	0.015		
Pteropus poliocephalus	Grey-headed Flying-fox	Mammalia	Nocturnal call-playback	0.023	0.010	0.007	
Pteropus scapulatus	Little Red Flying-fox	Mammalia	Nocturnal call-playback	0.003			
Rattus fuscipes	Bush Rat	Mammalia	Elliott trap	0.387	0.316	0.714	0.800
Rattus lutreolus	Swamp Rat	Mammalia	Elliott trap	0.097	0.050	0.020	
Rattus norvegicus	Brown Rat	Mammalia	Elliott trap		0.002		
Rattus rattus	Black Rat	Mammalia	Elliott trap	0.038	0.030	0.031	
Rattus tunneyi	Pale Field-rat	Mammalia	Elliott trap	0.017			
Rhinolophus megaphyllus	Eastern Horseshoe-bat	Mammalia	Harp trap	0.156	0.106	0.057	0.056
Rhinolophus megaphyllus	Eastern Horseshoe-bat	Mammalia	Bat ultrasound			0.033	0.067
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	Mammalia	Bat ultrasound				0.034
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	Mammalia	Harp trap		0.005		
Scoteanax rueppellii	Greater Broad-nosed Bat	Mammalia	Harp trap	0.072	0.055	0.020	0.028
Scoteanax rueppellii	Greater Broad-nosed Bat	Mammalia	Bat ultrasound			0.111	0.157
Scotorepens balstoni	Inland Broad-nosed Bat	Mammalia	Harp trap	0.003	0.008		
Scotorepens orion	Eastern Broad-nosed Bat	Mammalia	Harp trap	0.047	0.083	0.025	0.056
Scotorepens orion	Eastern Broad-nosed Bat	Mammalia	Bat ultrasound			0.214	0.191
Scotorepens sp.	Unidentified Broad-nosed Bat	Mammalia	Harp trap	0.016			

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Sminthopsis leucopus	White-footed Dunnart	Mammalia	Elliott trap			0.010	
Sminthopsis murina	Common Dunnart	Mammalia	Elliott trap	0.008	0.010		
Sus scrofa	Pig	Mammalia	Nocturnal call-playback	0.001			
Syconycteris australis	Common Blossom-bat	Mammalia	Harp trap		0.005		
Tachyglossus aculeatus	Short-beaked Echidna	Mammalia	Diurnal herpets	0.001			
Thylogale thetis	Red-necked Pademelon	Mammalia	Nocturnal call-playback	0.002	0.001		
Trichosurus caninus	Mountain Brushtail Possum	Mammalia	Nocturnal call-playback	0.069	0.083		
Trichosurus cunninghami	Mountain Brushtail Possum	Mammalia	Nocturnal call-playback			0.130	0.059
Trichosurus vulpecula	Common Brushtail Possum	Mammalia	Nocturnal call-playback	0.111	0.093		
Trichosurus vulpecula	Common Brushtail Possum	Mammalia	Site spotlighting			0.230	0.173
Vespadelus darlingtoni	Large Forest Bat	Mammalia	Harp trap	0.231	0.290	0.484	0.252
Vespadelus darlingtoni	Large Forest Bat	Mammalia	Bat ultrasound			0.587	0.506
Vespadelus pumilus	Eastern Forest Bat	Mammalia	Harp trap	0.355	0.227		
Vespadelus regulus	Southern Forest Bat	Mammalia	Harp trap	0.106	0.227	0.344	0.393
Vespadelus regulus	Southern Forest Bat	Mammalia	Bat ultrasound			0.333	0.112
Vespadelus sp.	Unidentified eptesicus	Mammalia	Harp trap	0.075			
Vespadelus troughtoni	Eastern Cave Bat	Mammalia	Bat ultrasound			0.006	0.079
Vespadelus troughtoni	Eastern Cave Bat	Mammalia	Harp trap		0.003		
Vespadelus vulturnus	Little Forest Bat	Mammalia	Harp trap	0.097	0.443	0.643	0.505
Vespadelus vulturnus	Little Forest Bat	Mammalia	Bat ultrasound			0.589	0.011
Vombatus ursinus	Common Wombat	Mammalia	Site spotlighting			0.034	
Vombatus ursinus	Common Wombat	Mammalia	Nocturnal call-playback		0.010		
Vulpes vulpes	Fox	Mammalia	Nocturnal call-playback	0.001	0.003		
Vulpes vulpes	Fox	Mammalia	Site spotlighting			0.009	0.026
Wallabia bicolor	Swamp Wallaby	Mammalia	Nocturnal call-playback	0.005	0.016		
Wallabia bicolor	Swamp Wallaby	Mammalia	Site spotlighting			0.024	0.043
Acritoscincus duperreyi	Eastern Three-lined Skink	Reptilia	Diurnal herpets			0.014	
Acritoscincus platynotus	Red-throated Skink	Reptilia	Diurnal herpets	0.040	0.057	0.038	
Amalosia lesueurii	Lesueur's Velvet Gecko	Reptilia	Diurnal herpets	0.020	0.072		
Amphibolurus muricatus	Jacky Lizard	Reptilia	Diurnal herpets	0.013	0.058	0.077	
Anepischetosia maccoyi	Highlands Forest-skink	Reptilia	Diurnal herpets			0.148	
Anilios nigrescens	Blackish Blind Snake	Reptilia	Diurnal herpets	0.041	0.019	0.013	
Anilios proximus	Proximus Blind Snake	Reptilia	Diurnal herpets	0.001			

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Anomalopus leuckartii	Two-clawed Worm-skink	Reptilia	Diurnal herpets	0.008	0.014		
Anomalopus swansoni	Punctate Worm-skink	Reptilia	Diurnal herpets		0.002		
Anomalopus verreauxii	Three-clawed Worm-skink	Reptilia	Diurnal herpets	0.005			
Antaresia childreni	Children's Python	Reptilia	Diurnal herpets	0.001			
Austrelaps ramsayi	Highland Copperhead	Reptilia	Diurnal herpets		0.002	0.029	
Austrelaps superbus	Lowland Copperhead	Reptilia	Diurnal herpets		0.004	0.009	
Bellatorias frerei	Major Skink	Reptilia	Diurnal herpets	0.008			
Bellatorias major	Land Mullet	Reptilia	Diurnal herpets	0.039	0.012		
Boiga irregularis	Brown Tree Snake	Reptilia	Diurnal herpets	0.005	0.001		
Cacophis krefftii	Southern Dwarf Crowned Snake	Reptilia	Diurnal herpets	0.020	0.005		
Cacophis squamulosus	Golden-crowned Snake	Reptilia	Diurnal herpets	0.009	0.004		
Calyptotis ruficauda	Red-tailed Calyptotis	Reptilia	Diurnal herpets	0.047	0.128		
Calyptotis scutirostrum	Scute-snouted Calyptotis	Reptilia	Diurnal herpets	0.278			
Carinascincus coventryi	Southern Forest Cool-skink	Reptilia	Diurnal herpets			0.067	
Carlia tetradactyla	Southern Rainbow-skink	Reptilia	Diurnal herpets	0.002		0.010	
Carlia vivax	Tussock Rainbow-skink	Reptilia	Diurnal herpets	0.021	0.001		
Chelodina longicollis	Eastern Snake-necked Turtle	Reptilia	Nocturnal streamside			0.021	0.037
Chelodina longicollis	Eastern Snake-necked Turtle	Reptilia	Nocturnal herpets		0.014		
Coeranoscincus reticulatus	Three-toed Snake-tooth Skink	Reptilia	Diurnal herpets	0.013			
Concinnia brachysoma	Northern Barsided Skink	Reptilia	Diurnal herpets	0.001			
Concinnia martini	Dark Barsided Skink	Reptilia	Diurnal herpets	0.116	0.001		
Concinnia tenuis	Barred-sided Skink	Reptilia	Diurnal herpets	0.063	0.019	0.024	
Cryptoblepharus virgatus	Cream-striped Shinning-skink	Reptilia	Diurnal herpets	0.041	0.029	0.014	
Cryptophis nigrescens	Eastern Small-eyed Snake	Reptilia	Diurnal herpets	0.039	0.035	0.010	
Ctenophorus femoralis	Long-tailed Sand-dragon	Reptilia	Nocturnal herpets		0.005		
Ctenotus eurydice	Brown-backed Yellow-lined Ctenotus	Reptilia	Diurnal herpets	0.013			
Ctenotus robustus	Robust Ctenotus	Reptilia	Diurnal herpets	0.010	0.020		
Ctenotus taeniolatus	Copper-tailed Skink	Reptilia	Diurnal herpets	0.060	0.075	0.033	
Cyclodomorphus casuarinae	Mainland She-oak Skink	Reptilia	Diurnal herpets		0.004		
Cyclodomorphus gerrardii	Pink-tongued Lizard	Reptilia	Diurnal herpets	0.001	0.002		
Delma plebeia	Leaden Delma	Reptilia	Diurnal herpets	0.001	0.002		
Demansia psammophis	Yellow-faced Whip Snake	Reptilia	Diurnal herpets	0.037	0.025		
Demansia torquata	Collared Whip Snake	Reptilia	Diurnal herpets		0.002		

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Dendrelaphis punctulatus	Common Tree Snake	Reptilia	Diurnal herpets	0.003	0.001		
Diplodactylus vittatus	Wood Gecko	Reptilia	Diurnal herpets	0.003	0.006	0.005	
Diporiphora australis	Tommy Roundhead	Reptilia	Diurnal herpets	0.001			
Diporiphora nobbi	Nobbi Dragon	Reptilia	Diurnal herpets	0.024	0.009		
Drysdalia coronoides	White-lipped Snake	Reptilia	Diurnal herpets			0.024	
Drysdalia rhodogaster	Mustard-bellied Snake	Reptilia	Diurnal herpets			0.010	
Egernia cunninghami	Cunningham's Skink	Reptilia	Diurnal herpets	0.022	0.014	0.010	
Egernia mcpheei	Eastern Crevice Skink	Reptilia	Diurnal herpets	0.048	0.011		
Egernia saxatilis	Black Rock Skink	Reptilia	Diurnal herpets	0.013		0.035	
Egernia striolata	Tree Skink	Reptilia	Diurnal herpets	0.005	0.011		
Emydura macquarii	Macquarie River Turtle	Reptilia	Diurnal herpets		0.001		
Eulamprus heatwolei	Yellow-bellied Water-skink	Reptilia	Diurnal herpets		0.114	0.236	
Eulamprus heatwolei	Yellow-bellied Water-skink	Reptilia	Nocturnal streamside				0.103
Eulamprus kosciuskoi	Alpine Water Skink	Reptilia	Diurnal herpets	0.002	0.030	0.029	
Eulamprus quoyii	Eastern Water-skink	Reptilia	Diurnal herpets	0.122	0.155	0.057	
Eulamprus tenuis/martini	Unidentified Bar-sided skink	Reptilia	Diurnal herpets	0.010	0.001		
Eulamprus tympanum	Southern Water-skink	Reptilia	Diurnal herpets			0.205	
Furina diadema	Red-naped Snake	Reptilia	Diurnal herpets	0.001	0.002		
Harrisoniascincus zia	Rainforest Cool-skink	Reptilia	Diurnal herpets	0.002	0.004		
Hemiaspis signata	Black-bellied Swamp Snake	Reptilia	Diurnal herpets	0.028	0.022		
Hemiergis decresiensis	Three-toed Earless Skink	Reptilia	Diurnal herpets	0.002	0.002	0.057	
Heteronotia binoei	Bynoe's Gecko	Reptilia	Diurnal herpets	0.005			
Hoplocephalus stephensii	Stephens' Banded Snake	Reptilia	Diurnal herpets	0.005			
Hoplocephalus stephensii	Stephens' Banded Snake	Reptilia	Nocturnal herpets		0.005		
Intellagama lesueurii	Eastern Water Dragon	Reptilia	Nocturnal herpets	0.114	0.113		
Intellagama lesueurii	Eastern Water Dragon	Reptilia	Nocturnal streamside			0.021	
Intellagama lesueurii howittii	Gippsland Water Dragon	Reptilia	Nocturnal streamside			0.125	0.065
Lampropholis amicula	Friendly Sunskink	Reptilia	Diurnal herpets	0.017	0.009		
Lampropholis caligula	Montane Sunskink	Reptilia	Diurnal herpets		0.013		
Lampropholis delicata	Dark-flecked Garden Sunskink	Reptilia	Diurnal herpets	0.621	0.559	0.437	
Lampropholis guichenoti	Pale-flecked Garden Sunskink	Reptilia	Diurnal herpets	0.047	0.072	0.288	
Lerista bougainvillii	South-eastern Slider	Reptilia	Diurnal herpets	0.001	0.007		
Lerista muelleri	Wood Mulch-slider	Reptilia	Diurnal herpets	0.002			

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Lialis burtonis	Burton’s Snake-lizard	Reptilia	Diurnal herpets	0.010	0.008		
Liopholis modesta	Eastern Ranges Rock-skink	Reptilia	Diurnal herpets		0.009		
Liopholis whitii	White's Skink	Reptilia	Diurnal herpets	0.023	0.072	0.024	
Lophosaurus spinipes	Southern Angle-headed Dragon	Reptilia	Diurnal herpets	0.006	0.006		
Lygisaurus foliorum	Tree-base Litter-skink	Reptilia	Diurnal herpets	0.001	0.022		
Menetia greyii	Common Dwarf Skink	Reptilia	Diurnal herpets		0.001		
Morelia spilota	Carpet & Diamond Pythons	Reptilia	Diurnal herpets	0.010	0.005		
Morelia spilota mcdowelli	Eastern Carpet Python	Reptilia	Nocturnal call-playback	0.001			
Morethia boulengeri	South-eastern Morethia Skink	Reptilia	Diurnal herpets	0.007	0.011		
Nebulifera robusta	Robust Velvet Gecko	Reptilia	Diurnal herpets	0.002			
Notechis scutatus	Tiger Snake	Reptilia	Diurnal herpets	0.003	0.006		
Oedura tryoni	Southern Spotted Velvet Gecko	Reptilia	Diurnal herpets	0.009	0.014		
Ophioscincus truncatus	Short-limbed Snake-skink	Reptilia	Diurnal herpets	0.051	0.002		
Phyllurus platurus	Broad-tailed Gecko	Reptilia	Diurnal herpets	0.003	0.043		
Pogona barbata	Bearded Dragon	Reptilia	Diurnal herpets	0.002	0.005		
Pseudechis porphyriacus	Red-bellied Black Snake	Reptilia	Diurnal herpets	0.018	0.030	0.043	
Pseudemoia entrecasteauxii	Tussock Cool-skink	Reptilia	Diurnal herpets		0.041	0.166	
Pseudemoia pagenstecheri	Tussock Skink	Reptilia	Diurnal herpets		0.006	0.024	
Pseudemoia spenceri	Trunk-climbing Cool-skink	Reptilia	Diurnal herpets			0.148	
Pseudonaja textilis	Eastern Brown Snake	Reptilia	Diurnal herpets	0.003	0.006	0.050	
Pygopus lepidopodus	Common Scaly-foot	Reptilia	Diurnal herpets		0.012		
Rankinia diemensis	Mountain Dragon	Reptilia	Diurnal herpets		0.032	0.014	
Rhinella marina	Cane Toad	Reptilia	Diurnal herpets	0.006			
Saiphos equalis	Three-toed Skink	Reptilia	Diurnal herpets	0.255	0.201		
Saltuarius swaini	Southern Leaf-tailed Gecko	Reptilia	Diurnal herpets	0.006	0.011		
Saproscincus challengeri	Orange-tailed Shadeskink	Reptilia	Diurnal herpets	0.132	0.041		
Saproscincus mustelinus	Weasel Skink	Reptilia	Diurnal herpets	0.008	0.105	0.109	
Saproscincus rosei	–	Reptilia	Diurnal herpets	0.014	0.019		
Saproscincus spectabilis	Pale-lipped Shadeskink	Reptilia	Diurnal herpets		0.002		
Silvascincus murrayi	Murray's Skink	Reptilia	Diurnal herpets	0.141	0.127		
Suta spectabilis	Mallee Black-headed Snake	Reptilia	Diurnal herpets	0.001			
Tiliqua nigrolutea	Blotched Blue-tongue	Reptilia	Diurnal herpets			0.009	
Tiliqua scincoides	Eastern Blue-tongue	Reptilia	Elliott trap	0.004			

Scientific name	Common name	Class	Method	UNE	LNE	South	Eden
Tiliqua scincoides	Eastern Blue-tongue	Reptilia	Diurnal herpets		0.001	0.005	
Tropidechis carinatus	Rough-scaled Snake	Reptilia	Nocturnal herpets	0.012	0.005		
Underwoodisaurus milii	Thick-tailed Gecko	Reptilia	Nocturnal herpets		0.005		
Uvidicolus sphyrurus	Border Thick-tailed Gecko	Reptilia	Diurnal herpets	0.002	0.005		
Varanus gouldii	Gould's Goanna	Reptilia	Diurnal herpets	0.002	0.001		
Varanus rosenbergi	Rosenberg's Goanna	Reptilia	Elliott trap			0.020	
Varanus varius	Lace Monitor	Reptilia	Diurnal herpets	0.050	0.075	0.033	
Vermicella annulata	Bandy-bandy	Reptilia	Diurnal herpets		0.001		

Notes:

1. Naïve occupancies are based on systematic surveys, either on a 1–2 ha site (NEFBS, CRA, Debus, Kavanagh) or along a 500-m walked transect line (EIS).
2. Naïve occupancy calculations based on following site sample sizes:

Region	Bat ultrasound	Diurnal bird	Diurnal herpets	Nocturnal herpets	Elliott trap	Harp	Nocturnal call-playback	Nocturnal streamside	Spotlight
UNE	-	789	848	166	238	331	1,320	-	-
LNE	-	919	812	213	402	397	997	-	-
Southern	141	486	229	-	98	200	389	48	235
Eden	89	158	142	-	5	107	56	27	83

3. Survey method abbreviations*
    a. Bat ultrasound: bat call acoustic recording and decoding
    b. Diurnal bird: diurnal bird species lists on site
    c. Diurnal herpets: diurnal searches on foot for reptiles and amphibians on site
    d. Harp trap: overnight, non-injurious bat trapping
    e. Elliott trap: baited aluminium box trap for capture, identification and release of small mammals
    f. Nocturnal call-playback: a combination of listening, broadcasting of pre-recorded of calls for fauna known to be call-responsive, and spotlighting
    g. Nocturnal herpets: nocturnal searches on foot for reptiles and amphibians
    h. Nocturnal streamside: nocturnal searches on foot for reptiles and amphibians along 100 m streamside transects
    i. Site spotlighting: nocturnal walk spotlight-only survey

   *The survey methods are described in more detail in Appendix 3.
4. Notes on the rationale of this naïve occupancy Table

a. The Table typically presents only the most effective survey method (i.e. the method generating the largest naïve occupancy values) for each species across the four RFA regions. However, in some regions, detection was only by a secondary or alternative method, and this result is shown separately
b. In some cases, a true 'primary' (most effective) method could not be designated from the naïve occupancy data alone (e.g. with frog searches, where 'Nocturnal herpets' or 'Nocturnal streamside' was the only detection method available in different RFA regions)
c. The secondary-alternative method inclusion has resulted in blank cells, both for the primary method and secondary-alternative method. The blanks for the primary method are, logically, true record absences. In some cases, however, the secondary-alternative method may also have resulted in a naïve occupancy at the site of the primary record (most effective naïve occupancy), but for simplicity, the secondary-alternative naïve occupancy values have not been entered. These naïve occupancies are available in the electronic datasets for each corporate survey and survey method accompanying the Project 2 Report and Appendices
d. For bat recordings, both Bat ultrasound and Harp trapping were undertaken in the Southern and Eden RFA, so both results are shown for comparative purposes, whereas in UNE–LNE only Harp trapping results were regarded as valid

Table 23. Total number of fauna species recorded by region and taxonomic group

Species group	UNE	LNE	Southern	Eden	Total
Native mammals	50	72	41	40	82
Birds	205	222	163	122	260
Reptiles	97	94	42	17	125
Amphibians	38	43	22	12	53
Total	**390**	**431**	**268**	**191**	**520**
Introduced mammals	11	11	7	6	13

7.1.2.3 Flora

Some 2,808 native plant species were recorded in the 5,248 plots in systematic surveys of public land in RFA regions (Upper North East, Lower North East, Southern, Eden) between 1987 and 2000 (Appendix 5a). This represents approximately 58% of the NSW native flora. A total of 2,617 native species were recorded in 4,811 plots in forested vegetation in these surveys. The majority (2,128 species, or 76%) of the 2,808 species had naïve occupancies < 1% across the whole study region (Figure 13), 1,058 species (38%) had naïve occupancies of < 0.1%, and 407 species (14%) were recorded in only one plot. Only 2% of species (70 species) had naïve occupancies ≥ 10%.

A total of 327 introduced plant species was recorded in systematic surveys from 1987–2000 (Appendix 5b), representing 10% of the total number of flora species recorded in these surveys (n = 3,135). Most introduced species (293 species, 90% of the total) had naïve occupancies < 1% (Figure 13), 186 species (57%) had naïve occupancies < 0.1%, and 90 species (28%) were recorded in only one plot. Only one introduced species (*Hypochaeris radicata*) occurred in ≥ 10% of plots.

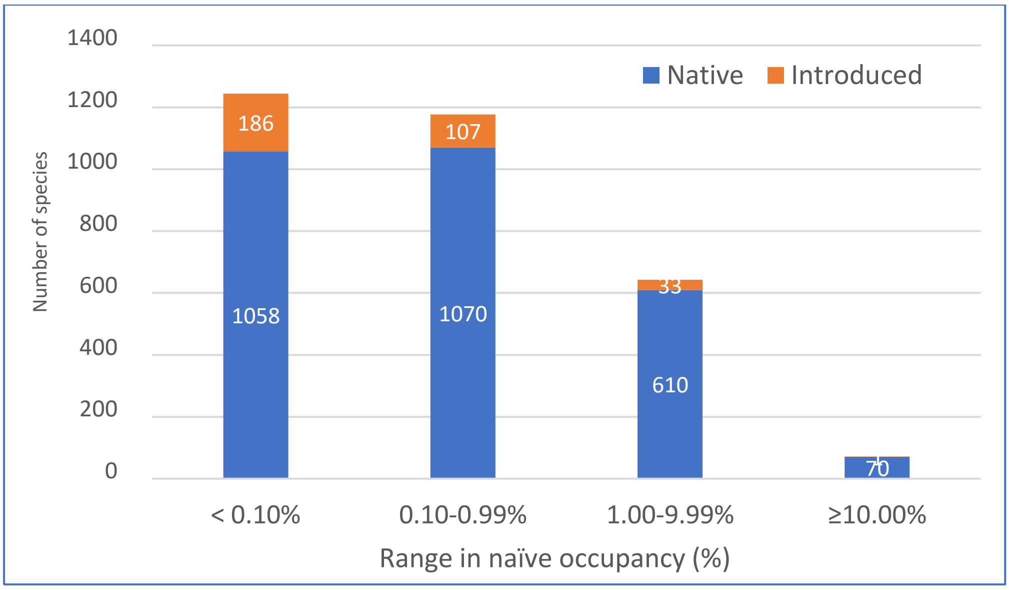


Figure 13. Frequency distribution of naïve occupancy for native and introduced flora species in systematic flora surveys in eastern NSW forests between 1987 and 2000

Native and introduced species richness averaged 37.0 and 1.4 species per plot across all regions, respectively, but varied significantly between RFA regions (Figure 14). Greatest native species richness was recorded in the LNE and UNE regions (41.7 and 38.7 species per plot, respectively), followed by Eden and Southern regions (33.0 and 32.6 species, respectively). Apart from Southern and Eden regions, the differences in native species richness between regions were statistically significant owing to the large sample sizes. Introduced species richness showed the reverse trend to native species richness, with significantly greater numbers of introduced species per plot in Southern region (2.1 introduced species) than in the other three regions (1.1–1.3 species).

Gamma (regional) diversity of native flora species showed a somewhat contrasting regional hierarchy to species richness at the plot scale (alpha diversity). Species accumulation curves for native plant species showed decreasing regional species diversity in order from UNE, LNE, Southern to Eden, these differences being significant once plot number reached 50–700, depending on the regions being compared (Figure 15). In the case of introduced species, and as with alpha diversity, Southern region showed greatest regional diversity, followed by LNE, UNE and Eden in decreasing order. The differences in regional diversity in introduced species between Southern, LNE and UNE regions were significant in excess of 700–900 plots, but gamma diversity of the Eden and UNE regions did not differ, given that only 847 plots were sampled in Eden.

The results of the disturbance and fire analyses and the raw results from which this summary is compiled are summarised in Appendix 6. Subject to considerations of sample size and correlations with environment, various thresholds may be applied to these results to indicate species which are potentially responsive to disturbance or fire history and may thus be given priority for modelling or monitoring. Table 24 summarises the numbers of species in various response classes if a change threshold of at least 30% is applied, with a confidence level of at least 95%. Given the number of sample plots available from the 1990s surveys, for each RFA region, approximately 40% of species had occupancy below that required to detect any difference at all with a confidence of 95% or greater, between COG classes or among fire history classes.

As Table 24 indicates, patterns of flora species response to disturbance and fire varied considerably among RFA regions. There are a number of reasons for this, including differences between regions in physical landscape characteristics and disturbance history, differences in how historical patterns of disturbance have been recorded and different patterns of sample bias. These aspects are discussed in Section 8.1.2.

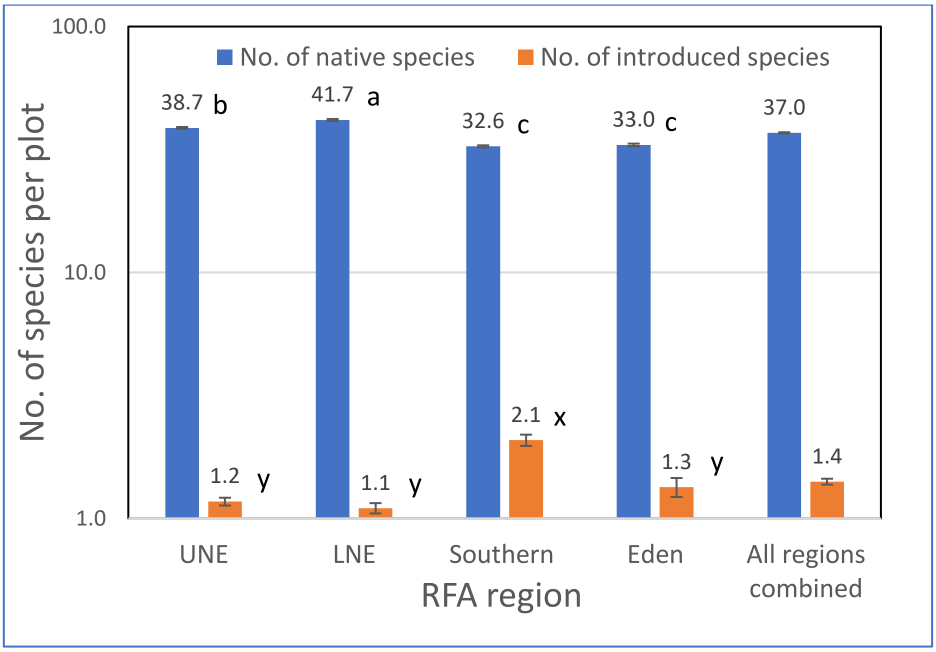


Figure 14. Native and introduced species richness per plot by RFA region, based on systematic flora surveys conducted in eastern NSW between 1987 and 2000

Number of plots in each region: UNE, n = 1,795; LNE, n = 1,282; Southern, n = 1,325; Eden, n = 847. Native species richness means followed by different letters differed significantly ($F = 139.74$, $df = 3,5244$, $P << 0.001$), as did richness of introduced species ($F = 34.56$, $df = 3,5244$, $P << 0.001$)

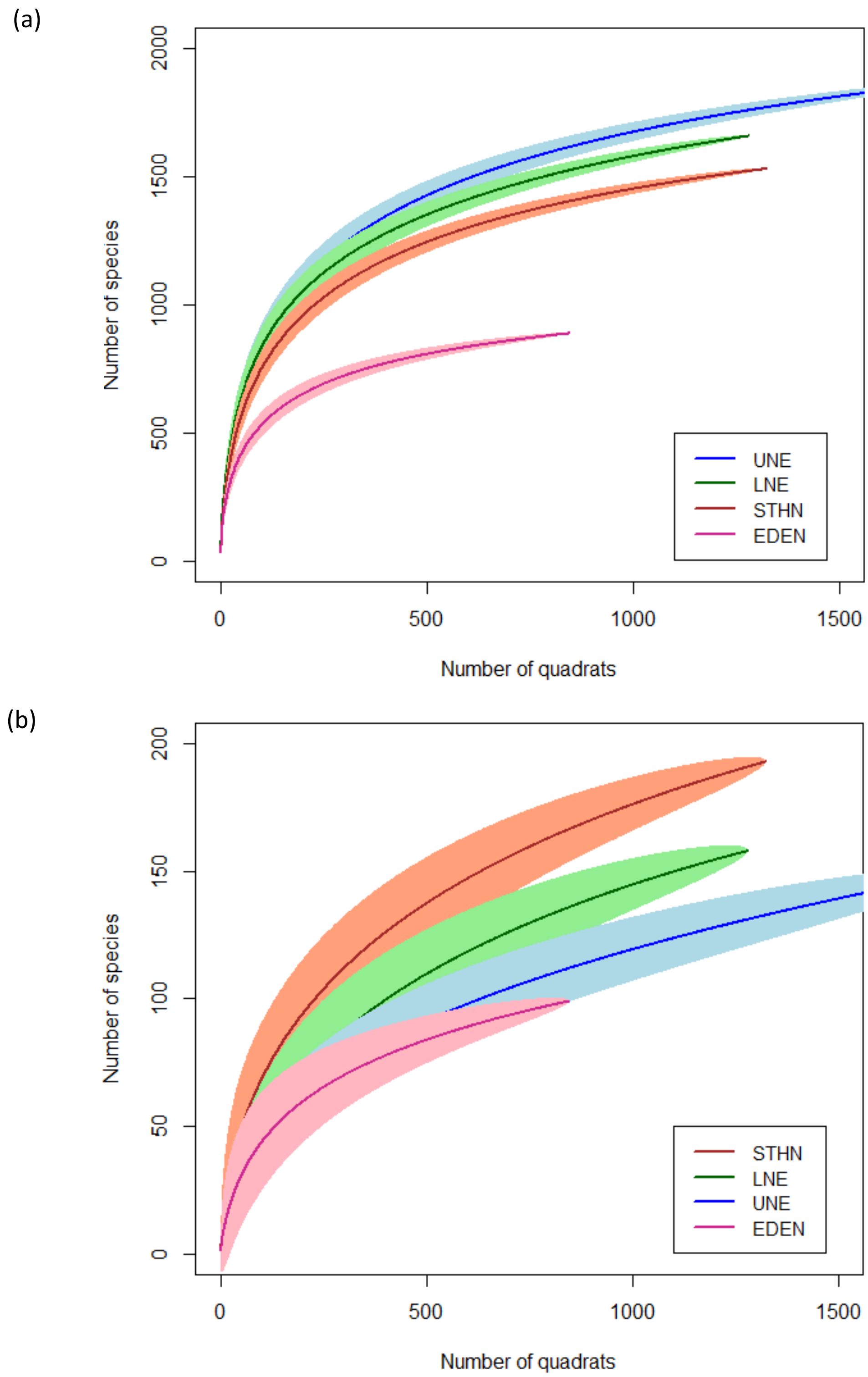


Figure 15. Species accumulation curves for (a) native and (b) introduced flora species by RFA region

Coloured solid lines represent the estimated accumulation in number of species per plot and the coloured shading represents the associated 95% confidence interval.

Table 24. The number of species of native flora responding significantly to COG and fire in each RFA region

The table reports the numbers of species that exceeded a 30% threshold of occurrence in response to COG (noting limitations with this dataset) or fire classes, with a confidence level of at least 95%. 'GAM' refers to results of generalised additive models and 'Bin' to occupancy results in different classes, based on confidence limits from binomial distribution. For Bin, all species were tested, but the 'Number tested' entry is the number of species for which occupancy was at least 0.01. This is approximately the threshold below which it was unlikely that any difference would be detectable using this method, at a confidence level of 95%. A positive COG response meant higher occupancy observed (Bin) or predicted (GAM) in undisturbed plots. A positive response with respect to fire indicated higher occupancy in unburnt relative to burnt plots, or higher occupancy in the unburnt class relative to at least one class of more recent fire or higher fire frequency.

RFA region	Response	COG GAM	COG Bin	Fire GAM	Fire Bin
UNE	Positive	16	34	76	58
	Negative	24	17	64	30
	Number tested	272	621	304	621
LNE	Positive	2	25	55	7
	Negative	8	27	28	50
	Number tested	223	655	259	655
Southern	Positive	8	11	44	55
	Negative	12	3	28	44
	Number tested	213	569	221	569
Eden	Positive	2	2	47	46
	Negative	10	4	30	19
	Number tested	158	421	160	421

7.2 Species modelling

7.2.1 Species occupancy models for fauna

Occupancy modelling was attempted for 28 priority fauna species in the combined northern region (UNE and LNE) and for 16 of these species in the combined southern region (Southern and Eden) for which there was sufficient data from systematic repeat surveys in the 1990s (Table 25). Eight species (*Perameles nasuta*, *Phascolarctos cinereus*, *Pseudocheirus peregrinus, Trichosurus caninus, Scoteanax rueppellii, Pteropus poliocephalus, Saccolaimus flaviventris* and *Manorina melanocephala*) had insufficient records to model in the combined southern region. Results from individual species occupancy modelling are presented in Appendices 7a (North East region) and 7b (Southern–Eden region) and include estimates for species detection probability based on the survey methods used, probability of occupancy after accounting for detection, influential covariates and maps of predicted occupancy. Four priority bat species (*Falsistrellus tasmaniensis*, *Scoteanax rueppellii*, *Saccolaimus flaviventris* and *Micronomus norfolkensis*) had too few captures or observation records to model successfully, and so ultrasonic data collected between 2003 and 2018 in northern NSW were compiled to yield occupancy models (see Appendix 7c for details of occupancy modelling for these bat species).

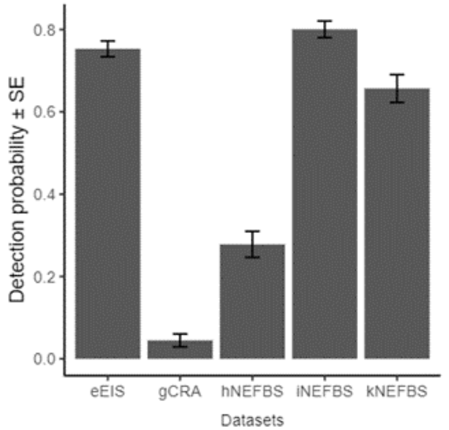
Plausible estimates of detection and occupancy were modelled for most of these species as reflected by the precision of the estimate, but spatial predictions of occupancy were considered unreliable for six species (Table 25). Detection probability can be used with power curves to estimate number of sites required for robust monitoring if the survey method is proposed for use in the future. Estimates of occupancy (and their error) account for imperfect detection and so provide the baseline estimate for forests in the 1990s that can be used to provide context for future monitoring. Species with high occupancy values were widely distributed across the forests in the 1990s (e.g. Australian King Parrot). Species with low occupancy were either sparsely distributed (e.g. Barking Owl), highly localised (e.g. Brown Treecreeper) or occurred more commonly in areas outside of the surveyed forests, such as in coastal vegetation (e.g. East-coast Free-tail Bat).

Influential covariates were highly variable across the different species modelled (Appendix 7). Mean annual temperature (correlated with elevation and latitude) and annual rainfall were commonly supported covariates, highlighting the role of climate in influencing species occupancy across the regions. Tenure, extent of old growth and fire were supported for a subset of species only and their influence was typically minor. A lack of support for old-growth extent may indicate the importance of scattered old-growth trees within regrowth forest, which are not, by themselves, mapped as old growth. Yellow-bellied Gliders were notable in that occupancy was estimated to be three times greater in state forests than national parks during the 1990s, and Greater Gliders were also more likely to occur in state forests at that time.

A detailed example of occupancy modelling for one species, the Greater Glider *Petauroides volans*, is provided below. Occupancy modelling used 814 detection sites and 1,286 non-detection sites from Northern Region. Detection probability was modelled first, and the various datasets used (i.e. observers and survey methods) had a greater influence on detection than season for this species (Figure 16). Median detection probability across the different datasets used was 0.753 ± 0.019 per site visit. This is a relatively high detection probability that is expected for the Greater Glider using the spotlighting method.

Using dataset-specific detection probability, an additive model with nine covariates was the most supported model for Greater Glider occupancy. Median occupancy probability across the range of conditions surveyed for the species was 0.52 ± 0.05, indicating that the species could be expected to occur on approximately 52% of surveyed sites. Clearly, occupancy was higher or lower in specific areas depending on the conditions in those forests. The median estimate provides a 1990s baseline for Greater Glider occupancy across the sites surveyed in the forests of the Northern Region.

Mean annual temperature was the most supported covariate influencing Greater Glider occupancy, with occupancy declining in a quadratic relationship with (increasing) temperature. Other covariates also influenced occupancy (Figure 17). Overall, the data were assessed to be a poor fit to the supported model as assessed by the Pearson chi-squared statistic ($\chi^2 = 131.7$, $p = 0.003$, $\hat{c} = 2.543$) and so supported covariates and their relationship to Greater Glider occupancy should be treated with caution. Extrapolating these relationships spatially to produce an occupancy map suggest that Greater Gliders had a widespread distribution in the 1990s with greatest occupancy occurring in cooler, wetter, high elevation forests, particularly those occurring on more productive sites (Figure 18). Forest type and tenure also influenced occupancy. This is consistent with our knowledge of the species (e.g. Kavanagh *et al.* 1995). Occupancy maps could be produced in the future by combining multiple years of monitoring to achieve an adequate sample size to spatially model occupancy. Future occupancy maps can be compared to the 1990s baseline to highlight where changes in occupancy have occurred.



Codes for datasets: eEIS = Forest EIS (Section 6.1.1.1); gCRA = CRA (Section 6.1.1.3); hNEFBS = NEFBS (Section 6.1.1.2); iNEFBS = Debus nocturnal call-playback (NOCPB), and kNEFBS = Kavanagh NOCPB (Section 6.1.1.4).

Figure 16. Effect of different survey datasets on detection probability of the Greater Glider

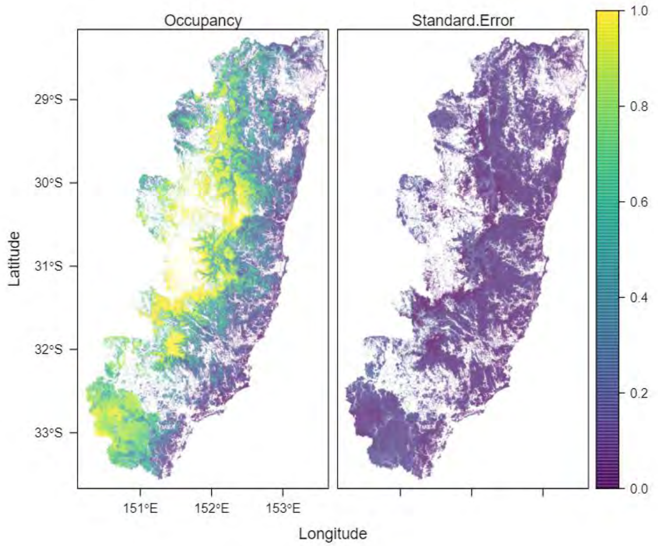


Figure 17. Occupancy map (left) and associated standard error (right) for Greater Gliders in North East region

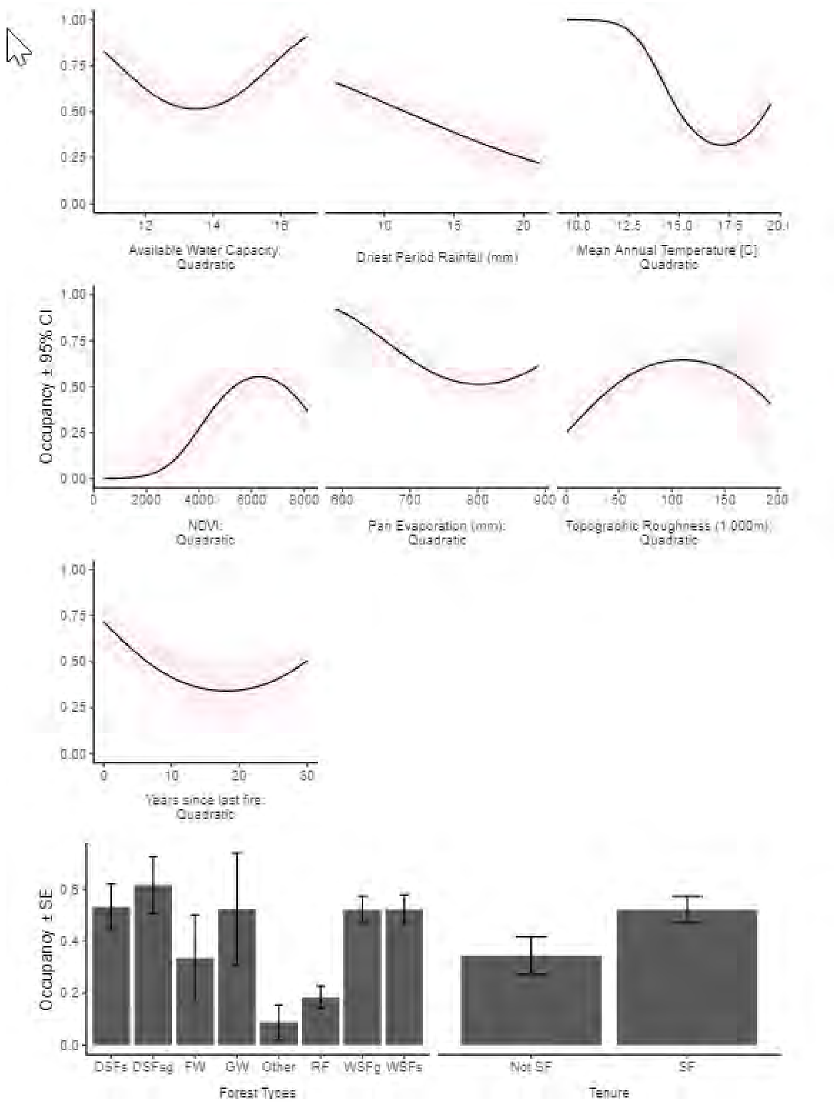


Figure 18. Relationships between covariates and probability of occupancy for Greater Gliders in North East region

Table 25. Detection and occupancy estimates for fauna identified by this project as priority species in combined northern and southern RFA regions

The detection and occupancy metrics were derived from repeat visits in systematic surveys conducted in the 1990s, except for surveys of four bat species using ultrasonics, which were conducted in northern NSW between 2000 and 2018. Probability of occupancy is estimated for median conditions at forest sites surveyed for a given species in each region. Standard error associated with each estimate is also provided. NOCPB = nocturnal listening, call-playback and/or spotlighting. OpRecs = opportunistic records. Indicative = distribution broadly ok but not always accurate at a local scale

Scientific Name	Common Name	Region	Survey Method	Probability of detection	Probability of occupancy	Map reliability	Suitable for occupancy monitoring across region
Alisterus scapularis	Australian King-Parrot	Northern	Diurnal Bird	0.47	0.81 ± 0.03	Good	Yes
Calyptorhynchus lathami	Glossy Black-Cockatoo	Northern	Diurnal Bird	0.24	0.52 ± 0.07	Poor	Yes
Climacteris picumnus	Brown Treecreeper	Northern	Diurnal Bird	0.47	0.004 ± 0.003	Good	No
Daphoenositta chrysoptera	Varied Sittella	Northern	Diurnal Bird	0.08	0.96 ± 0.06	Poor	Yes
Falsistrellus tasmaniensis	Eastern False Pipistrelle	Northern	Ultrasonics **	0.55	0.13 ± 0.07	Good	Yes
Manorina melanocephala	Noisy Miner	Northern	Diurnal Bird	0.48	0.04 ± 0.01	Good	No
Manorina melanophrys	Bell Miner	Northern	Diurnal Bird	0.75	0.28 ± 0.04	Good	Yes
Micronomus norfolkensis	East-coast Freetail Bat	Northern	Ultrasonics **	0.45	0.18 ± 0.14	Indicative	Yes
Myiagra cyanoleuca	Satin Flycatcher	Northern	Diurnal Bird	0.41	0.09 ± 0.02	Good	No
Myiagra rubecula	Leaden Flycatcher	Northern	Diurnal Bird	0.30	0.54 ± 0.07	Indicative	Yes
Ninox novaeseelandiae	Southern Boobook	Northern	NOCPB	0.26	0.60 ± 0.06	Indicative	Yes
Ninox connivens	Barking Owl	Northern	NOCPB	0.02	0.004 ± 0.003	Indicative	No
Ninox strenua	Powerful Owl	Northern	NOCPB	0.16	0.56 ± 0.07	Good	Yes
Perameles nasuta	Long-nosed Bandicoot	Northern	NOCPB	0.10	0.62 ± 0.13	Good	Yes
Petauroides volans	Greater Glider	Northern	NOCPB	0.75	0.52 ± 0.05	Good	Yes
Petaurus australis	Yellow-bellied Glider	Northern	NOCPB	0.34	0.39 ± 0.05	Good	Yes
Petaurus breviceps	Sugar Glider	Northern	NOCPB	0.30	0.71 ± 0.06	Good	Yes
Phascolarctos cinereus	Koala	Northern	NOCPB	0.09	0.27 ± 0.17	Indicative	Yes
Phoniscus papuensis	Golden-tipped Bat *	Northern	Harp	0.22	0.26 ± 0.24	–	Yes
Pomatostomus temporalis	Grey-crowned Babbler	Northern	Diurnal Bird	0.54	0.003 ± 0.004	Indicative	No
Pseudocheirus peregrinus	Common Ringtail Possum	Northern	NOCPB	0.43	0.12 ± 0.03	Indicative	Yes
Pteropus poliocephalus	Grey-headed Flying-fox	Northern	NOCPB	0.01	0.05 ± 0.05	Poor	No
Saccolaimus flaviventris	Yellow-bellied Sheathtail Bat	Northern	Ultrasonics **	0.58	0.05 ± 0.03	Indicative	No

Scientific Name	Common Name	Region	Survey Method	Probability of detection	Probability of occupancy	Map reliability	Suitable for occupancy monitoring across region
Scoteanax rueppellii	Greater Broad-nosed Bat	Northern	Ultrasonics **	0.48	0.11 ± 0.04	Poor	Yes
Trichosurus caninus	Mountain Brushtail Possum	Northern	NOCPB	0.26	0.27 ± 0.05	Good	Yes
Trichosurus vulpecula	Common Brushtail Possum	Northern	NOCPB	0.33	0.45 ± 0.08	Poor	Yes
Tyto novaehollandiae	Masked Owl	Northern	NOCPB	0.11	0.25 ± 0.07	Good	Yes
Tyto tenebricosa	Sooty Owl	Northern	NOCPB	0.13	0.68 ± 0.15	Good	Yes
Alisterus scapularis	Australian King-Parrot	Southern	Diurnal Bird / OpRecs	0.12	0.71 ± 0.42	Indicative	Yes
Calyptorhynchus lathami	Glossy Black-Cockatoo	Southern	Diurnal Bird / OpRecs	0.30	0.03 ± 0.03	Good	No
Climacteris picumnus	Brown Treecreeper	Southern	Diurnal Bird / OpRecs	0.24	0.02 ± 0.01	Indicative	No
Daphoenositta chrysoptera	Varied Sittella	Southern	Diurnal Bird / OpRecs	0.02	0.87 ± 0.19	Poor	Yes
Falsistrellus tasmaniensis	Eastern False Pipistrelle	Southern	Harp	0.38	0.85 ± 0.21	Good	Yes
Manorina melanophrys	Bell Miner	Southern	Diurnal Bird / OpRecs	0.41	0.001 ± 0.001	Good	No
Myiagra cyanoleuca	Satin Flycatcher	Southern	Diurnal Bird / OpRecs	0.35	0.37 ± 0.38	Indicative	Yes
Myiagra rubecula	Leaden Flycatcher	Southern	Diurnal Bird / OpRecs	0.01	0.57 ± 0.42	Indicative	Yes
Ninox boobook	Southern Boobook	Southern	NOCPB / Spotlighting	0.51	0.80 ± 0.18	Good	Yes
Ninox strenua	Powerful Owl	Southern	NOCPB / Spotlighting	0.11	0.58 ± 0.26	Indicative	Yes
Petauroides volans	Greater Glider	Southern	NOCPB / Spotlighting	0.51	0.62 ± 0.11	Good	Yes
Petaurus australis	Yellow-bellied Glider	Southern	NOCPB / Spotlighting	0.73	0.17 ± 0.05	Good	Yes
Petaurus breviceps	Sugar Glider	Southern	NOCPB / Spotlighting	0.77	0.99 ± 0.02	Indicative	Yes
Trichosurus vulpecula	Common Brushtail Possum	Southern	NOCPB / Spotlighting	0.33	0.28 ± 0.08	Indicative	Yes
Tyto novaehollandiae	Masked Owl	Southern	NOCPB / Spotlighting	0.44	0.07 ± 0.06	Good	No
Tyto tenebricosa	Sooty Owl	Southern	NOCPB / Spotlighting	0.01	0.13 ± 0.08	Good	Yes

* Golden-tipped Bat: map not included, but modelled as a trial species.

** Ultrasonic bat surveys are based on collated data from 2000 to pre-2019 bushfires (see Appendix 7c).

7.2.2 Environmental niche models

7.2.2.1 Maxent fauna models

Fauna environmental niche models (ENMs) were successfully fitted to 444 of the 470 NSW taxa included for this FMIP Baseline Project 2 study (Table 26). The remaining 26 taxa could not be modelled due to very low numbers of occurrence records remaining after the spatial and temporal filters for the FMIP Baseline Project 2 modelling were applied. Appendix 10 provides the report of each Maxent fauna species model.

The Boyce index provides a measure of the level of distortion introduced by the model by comparing the frequency of predicted environmental classes to the frequency of environmental classes observed at occurrence locations. A perfect model returns a continuous Boyce index of 1, and good models produce indices close to one. Although there is no commonly used heuristic as used for AUC values, values greater than 0.85 suggest that models exhibited an acceptably low level of distortion. Figure 19b shows the distribution of continuous Boyce values for the successfully fitted Maxent fauna models. The values for the Boyce index do, however, indicate that 62 models (14% of fitted models) returned low to very low Boyce indices. This implies that the occurrence data for these taxa has deeper levels of sampling bias than can be accounted for using the bias-adjusting aggregation method.

In addition to AUC and continuous Boyce values, the omission rate may be informative regarding the usefulness of fitted models. It requires the application of a threshold value to the model out values to determine the fraction of observed occurrences which would be omitted if that threshold value was used to divide suitability into ‘good’ and ‘poor’ classes. The values of omission rate (OR) provided in Table 26 and plotted in Figure 19c were computed using a universal threshold of 0.5 to enable a rapid comparison across fitted models to be made. The spread of values for OR across the fitted Maxent models suggests that omission rates could be higher than might be considered acceptable for models being applied to threatened taxa. A clearer view of the OR performance for the fitted models may be possible by computing optimised threshold values for each model, however, the simpler method applied to these results is indicative of a level of concern about the application of the fitted models without further detailed model tuning and evaluation.

Our expert team reviewed 441 of the Maxent fauna models to determine if they were a good fit to contemporary understanding of the range and habitat suitability of each species in the study region. Some 77% of models were judged satisfactory (i.e. indicative) or better, with reptile models judged more harshly (71% of models satisfactory or better) than for mammals (85%). Bird (76%) and amphibian (77%) models were rated in between.

The contribution or importance of covariates varied widely between taxa. However, cumulative data indicated that several covariates were highly important in a majority of models (Table 27). These included Candidate Old-growth Forest within a 2-km radius of the focal grid cell, Annual Mean Temperature, Minimum Temperature of the Coldest Period, Maximum Temperature of the Warmest Period, Temperature Seasonality, Precipitation Seasonality, Topographic Roughness, and NDVI. While these covariates dominated the fitted models in the frequency with which they were found to be important contributors to a model, Table 27 demonstrates that all covariates had important roles in models for a diverse array of taxa.

Determining trends across taxonomic groups or guilds can be problematic using information like that presented in Table 27. ENMs are statistical models of the realised niche of a species, and it is expected that the modelled niche (reflected in variable importance information) will vary between species, even those in the same ecological guild or taxonomic group. The recovered statistical relationship is conditioned on the quality of the occurrence data and the choice of covariates, and the output of ENMs is an index of suitability of environments for the occurrence of a species. Paradoxically, a covariate may be of low importance in predicting environmental suitability (and indirectly inferring likely occurrence) but of critical importance at key stages of the species' life-cycle. However, ENMs do not directly model critical population attributes (e.g. abundance) or processes (e.g. dispersal, survival or reproductive success).

For example, Table 27 shows that Candidate Old-growth Forest (COG, represented by covariate COG_2000m90) had an important contribution to only 185 out of 446 fitted ENMs. However, we can only conclude that COG is not constraining the distribution or occurrence of the majority of fauna species considered in this report. We cannot conclude that COG has no importance for the viability of populations, even those taxa where it was unimportant in fitted ENMs, because ENMs do not directly measure abundance, survival, or reproductive success of populations.

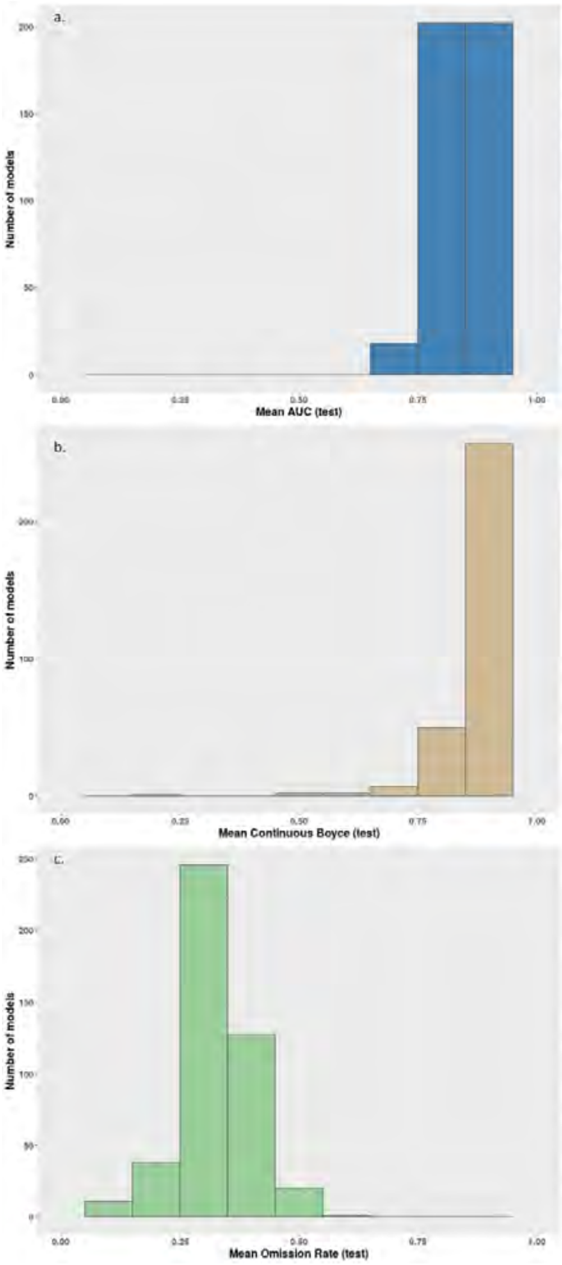


Figure 19. Histograms of the mean AUC, (b) mean continuous Boyce, and (c) mean Omission Rate for Maxent models for 446 fauna species

Table 26. Maxent fauna model performance summary

Values are averages over replicate model fits performed during model tuning. AUC refers to the Area Under the Curve of the Receiver Operating Characteristic; cBoyce is the continuous Boyce index computed following Hirzel et al. *(2006); and OR is the omission rate, the fraction of occurrence records classified as outside suitable habitat when a threshold is applied to the continuous suitability score. A frequent convention allowing cross-model comparisons is to use a threshold of 0.5. Values for 'training' are those calculated on occurrence data used to fit a model and 'test' to the score computed using a fraction of data withheld during model fitting to be used as test case applied to the fitted model. Values in bold highlight models above a Test AUC or cBoyce value of 0.75, which represents models with good predictive performance in cross-validation tests*

Taxon	**Common name**	**Mean AUC Training**	**Mean AUC Test**	**Mean cBoyce Training**	**Mean cBoyce Test**	**Mean OR Train**	**Mean OR Test**
Acanthiza apicalis	Broad-tailed Thornbill	0.00	0.00	0.00	0.00	0.00	0.00
Acanthiza chrysorrhoa	Yellow-rumped Thornbill	0.77	0.77	0.98	**0.94**	0.31	0.29
Acanthiza lineata	Striated Thornbill	0.79	0.79	0.99	**0.98**	0.29	0.29
Acanthiza nana	Yellow Thornbill	0.84	0.83	0.99	**0.93**	0.31	0.33
Acanthiza pusilla	Brown Thornbill	0.80	0.80	1.00	**0.99**	0.31	0.31
Acanthiza reguloides	Buff-rumped Thornbill	0.78	0.77	0.99	**0.95**	0.33	0.34
Acanthorhynchus tenuirostris	Eastern Spinebill	0.81	0.81	1.00	**0.99**	0.28	0.29
Accipiter cirrocephalus	Collared Sparrowhawk	0.78	0.78	0.96	**0.88**	0.29	0.29
Accipiter fasciatus	Brown Goshawk	0.75	0.73	0.98	**0.90**	0.38	0.39
Accipiter novaehollandiae	Grey Goshawk	0.86	**0.85**	0.98	**0.90**	0.28	0.29
Acritoscincus platynotus	Red-throated Skink	0.89	**0.88**	0.96	**0.92**	0.25	0.27
Acrobates pygmaeus	Feathertail Glider	0.85	0.82	0.98	**0.92**	0.25	0.29
Adelotus brevis	Tusked Frog	0.91	**0.90**	0.97	**0.92**	0.32	0.32
Aegotheles cristatus	Australian Owlet-nightjar	0.84	0.84	1.00	**0.99**	0.28	0.29
Aepyprymnus rufescens	Rufous Bettong	0.92	**0.91**	0.98	**0.93**	0.19	0.21
Ailuroedus crassirostris	Green Catbird	0.92	**0.91**	0.99	**0.96**	0.32	0.33
Alectura lathami	Australian Brush-turkey	0.89	**0.89**	0.98	**0.94**	0.29	0.30
Alisterus scapularis	Australian King-parrot	0.80	0.80	1.00	**0.97**	0.31	0.32
Amalosia lesueurii	Lesueur's Velvet Gecko	0.92	**0.90**	0.97	**0.88**	0.17	0.22
Amphibolurus muricatus	Jacky Lizard	0.82	0.82	0.99	**0.95**	0.30	0.30
Anas castanea	Chestnut Teal	0.95	**0.94**	0.97	**0.89**	0.30	0.32
Anas gracilis	Grey Teal	0.88	**0.88**	0.98	**0.91**	0.33	0.34
Anas superciliosa	Pacific Black Duck	0.84	0.84	0.99	**0.97**	0.37	0.37
Anepischetosia maccoyi	Highlands Forest-skink	0.90	**0.85**	0.90	0.81	0.17	0.32
Anilios nigrescens	Blackish Blind Snake	0.86	0.83	0.96	**0.91**	0.33	0.36
Anilios proximus	Proximus Blind Snake	0.00	0.00	0.00	0.00	0.00	0.00
Anomalopus leuckartii	Two-clawed Worm-skink	0.92	0.84	0.91	**0.85**	0.23	0.50
Anomalopus swansoni	Punctate Worm-skink	0.00	0.00	0.00	0.00	0.00	0.00
Anomalopus verreauxii	Three-clawed Worm-skink	0.90	0.84	0.89	0.60	0.13	0.37
Antechinus flavipes	Yellow-footed Antechinus	0.84	0.81	0.98	**0.90**	0.35	0.42
Antechinus stuartii	Brown Antechinus	0.87	**0.87**	1.00	**0.98**	0.29	0.29
Antechinus swainsonii	Dusky Antechinus	0.90	**0.90**	0.93	**0.91**	0.39	0.40
Anthochaera carunculata	Red Wattlebird	0.79	0.79	1.00	**0.97**	0.28	0.28
Anthochaera chrysoptera	Little Wattlebird	0.88	**0.88**	0.98	**0.90**	0.35	0.36
Anthochaera phrygia	Regent Honeyeater	0.87	0.82	0.96	**0.87**	0.25	0.33

Taxon	Common name	Mean AUC Training	Mean AUC Test	Mean cBoyce Training	Mean cBoyce Test	Mean OR Train	Mean OR Test
Anthus novaeseelandiae	Australasian Pipit	0.85	0.84	0.98	**0.92**	0.40	0.42
Apus pacificus	Fork-tailed Swift	0.84	0.81	0.92	**0.94**	0.36	0.40
Aquila audax	Wedge-tailed Eagle	0.70	0.69	0.99	**0.94**	0.26	0.28
Ardea alba	Great Egret	0.94	**0.93**	0.98	**0.94**	0.31	0.34
Ardenna pacifica	Wedge-tailed Shearwater	0.96	**0.94**	0.89	0.81	0.24	0.41
Artamus cyanopterus	Dusky Woodswallow	0.76	0.75	0.98	**0.94**	0.25	0.28
Artamus leucorynchus	White-breasted Woodswallow	0.94	**0.94**	0.92	**0.89**	0.16	0.11
Artamus superciliosus	White-browed Woodswallow	0.86	0.82	0.94	**0.86**	0.29	0.35
Assa darlingtoni	Marsupial Frog	0.98	**0.97**	0.88	**0.90**	0.37	0.50
Atrichornis rufescens	Rufous Scrub-Bird	0.96	**0.96**	0.93	**0.89**	0.17	0.18
Austrelaps ramsayi	Highland Copperhead	0.95	**0.94**	0.95	**0.90**	0.03	0.06
Austrelaps superbus	Lowland Copperhead	0.88	0.81	0.90	**0.94**	0.30	0.44
Austronomus australis	White-striped Freetail-bat	0.79	0.79	0.99	**0.96**	0.32	0.34
Aviceda subcristata	Pacific Baza	0.88	**0.86**	0.98	**0.91**	0.32	0.35
Bellatorias frerei	Major Skink	0.91	**0.86**	0.88	**0.92**	0.36	0.38
Bellatorias major	Land Mullet	0.90	**0.89**	0.96	**0.89**	0.32	0.32
Boiga irregularis	Brown Tree Snake	0.83	0.83	0.91	**0.89**	0.26	0.28
Bos taurus	European Cattle	0.84	0.82	0.96	**0.92**	0.33	0.34
Burhinus grallarius	Bush Stone-curlew	0.93	**0.90**	0.89	**0.89**	0.18	0.24
Cacatua galerita	Sulphur-crested Cockatoo	0.73	0.72	0.99	**0.95**	0.26	0.29
Cacomantis flabelliformis	Fan-tailed Cuckoo	0.80	0.79	1.00	**0.99**	0.30	0.33
Cacomantis pallidus	Pallid Cuckoo	0.82	**0.86**	0.83	**0.95**	0.35	0.27
Cacomantis variolosus	Brush Cuckoo	0.84	0.83	0.98	**0.94**	0.29	0.30
Cacophis krefftii	Southern Dwarf Crowned Snake	0.89	**0.87**	0.93	0.82	0.30	0.37
Cacophis squamulosus	Golden-crowned Snake	0.91	**0.86**	0.92	**0.85**	0.33	0.47
Hylacola phyrrhopygia	Chestnut-rumped Heathwren	0.85	0.82	0.94	0.73	0.33	0.41
Calidris acuminata	Sharp-tailed Sandpiper	0.98	**0.97**	0.90	**0.90**	0.22	0.29
Caligavis chrysops	Yellow-faced Honeyeater	0.77	0.77	1.00	**0.99**	0.30	0.29
Callocephalon fimbriatum	Gang-gang Cockatoo	0.78	0.77	0.99	**0.95**	0.29	0.31
Calyptorhynchus banksii	Red-tailed Black Cockatoo	0.00	0.00	0.00	0.00	0.00	0.00
Calyptorhynchus funereus	Yellow-tailed Black-cockatoo	0.81	0.81	1.00	**0.98**	0.28	0.29
Calyptorhynchus lathami	Glossy Black-Cockatoo	0.84	0.84	1.00	**0.99**	0.25	0.25
Calyptotis ruficauda	Red-tailed Calyptotis	0.90	**0.89**	0.98	**0.88**	0.24	0.28
Calyptotis scutirostrum	Scute-snouted Calyptotis	0.92	**0.91**	0.98	**0.95**	0.24	0.23
Canis familiaris	Common Dog, Dingo	0.00	0.00	0.00	0.00	0.00	0.00
Capra hircus	Goat	0.81	0.75	0.89	0.83	0.32	0.45
Carinascincus coventryi	Southern Forest Cool-skink	0.94	**0.91**	0.90	0.84	0.11	0.29
Carlia tetradactyla	Southern Rainbow-skink	0.85	0.79	0.90	**0.91**	0.27	0.44
Carlia vivax	Lively Rainbow Skink	0.91	**0.87**	0.95	0.84	0.17	0.26
Carterornis leucotis	White-eared Monarch	0.98	**0.98**	0.85	0.79	0.21	0.18
Centropus phasianinus	Pheasant Coucal	0.90	**0.90**	0.98	**0.92**	0.35	0.35
Cercartetus nanus	Eastern Pygmy-possum	0.84	0.81	0.86	**0.87**	0.30	0.39
Ceyx azureus	Azure Kingfisher	0.88	**0.88**	0.98	**0.89**	0.38	0.39
Chalcites basalis	Horsfield’s Bronze-cuckoo	0.82	0.83	0.96	**0.90**	0.38	0.36

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Chalcites lucidus	Shining Bronze-cuckoo	0.84	0.83	0.99	**0.96**	0.33	0.33
Chalcophaps indica	Emerald Dove	0.90	**0.90**	0.97	**0.86**	0.35	0.37
Chalinolobus dwyeri	Large Pied Bat	0.86	0.83	0.88	0.81	0.27	0.29
Chalinolobus gouldii	Gould's Wattled Bat	0.81	0.80	0.99	**0.95**	0.29	0.31
Chalinolobus morio	Chocolate Wattled Bat	0.83	0.83	0.99	**0.97**	0.31	0.30
Chalinolobus nigrogriseus	Hoary Wattled Bat	0.85	**0.87**	0.89	**0.91**	0.20	0.13
Chelodina longicollis	Eastern Long-necked Turtle	0.84	0.84	0.96	**0.86**	0.31	0.34
Chenonetta jubata	Australian Wood Duck	0.80	0.79	0.99	**0.95**	0.38	0.40
Cheramoeca leucosterna	White-backed Swallow	0.77	0.71	0.80	0.80	0.14	0.25
Chloris chloris	Common Greenfinch	0.92	**0.85**	0.91	**0.95**	0.12	0.29
Chroicocephalus novaehollandiae	Silver Gull	0.96	**0.95**	0.97	**0.92**	0.33	0.36
Chthonicola sagittata	Speckled Warbler	0.85	0.80	0.96	0.79	0.23	0.34
Cincloramphus cruralis	Brown Songlark	0.87	0.82	0.89	**0.90**	0.30	0.39
Cinclosoma punctatum	Spotted Quail-Thrush	0.83	0.82	0.99	**0.96**	0.32	0.33
Cisticola exilis	Golden-headed Cisticola	0.93	**0.93**	0.93	**0.90**	0.29	0.26
Climacteris erythrops	Red-browed Treecreeper	0.87	**0.87**	0.99	**0.97**	0.34	0.34
Climacteris picumnus	Brown Treecreeper	0.81	0.79	0.98	**0.91**	0.26	0.29
Coeranoscincus reticulatus	Three-toed Snake-tooth Skink	0.96	**0.95**	0.83	**0.97**	0.28	0.36
Colluricincla harmonica	Grey Shrike-thrush	0.77	0.77	0.99	**0.99**	0.31	0.32
Colluricincla megarhyncha	Little Shrike-thrush	0.96	**0.95**	0.89	**0.88**	0.33	0.35
Columba leucomela	White-headed Pigeon	0.89	**0.88**	0.98	**0.89**	0.33	0.36
Concinnia brachysoma	Northern Bardsided Skink	0.00	0.00	0.00	0.00	0.00	0.00
Concinnia martini	Dark Barsided Skink	0.89	**0.86**	0.97	**0.89**	0.25	0.33
Concinnia tenuis	Barred-sided Skink	0.85	0.84	0.96	**0.91**	0.32	0.31
Coracina novaehollandiae	Black-faced Cuckoo-shrike	0.79	0.78	1.00	**0.99**	0.32	0.32
Coracina papuensis	White-bellied Cuckoo-shrike	0.80	0.79	0.97	**0.87**	0.32	0.34
Coracina tenuirostris	Cicadabird	0.80	0.71	0.85	**0.88**	0.23	0.43
Corcorax melanorhamphos	White-winged Chough	0.75	0.74	0.98	**0.93**	0.25	0.28
Cormobates leucophaea	White-throated Treecreeper	0.77	0.77	0.99	**0.99**	0.31	0.31
Corvus coronoides	Australian Raven	0.76	0.76	1.00	**0.97**	0.37	0.37
Corvus mellori	Little Raven	0.91	**0.88**	0.88	**0.93**	0.43	0.46
Corvus orru	Torresian Crow	0.87	**0.87**	0.99	**0.95**	0.34	0.35
Corvus tasmanicus	Forest Raven	0.92	**0.92**	0.97	**0.87**	0.24	0.29
Coturnix pectoralis	Stubble Quail	0.82	0.77	0.92	**0.92**	0.33	0.46
Coturnix ypsilophora	Brown Quail	0.92	**0.88**	0.94	**0.90**	0.30	0.34
Cracticus nigrogularis	Pied Butcherbird	0.86	**0.85**	0.99	**0.94**	0.30	0.31
Cracticus torquatus	Grey Butcherbird	0.79	0.79	0.99	**0.98**	0.33	0.33
Crinia parinsignifera	Eastern Sign-bearing Froglet	0.86	0.83	0.97	**0.88**	0.29	0.34
Crinia signifera	Common Eastern Froglet	0.79	0.79	1.00	**0.98**	0.31	0.30
Crinia tinnula	Tinkling Froglet	0.98	**0.98**	0.93	0.83	0.26	0.26
Cryptophis nigrescens	Eastern Small-eyed Snake	0.86	**0.85**	0.98	**0.91**	0.25	0.30
Ctenotus eurydice	Brown-backed Yellow-lined Ctenotus	0.89	**0.90**	0.87	**0.92**	0.05	0.07
Ctenotus robustus	Robust Ctenotus	0.90	**0.87**	0.84	**0.91**	0.46	0.52

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Ctenotus taeniolatus	Copper-tailed Skink	0.86	0.84	0.99	**0.95**	0.27	0.30
Cuculus optatus	Oriental Cuckoo	0.00	0.00	0.00	0.00	0.00	0.00
Cyclodomorphus gerrardii	Pink-tongued Lizard	0.90	0.83	0.85	**0.91**	0.28	0.41
Dacelo novaeguineae	Kookaburra	0.78	0.77	1.00	**0.99**	0.29	0.30
Dama dama	Fallow Deer	0.00	0.00	0.00	0.00	0.00	0.00
Daphoenositta chrysoptera	Varied Sittella	0.78	0.77	0.99	**0.97**	0.33	0.33
Dasyurus maculatus	Spotted-tailed Quoll	0.81	0.81	0.99	**0.97**	0.34	0.35
Delma plebeia	Leaden Delma	0.00	0.00	0.00	0.00	0.00	0.00
Demansia psammophis	Yellow-faced Whip Snake	0.85	0.84	0.97	**0.85**	0.35	0.39
Dendrelaphis punctulatus	Common or Green Tree Snake	0.88	**0.87**	0.95	0.83	0.35	0.39
Dicaeum hirundinaceum	Mistletoebird	0.81	0.80	1.00	**0.99**	0.30	0.31
Dicrurus bracteatus	Spangled Drongo	0.91	**0.91**	0.99	**0.95**	0.35	0.35
Diplodactylus vittatus	Eastern Stone Gecko	0.84	0.83	0.89	**0.90**	0.20	0.16
Diporiphora australis	Tommy Roundhead	0.00	0.00	0.00	0.00	0.00	0.00
Diporiphora nobbi	Nobbi Dragon	0.86	0.84	0.96	**0.90**	0.26	0.29
Egernia cunninghami	Cunningham's Skink	0.83	0.78	0.95	**0.89**	0.39	0.46
Egernia mcpheei	Eastern Crevice Skink	0.90	**0.88**	0.95	0.84	0.33	0.39
Egernia saxatilis	Black Rock Skink	0.90	**0.89**	0.95	**0.90**	0.12	0.17
Egernia striolata	Tree Skink	0.86	**0.86**	0.87	0.84	0.17	0.21
Egretta novaehollandiae	White-faced Heron	0.89	**0.88**	0.98	**0.92**	0.40	0.40
Elseyornis melanops	Black-fronted Dotterel	0.89	**0.88**	0.94	**0.91**	0.31	0.34
Emydura macquarii macquarii	Macquarie River Turtle	0.88	**0.87**	0.96	0.75	0.07	0.12
Entomyzon cyanotis	Blue-faced Honeyeater	0.89	**0.88**	0.96	**0.88**	0.38	0.44
Eolophus roseicapilla	Galah	0.83	0.84	0.99	**0.97**	0.38	0.35
Eopsaltria australis	Eastern Yellow Robin	0.79	0.79	1.00	**0.99**	0.29	0.30
Ephippiorhynchus asiaticus	Black-necked Stork	0.94	**0.94**	0.98	**0.93**	0.23	0.23
Equus caballus	Brumby	0.86	0.80	0.95	**0.89**	0.30	0.44
Eudynamys orientalis	Eastern Koel	0.88	**0.87**	0.99	**0.96**	0.31	0.34
Eulamprus heatwolei	Yellow-bellied Water-skink	0.94	**0.93**	0.98	**0.94**	0.26	0.28
Eulamprus kosciuskoi	Alpine Water-skink	0.89	**0.88**	0.99	**0.96**	0.32	0.34
Eulamprus quoyii	Eastern Water-skink	0.84	0.83	0.99	**0.96**	0.28	0.29
Eurostopodus mystacalis	White-throated Nightjar	0.86	**0.86**	0.99	**0.96**	0.22	0.21
Eurystomus orientalis	Dollarbird	0.85	0.84	0.99	**0.94**	0.37	0.37
Falco berigora	Brown Falcon	0.75	0.72	0.98	**0.89**	0.36	0.38
Falco cenchroides	Nankeen Kestrel	0.81	0.80	0.99	**0.94**	0.37	0.40
Falco hypoleucos	Grey Falcon	0.90	0.79	0.92	**0.92**	0.17	0.28
Falco longipennis	Australian Hobby	0.85	**0.85**	0.96	**0.87**	0.35	0.34
Falco peregrinus	Peregrine Falcon	0.78	0.74	0.95	0.84	0.38	0.44
Falcunculus frontatus	Crested Shrike-tit	0.77	0.77	0.99	**0.95**	0.38	0.38
Falsistrellus tasmaniensis	Eastern False Pipistrelle	0.84	0.83	0.98	**0.93**	0.34	0.34
Felis catus	Cat	0.84	0.83	0.99	**0.95**	0.30	0.29
Furina diadema	Red-naped Snake	0.71	0.71	0.81	0.50	0.00	0.00
Gallinula tenebrosa	Dusky Moorhen	0.89	**0.89**	0.98	**0.94**	0.29	0.29
Gallirallus philippensis	Buff-banded Rail	0.93	**0.95**	0.86	**0.97**	0.05	0.04

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Geopelia humeralis	Bar-shouldered Dove	0.91	**0.91**	0.98	**0.90**	0.38	0.40
Geopelia striata	Peaceful Dove	0.85	0.84	0.95	**0.87**	0.33	0.33
Gerygone mouki	Brown Gerygone	0.86	**0.86**	1.00	**0.98**	0.30	0.30
Gerygone olivacea	White-throated Gerygone	0.78	0.77	0.99	**0.96**	0.29	0.32
Gliciphila melanops	Tawny-crowned Honeyeater	0.97	**0.93**	0.91	0.79	0.22	0.20
Glossopsitta concinna	Musk Lorikeet	0.81	0.77	0.99	**0.94**	0.26	0.31
Grallina cyanoleuca	Magpie-lark	0.84	0.83	0.99	**0.96**	0.33	0.32
Gymnorhina tibicen	Australian Magpie	0.76	0.76	1.00	**0.99**	0.38	0.38
Haliaeetus leucogaster	White-bellied Sea-eagle	0.93	**0.93**	0.98	**0.95**	0.33	0.33
Haliastur indus	Brahminy Kite	0.97	**0.97**	0.94	**0.87**	0.34	0.32
Haliastur sphenurus	Whistling Kite	0.93	**0.93**	0.96	**0.92**	0.33	0.36
Harrisoniascincus zia	Rainforest Cool-Skink	0.98	**0.96**	0.83	**0.96**	0.31	0.40
Heleioporus australiacus	Giant Burrowing Frog	0.86	0.84	0.95	0.84	0.14	0.17
Hemiaspis signata	Black-bellied Swamp Snake	0.86	0.84	0.96	**0.86**	0.35	0.41
Hemiergis decresiensis	Three-toed Earless Skink	0.86	0.76	0.93	0.80	0.16	0.33
Heteronotia binoei	Bynoe’s Gecko	0.96	**0.93**	0.83	0.81	0.03	0.15
Hieraaetus morphnoides	Little Eagle	0.79	0.75	0.97	0.84	0.33	0.41
Hirundapus caudacutus	Spine-tailed Swift	0.83	0.83	0.99	**0.95**	0.33	0.32
Hirundo neoxena	Welcome Swallow	0.83	0.82	1.00	**0.97**	0.37	0.39
Hoplocephalus bitorquatus	Pale-headed Snake	0.00	0.00	0.00	0.00	0.00	0.00
Hoplocephalus bungaroides	Broad-headed Snake	0.88	0.84	0.77	**0.90**	0.20	0.42
Hoplocephalus stephensii	Stephens’ Banded Snake	0.88	**0.86**	0.88	**0.88**	0.37	0.40
Hydromys chrysogaster	Water-rat	0.85	0.82	0.91	**0.90**	0.37	0.44
Hydroprogne caspia	Caspian Tern	0.97	**0.97**	0.93	**0.90**	0.22	0.23
Intellagama lesueurii	Eastern Water Dragon	0.85	0.84	0.99	**0.96**	0.31	0.31
Isoodon macrourus	Northern Brown Bandicoot	0.87	**0.85**	0.98	**0.91**	0.38	0.42
Isoodon obesulus	Southern Brown Bandicoot	0.95	**0.93**	0.90	0.82	0.25	0.34
Lalage leucomela	Varied Triller	0.93	**0.92**	0.94	**0.91**	0.36	0.37
Lalage sueurii	White-winged Triller	0.81	0.78	0.94	**0.85**	0.39	0.40
Lampropholis amicula	Friendly Sunskink	0.85	0.82	0.94	0.81	0.24	0.27
Lampropholis caligula	Montane Sunskink	0.99	**0.98**	0.89	0.74	0.20	0.21
Lampropholis delicata	Dark-flecked Garden Sunskink	0.85	**0.85**	1.00	**0.98**	0.31	0.31
Lampropholis guichenoti	Pale-flecked Garden Sunskink	0.83	0.82	0.98	**0.95**	0.31	0.33
Lathamus discolor	Swift Parrot	0.82	0.81	0.85	**0.91**	0.44	0.40
Lechriodus fletcheri	Fletcher’s Frog	0.95	**0.94**	0.96	**0.92**	0.23	0.25
Lepus capensis	Brown Hare	0.84	0.80	0.96	**0.89**	0.29	0.35
Lerista bougainvillii	South-eastern Slider	0.83	0.71	0.76	0.79	0.10	0.32
Lerista muelleri	Wood Mulch-slider	0.00	0.00	0.00	0.00	0.00	0.00
Leucosarcia melanoleuca	Wonga Pigeon	0.83	0.83	0.99	**0.97**	0.28	0.29
Lialis burtonis	Burton’s Snake-lizard	0.86	**0.86**	0.93	**0.91**	0.29	0.26
Lichenostomus melanops	Yellow-tufted Honeyeater	0.83	0.80	0.98	**0.90**	0.24	0.29
Lichmera indistincta	Brown Honeyeater	0.93	**0.93**	0.96	**0.90**	0.35	0.33
Limnodynastes dumerilii	Eastern Banjo Frog	0.76	0.75	0.98	**0.86**	0.39	0.40
Limnodynastes fletcheri	Barking Frog	0.00	0.00	0.00	0.00	0.00	0.00

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Limnodynastes peronii	Brown-striped Frog	0.89	**0.88**	0.99	**0.96**	0.33	0.35
Limnodynastes tasmaniensis	Spotted Grass Frog	0.78	0.76	0.98	**0.86**	0.31	0.36
Limnodynastes terraereginae	Northern Banjo Frog	0.94	**0.91**	0.90	**0.90**	0.33	0.40
Limosa lapponica	Bar-tailed Godwit	0.98	**0.98**	0.89	0.81	0.36	0.36
Liopholis modesta	Eastern Ranges Rock-skink	0.85	0.83	0.71	0.16	0.06	0.00
Liopholis whitii	White’s Skink	0.86	0.83	0.98	**0.90**	0.30	0.36
Litoria booroolongensis	Booroolong Frog	0.00	0.00	0.00	0.00	0.00	0.00
Litoria brevipalmata	Green-thighed Frog	0.89	0.84	0.88	0.74	0.25	0.40
Litoria caerulea	Green Tree Frog	0.91	**0.90**	0.96	**0.89**	0.38	0.38
Litoria chloris	Red-eyed Tree Frog	0.91	**0.90**	0.93	**0.90**	0.31	0.33
Litoria citropa	Blue Mountains Tree Frog	0.89	**0.89**	0.84	0.58	0.18	0.16
Litoria daviesae	Davies’ Tree Frog	0.95	**0.93**	0.92	0.83	0.18	0.25
Litoria dentata	Bleating Tree Frog	0.84	0.84	0.98	**0.94**	0.27	0.28
Litoria fallax	Eastern Dwarf Tree Frog	0.87	**0.86**	0.99	**0.96**	0.31	0.33
Litoria freycineti	Freycinet’s Frog	0.93	**0.92**	0.93	**0.90**	0.33	0.35
Litoria gracilenta	Dainty Green Tree Frog	0.92	**0.91**	0.94	**0.91**	0.26	0.28
Litoria jervisiensis	Jervis Bay Tree Frog	0.93	**0.91**	0.88	**0.86**	0.30	0.39
Litoria latopalmata	Broad-Palmed Frog	0.81	0.80	0.98	**0.91**	0.30	0.32
Litoria lesueuri	Lesueur’s Frog	0.85	**0.85**	0.99	**0.97**	0.34	0.36
Litoria littlejohni	Heath Frog	0.00	0.00	0.00	0.00	0.00	0.00
Litoria nasuta	Rocket Frog	0.94	**0.93**	0.97	**0.89**	0.33	0.36
Litoria nudidigita	Leaf Green River Tree Frog	0.00	0.00	0.00	0.00	0.00	0.00
Litoria pearsoniana	Pearson’s Frog	0.92	**0.92**	0.94	**0.89**	0.36	0.37
Litoria peronii	Peron’s Tree Frog	0.82	0.81	0.99	**0.96**	0.28	0.30
Litoria phyllochroa	Green Stream Frog	0.87	**0.86**	0.98	**0.92**	0.30	0.32
Litoria revelata	Revealed Frog	0.90	0.84	0.87	0.80	0.29	0.46
Litoria rubella	Little Red Tree Frog	0.00	0.00	0.00	0.00	0.00	0.00
Litoria subglandulosa	Glandular Frog	0.98	**0.97**	0.87	0.76	0.05	0.12
Litoria tyleri	Tyler’s Tree Frog	0.90	**0.89**	0.97	**0.88**	0.31	0.33
Litoria verreauxii	Verreaux’s Frog	0.82	0.79	0.98	**0.91**	0.33	0.37
Lophoictinia isura	Square-tailed Kite	0.89	**0.88**	0.91	**0.89**	0.28	0.30
Lopholaimus antarcticus	Topknot Pigeon	0.89	**0.87**	0.97	**0.89**	0.39	0.43
Lophosaurus spinipes	Southern Angle-headed Dragon	0.95	**0.93**	0.94	**0.87**	0.29	0.33
Lygisaurus foliorum	Tree-base Litter-skink	0.89	0.81	0.92	0.83	0.39	0.55
Macropus giganteus	Eastern Grey Kangaroo	0.79	0.78	0.99	**0.97**	0.33	0.34
Macropygia phasianella	Brown Cuckoo-dove	0.88	**0.88**	0.99	**0.97**	0.33	0.33
Malurus cyaneus	Superb Fairy-wren	0.77	0.76	1.00	**0.98**	0.36	0.37
Malurus lamberti	Variegated Fairy-wren	0.85	**0.85**	0.99	**0.96**	0.28	0.30
Malurus melanocephalus	Red-Backed Fairy-wren	0.89	**0.89**	0.98	**0.88**	0.32	0.33
Manorina melanocephala	Noisy Miner	0.84	0.83	0.98	**0.97**	0.31	0.31
Manorina melanophrys	Bell Miner	0.85	0.84	0.99	**0.97**	0.25	0.28
Mastacomys fuscus	Broad-toothed Rat	0.98	**0.98**	0.90	**0.92**	0.29	0.28
Megalurus timoriensis	Tawny Grassbird	0.91	**0.89**	0.93	**0.89**	0.11	0.14
Melanodryas cucullata	Hooded Robin	0.81	0.80	0.91	**0.85**	0.14	0.18

Taxon	**Common name**	**Mean AUC Training**	**Mean AUC Test**	**Mean cBoyce Training**	**Mean cBoyce Test**	**Mean OR Train**	**Mean OR Test**
Meliphaga lewinii	Lewin's Honeyeater	0.86	**0.85**	1.00	**0.99**	0.31	0.32
Melithreptus albogularis	White-throated Honeyeater	0.96	**0.94**	0.93	0.79	0.32	0.39
Melithreptus brevirostris	Brown-headed Honeyeater	0.76	0.72	0.98	**0.91**	0.21	0.28
Melithreptus gularis	Black-chinned Honeyeater	0.89	**0.86**	0.96	**0.87**	0.21	0.26
Melithreptus lunatus	White-naped Honeyeater	0.79	0.79	1.00	**0.99**	0.27	0.28
Melomys cervinipes	Fawn-footed Melomys	0.93	**0.92**	0.98	**0.92**	0.33	0.33
Menetia greyii	Common Dwarf Skink	0.00	0.00	0.00	0.00	0.00	0.00
Menura alberti	Albert's Lyrebird	0.99	**0.98**	0.92	0.73	0.19	0.18
Menura novaehollandiae	Superb Lyrebird	0.85	**0.85**	1.00	**0.98**	0.29	0.29
Merops ornatus	Rainbow Bee-eater	0.85	**0.85**	0.98	**0.93**	0.38	0.39
Microcarbo melanoleucos	Little Pied Cormorant	0.91	**0.91**	0.99	**0.96**	0.34	0.35
Microeca fascinans	Jacky Winter	0.78	0.77	0.99	**0.96**	0.27	0.28
Micronomus norfolkensis	Eastern Freetail-bat	0.80	0.78	0.95	0.82	0.24	0.30
Miniopterus australis	Little Bentwing-bat	0.89	**0.88**	0.98	**0.93**	0.35	0.39
Miniopterus orianae	Northern Bentwing-bat	0.83	0.83	0.99	**0.94**	0.26	0.26
Mixophyes balbus	Stuttering Frog	0.94	**0.94**	0.93	**0.88**	0.37	0.34
Mixophyes fasciolatus	Great Barred Frog	0.90	**0.89**	0.99	**0.95**	0.28	0.31
Mixophyes fleayi	Fleay's Barred Frog	0.00	0.00	0.00	0.00	0.00	0.00
Mixophyes iteratus	Giant Barred Frog	0.93	**0.92**	0.94	**0.91**	0.34	0.36
Monarcha melanopsis	Black-faced Monarch	0.86	**0.86**	0.99	**0.98**	0.28	0.28
Morelia spilota	Carpet Python	0.88	**0.87**	0.99	**0.94**	0.29	0.32
Morelia spilota mcdowelli	Carpet Python	0.95	**0.94**	0.95	**0.86**	0.33	0.37
Morelia spilota spilota	Diamond Python	0.85	0.82	0.89	0.82	0.27	0.41
Morethia boulengeri	Boulenger's Snake-eyed Skink	0.85	0.78	0.90	0.75	0.15	0.27
Mus musculus	House Mouse	0.86	**0.86**	0.98	**0.89**	0.40	0.42
Myiagra cyanoleuca	Satin Flycatcher	0.80	0.79	0.97	**0.89**	0.30	0.31
Myiagra inquieta	Restless Flycatcher	0.77	0.75	0.98	**0.93**	0.25	0.26
Myiagra rubecula	Leaden Flycatcher	0.83	0.83	1.00	**0.98**	0.30	0.29
Myotis macropus	Large-footed Myotis	0.86	**0.85**	0.96	**0.86**	0.28	0.32
Myzomela sanguinolenta	Scarlet Honeyeater	0.88	**0.88**	0.99	**0.98**	0.32	0.32
Nebulifera robusta	Robust Velvet Gecko	0.91	0.82	0.91	**0.88**	0.09	0.32
Neochmia temporalis	Red-browed Finch	0.80	0.80	1.00	**0.99**	0.28	0.28
Neophema pulchella	Turquoise Parrot	0.87	0.83	0.96	**0.89**	0.28	0.34
Nesoptilotis leucotis	White-eared Honeyeater	0.81	0.80	1.00	**0.97**	0.22	0.23
Ninox connivens	Barking Owl	0.80	0.70	0.97	0.74	0.25	0.40
Ninox novaeseelandiae	Southern Boobook	0.82	0.82	1.00	**0.99**	0.29	0.30
Ninox strenua	Powerful Owl	0.86	**0.86**	1.00	**0.98**	0.29	0.29
Notamacropus dorsalis	Black-striped Wallaby	0.89	0.83	0.80	0.71	0.11	0.13
Notamacropus parma	Parma Wallaby	0.94	**0.93**	0.98	**0.89**	0.28	0.31
Notamacropus parryi	Whiptail Wallaby	0.89	**0.85**	0.95	**0.87**	0.24	0.29
Notamacropus rufogriseus	Red-necked Wallaby	0.84	0.84	1.00	**0.99**	0.31	0.31
Notechis scutatus	Tiger Snake	0.86	0.81	0.90	**0.88**	0.35	0.46
Numenius madagascariensis	Eastern Curlew	0.98	**0.97**	0.89	**0.86**	0.32	0.34
Nycticorax caledonicus	Nankeen Night-heron	0.92	**0.90**	0.80	**0.89**	0.40	0.44

Taxon	Common name	Mean AUC Training	Mean AUC Test	Mean cBoyce Training	Mean cBoyce Test	Mean OR Train	Mean OR Test
Nyctophilus bifax	Eastern Long-eared Bat	0.95	**0.93**	0.86	**0.88**	0.35	0.43
Nyctophilus geoffroyi	Lesser Long-eared Bat	0.78	0.78	0.99	**0.92**	0.34	0.35
Nyctophilus gouldi	Gould's Long-eared Bat	0.84	0.84	0.99	**0.96**	0.31	0.30
Oedura tryoni	Southern Spotted Velvet Gecko	0.94	**0.89**	0.91	**0.91**	0.23	0.39
Ophioscincus truncatus	Short-limbed Snake-Skink	0.93	**0.91**	0.95	0.83	0.19	0.25
Origma solitaria	Rockwarbler	0.88	0.83	0.96	0.80	0.18	0.31
Oriolus sagittatus	Olive-backed Oriole	0.83	0.82	0.99	**0.98**	0.31	0.32
Ornithorhynchus anatinus	Platypus	0.80	0.77	0.97	**0.89**	0.31	0.35
Orthonyx temminckii	Australian Logrunner	0.93	**0.93**	0.98	**0.92**	0.32	0.32
Oryctolagus cuniculus	Rabbit	0.77	0.76	0.99	**0.95**	0.30	0.30
Osphranter robustus	Common Wallaroo	0.83	0.79	0.97	**0.88**	0.28	0.34
Ovis aries	Sheep	0.84	0.68	0.89	0.46	0.15	0.22
Ozimops planiceps	South-eastern Free-tailed Bat	0.85	0.79	0.93	0.82	0.16	0.31
Ozimops ridei	Ride's Free-tailed Bat	0.82	0.77	0.95	**0.87**	0.23	0.32
Pachycephala olivacea	Olive Whistler	0.93	**0.91**	0.96	**0.90**	0.25	0.27
Pachycephala pectoralis	Golden Whistler	0.80	0.80	1.00	**0.98**	0.31	0.31
Pachycephala rufiventris	Rufous Whistler	0.78	0.77	1.00	**0.99**	0.33	0.34
Pardalotus punctatus	Spotted Pardalote	0.77	0.77	1.00	**0.99**	0.29	0.31
Pardalotus striatus	Striated Pardalote	0.75	0.74	1.00	**0.98**	0.33	0.35
Parvipsitta pusilla	Little Lorikeet	0.83	0.82	0.99	**0.95**	0.32	0.33
Pelecanus conspicillatus	Australian Pelican	0.94	**0.95**	0.98	**0.94**	0.34	0.34
Perameles nasuta	Long-nosed Bandicoot	0.87	**0.87**	0.99	**0.96**	0.27	0.28
Petauroides volans	Greater Glider	0.89	0.89	0.99	–	–	–
Petaurus australis	Yellow-bellied Glider	0.88	**0.88**	1.00	**0.98**	0.30	0.29
Petaurus breviceps	Sugar Glider	0.84	0.84	1.00	**0.99**	0.28	0.29
Petaurus norfolcensis	Squirrel Glider	0.88	**0.87**	0.96	**0.89**	0.31	0.32
Petrochelidon ariel	Fairy Martin	0.90	**0.86**	0.93	**0.86**	0.33	0.38
Petrochelidon nigricans	Tree Martin	0.83	0.80	0.97	**0.86**	0.35	0.38
Petrogale penicillata	Brush-tailed Rock-wallaby	0.92	**0.92**	0.97	**0.92**	0.34	0.36
Petroica boodang	Scarlet Robin	0.79	0.76	0.99	**0.90**	0.39	0.46
Petroica goodenovii	Red-capped Robin	0.87	0.82	0.89	**0.91**	0.18	0.32
Petroica phoenicea	Flame Robin	0.87	**0.87**	0.99	**0.94**	0.29	0.30
Petroica rosea	Rose Robin	0.85	0.84	0.99	**0.96**	0.34	0.35
Phalacrocorax carbo	Great Cormorant	0.93	**0.91**	0.97	**0.90**	0.34	0.37
Phalacrocorax sulcirostris	Little Black Cormorant	0.93	**0.91**	0.97	**0.90**	0.34	0.37
Phalacrocorax varius	Pied Cormorant	0.95	**0.95**	0.95	**0.88**	0.35	0.33
Phaps chalcoptera	Common Bronzewing	0.80	0.77	0.99	**0.92**	0.25	0.29
Phaps elegans	Brush Bronzewing	0.91	**0.90**	0.97	0.83	0.15	0.18
Phascogale tapoatafa	Brush-tailed Phascogale	0.92	**0.90**	0.95	**0.88**	0.26	0.28
Phascolarctos cinereus	Koala	0.88	**0.88**	1.00	**0.99**	0.33	0.32
Philemon citreogularis	Little Friarbird	0.85	0.80	0.93	**0.87**	0.41	0.46
Philemon corniculatus	Noisy Friarbird	0.79	0.78	1.00	**0.99**	0.29	0.30
Philoria loveridgei	Loveridge's Frog	0.95	**0.94**	0.89	NA	0.32	0.24
Philoria sphagnicola	Sphagnum Frog	0.98	**0.97**	0.89	0.78	0.25	0.36

Taxon	Common name	Mean AUC Training	Mean AUC Test	Mean cBoyce Training	Mean cBoyce Test	Mean OR Train	Mean OR Test
Phoniscus papuensis	Golden-tipped Bat	0.92	**0.91**	0.94	**0.91**	0.32	0.36
Phylidonyris niger	White-cheeked Honeyeater	0.93	**0.92**	0.95	**0.91**	0.37	0.38
Phylidonyris novaehollandiae	New Holland Honeyeater	0.87	**0.87**	0.99	**0.95**	0.30	0.28
Phylidonyris pyrrhoptera	Crescent Honeyeater	0.94	**0.86**	0.90	**0.97**	0.24	0.52
Phyllurus platurus	Broad-tailed Gecko	0.86	0.81	0.97	0.84	0.13	0.22
Pitta versicolor	Noisy Pitta	0.92	**0.91**	0.97	**0.89**	0.31	0.35
Planigale maculata	Common Planigale	0.91	**0.87**	0.89	**0.93**	0.22	0.33
Platycercus elegans	Crimson Rosella	0.78	0.77	0.99	**0.98**	0.30	0.31
Platycercus eximius	Eastern Rosella	0.82	0.80	0.99	**0.92**	0.29	0.33
Platyplectrum ornatum	Ornate Burrowing Frog	0.90	**0.88**	0.94	**0.87**	0.37	0.39
Plectorhyncha lanceolata	Striped Honeyeater	0.93	**0.92**	0.93	**0.91**	0.38	0.37
Podargus ocellatus	Marbled Frogmouth	0.97	**0.98**	0.89	**0.86**	0.13	0.13
Podargus strigoides	Tawny Frogmouth	0.82	0.82	1.00	**0.98**	0.31	0.33
Pogona barbata	Bearded Dragon	0.87	0.84	0.96	**0.89**	0.37	0.42
Pomatostomus superciliosus	White-browed Babbler	0.93	**0.91**	0.95	**0.94**	0.07	0.13
Pomatostomus temporalis	Grey-crowned Babbler	0.92	**0.93**	0.98	**0.93**	0.31	0.30
Porphyrio porphyrio	Purple Swamphen	0.92	**0.91**	0.96	**0.90**	0.31	0.31
Potorous tridactylus	Long-nosed Potoroo	0.92	**0.91**	0.93	**0.91**	0.35	0.32
Pseudechis porphyriacus	Red-bellied Black Snake	0.80	0.79	0.98	**0.95**	0.23	0.24
Pseudemoia entrecasteauxii	Southern Grass Skink	0.96	**0.95**	0.89	**0.88**	0.36	0.42
Pseudemoia spenceri	Trunk-climbing Cool-Skink	0.96	**0.91**	0.87	**0.89**	0.24	0.52
Pseudocheirus peregrinus	Common Ringtail Possum	0.85	**0.85**	0.99	**0.98**	0.33	0.34
Pseudomys fumeus	Smokey Mouse	0.97	**0.95**	0.85	**0.92**	0.18	0.28
Pseudomys gracilicaudatus	Eastern Chestnut Mouse	0.95	**0.87**	0.92	**0.89**	0.24	0.44
Pseudomys novaehollandiae	New Holland Mouse	0.87	**0.87**	0.91	**0.91**	0.31	0.36
Pseudomys oralis	Hastings River Mouse	0.93	**0.94**	0.98	**0.87**	0.06	0.04
Pseudonaja textilis	Common Brown Snake	0.80	0.74	0.93	**0.85**	0.45	0.53
Pseudophryne australis	Red-crowned Toadlet	0.93	**0.92**	0.91	**0.92**	0.32	0.37
Pseudophryne bibronii	Bibron’s Toadlet	0.90	**0.85**	0.91	**0.88**	0.40	0.46
Pseudophryne coriacea	Red-backed Toadlet	0.90	**0.90**	0.99	**0.97**	0.26	0.27
Psophodes olivaceus	Eastern Whipbird	0.85	0.84	1.00	**0.99**	0.30	0.31
Pteropus alecto gouldii	Black Flying-fox	0.95	**0.95**	0.75	0.71	0.13	0.26
Pteropus poliocephalus	Grey-headed Flying-fox	0.90	**0.90**	0.99	**0.95**	0.32	0.33
Pteropus scapulatus	Little Red Flying-fox	0.89	**0.87**	0.93	**0.85**	0.30	0.38
Ptilinopus magnificus	Wompoo Fruit-dove	0.94	**0.94**	0.98	**0.91**	0.32	0.35
Ptilinopus regina	Rose-Crowned Fruit-dove	0.96	**0.95**	0.94	**0.85**	0.33	0.37
Ptilinopus superbus	Superb Fruit-dove	0.94	**0.87**	0.87	**0.94**	0.34	0.45
Ptilonorhynchus violaceus	Satin Bowerbird	0.84	0.83	0.99	**0.98**	0.32	0.33
Ptiloris paradiseus	Paradise Riflebird	0.95	**0.95**	0.97	**0.90**	0.29	0.28
Ptilotula fusca	Fuscous Honeyeater	0.82	0.81	0.98	**0.92**	0.24	0.27
Ptilotula penicillata	White-plumed Honeyeater	0.84	0.83	0.97	**0.87**	0.26	0.26
Purnella albifrons	White-fronted Honeyeater	0.00	0.00	0.00	0.00	0.00	0.00
Pycnoptilus floccosus	Pilotbird	0.92	**0.90**	0.97	**0.89**	0.24	0.25
Pygopus lepidopodus	Common Scaly-foot	0.87	0.82	0.72	**0.90**	0.45	0.55

Taxon	Common name	Mean AUC Training	Mean AUC Test	Mean cBoyce Training	Mean cBoyce Test	Mean OR Train	Mean OR Test
Rankinia diemensis	Mountain Dragon	0.92	**0.86**	0.93	**0.91**	0.22	0.33
Rattus fuscipes	Bush Rat	0.87	**0.88**	1.00	**0.98**	0.30	0.30
Rattus lutreolus	Swamp Rat	0.91	**0.89**	0.97	**0.89**	0.40	0.44
Rattus norvegicus	Brown Rat	0.00	0.00	0.00	0.00	0.00	0.00
Rattus rattus	Black Rat	0.89	**0.87**	0.94	**0.85**	0.42	0.44
Rattus tunneyi	Pale Field-rat	0.95	**0.91**	0.92	**0.95**	0.31	0.39
Rhinella marina	Cane Toad	0.98	**0.98**	0.90	0.79	0.35	0.35
Rhinolophus megaphyllus	Eastern Horseshoe Bat	0.86	**0.85**	0.98	**0.92**	0.35	0.36
Rhipidura albiscapa	Grey Fantail	0.79	0.78	1.00	**0.99**	0.30	0.31
Rhipidura leucophrys	Willie Wagtail	0.82	0.81	0.98	**0.96**	0.34	0.34
Rhipidura rufifrons	Rufous Fantail	0.88	**0.88**	0.99	**0.98**	0.31	0.31
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	0.82	0.77	0.89	**0.86**	0.27	0.29
Saiphos equalis	Three-toed Skink	0.87	**0.86**	0.99	**0.96**	0.30	0.31
Saltuarius cornutus	Northern Leaf-tailed Gecko	0.89	0.83	0.82	**0.88**	0.24	0.29
Saltuarius swaini	Southern Leaf-tailed Gecko	0.87	**0.86**	0.93	0.78	0.31	0.34
Saproscincus challengeri	Orange-tailed Shadeskink	0.95	**0.95**	0.97	**0.90**	0.31	0.33
Saproscincus mustelinus	Weasel Skink	0.89	**0.89**	0.98	**0.92**	0.34	0.33
Saproscincus rosei	Highland Forest Skink	0.92	**0.90**	0.93	**0.90**	0.27	0.32
Saproscincus spectabilis	Gully Skink	0.94	**0.91**	0.89	**0.89**	0.33	0.38
Scoteanax rueppellii	Greater Broad-nosed Bat	0.84	0.84	0.98	**0.92**	0.27	0.29
Scotorepens balstoni	Inland Broad-nosed Bat	0.00	0.00	0.00	0.00	0.00	0.00
Scotorepens greyii	Little Broad-nosed Bat	0.93	**0.92**	0.87	**0.94**	0.12	0.20
Scotorepens orion	Eastern Broad-nosed Bat	0.84	0.83	0.99	**0.95**	0.28	0.29
Scythrops novaehollandiae	Channel-billed Cuckoo	0.83	0.83	0.99	**0.96**	0.25	0.24
Sericornis citreogularis	Yellow-throated Scrubwren	0.91	**0.90**	0.99	**0.94**	0.30	0.32
Sericornis frontalis	White-browed Scrubwren	0.82	0.81	1.00	**0.99**	0.31	0.32
Sericornis magnirostra	Large-billed Scrubwren	0.91	**0.90**	0.99	**0.95**	0.33	0.37
Sericulus chrysocephalus	Regent Bowerbird	0.90	**0.88**	0.98	**0.89**	0.26	0.33
Silvascincus murrayi	Murray's Skink	0.94	**0.94**	0.97	**0.93**	0.27	0.27
Smicrornis brevirostris	Weebill	0.81	0.80	0.97	**0.92**	0.25	0.28
Sminthopsis crassicaudata	Fat-tailed Dunnart	0.00	0.00	0.00	0.00	0.00	0.00
Sminthopsis murina	Common Dunnart	0.84	0.81	0.95	**0.86**	0.32	0.37
Sphecotheres vieilloti	Australasian Figbird	0.94	**0.94**	0.94	**0.88**	0.32	0.34
Stagonopleura bella	Beautiful Firetail	0.90	0.84	0.92	**0.95**	0.23	0.35
Stipiturus malachurus	Southern Emu-wren	0.97	**0.95**	0.94	**0.85**	0.32	0.37
Stizoptera bichenovii	Double-barred Finch	0.83	0.77	0.91	**0.92**	0.30	0.38
Strepera graculina	Pied Currawong	0.79	0.79	1.00	**0.99**	0.31	0.32
Strepera versicolor	Grey Currawong	0.89	**0.87**	0.96	**0.88**	0.28	0.31
Sus scrofa	Pig	0.84	**0.86**	0.94	**0.88**	0.38	0.37
Syconycteris australis	Common Blossom-bat	0.97	**0.96**	0.93	**0.92**	0.18	0.23
Symposiachrus trivirgatus	Spectacled Monarch	0.91	**0.91**	0.97	**0.90**	0.34	0.32
Tachybaptus novaehollandiae	Australasian Grebe	0.86	0.84	0.97	**0.91**	0.33	0.35
Tachyglossus aculeatus	Short-Beaked Echidna	0.80	0.79	0.99	**0.96**	0.32	0.33
Thylogale stigmatica	Red-legged Pademelon	0.94	**0.92**	0.92	**0.92**	0.29	0.31

Taxon	Common name	Mean AUC Training	Mean AUC Test	Mean cBoyce Training	Mean cBoyce Test	Mean OR Train	Mean OR Test
Thylogale thetis	Red-necked Pademelon	0.92	**0.91**	0.98	**0.93**	0.26	0.29
Tiliqua scincoides	Eastern Blue-tongue	0.89	**0.86**	0.96	**0.90**	0.35	0.38
Todiramphus macleayii	Forest Kingfisher	0.93	**0.94**	0.94	**0.85**	0.22	0.25
Todiramphus sanctus	Sacred Kingfisher	0.82	0.82	1.00	**0.98**	0.33	0.33
Tregellasia capito	Pale-yellow Robin	0.93	**0.92**	0.97	**0.91**	0.25	0.29
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet	0.92	**0.91**	0.98	**0.94**	0.31	0.34
Trichoglossus haematodus	Rainbow Lorikeet	0.88	**0.88**	0.99	**0.98**	0.25	0.24
Trichosurus caninus	Northern Mountain Brushtail Possum	0.91	**0.91**	0.99	**0.96**	0.32	0.32
Trichosurus cunninghami	Southern Mountain Brushtail Possum	0.92	**0.91**	0.93	**0.93**	0.25	0.26
Trichosurus vulpecula	Common Brushtail Possum	0.77	0.76	1.00	**0.98**	0.27	0.28
Tringa nebularia	Common Greenshank	0.98	**0.98**	0.90	0.82	0.29	0.32
Tropidechis carinatus	Rough-scaled Snake	0.94	**0.92**	0.85	**0.88**	0.38	0.47
Turdus merula	Blackbird	0.84	0.82	0.96	**0.85**	0.21	0.23
Turnix melanogaster	Black-breasted Button-quail	0.00	0.00	0.00	0.00	0.00	0.00
Turnix varius	Painted Button-quail	0.84	0.82	0.98	**0.92**	0.27	0.33
Tyto alba	Barn Owl	0.85	0.79	0.95	**0.89**	0.31	0.39
Tyto longimembris	Eastern Grass Owl	0.00	0.00	0.00	0.00	0.00	0.00
Tyto novaehollandiae	Masked Owl	0.86	**0.85**	0.99	**0.97**	0.26	0.28
Tyto tenebricosa	Sooty Owl	0.91	**0.91**	1.00	**0.98**	0.27	0.28
Underwoodisaurus milii	Barking Gecko	0.91	**0.90**	0.88	0.81	0.20	0.19
Uperoleia fusca	Dusky Toadlet	0.85	**0.85**	0.97	**0.88**	0.29	0.30
Uperoleia laevigata	Smooth Toadlet	0.80	0.78	0.98	**0.89**	0.37	0.41
Uperoleia tyleri	Tyler's Toadlet	0.94	**0.88**	0.89	**0.98**	0.29	0.52
Uvidicolus sphyrurus	Border Thick-tailed Gecko	0.96	**0.88**	0.82	0.83	0.11	0.35
Vanellus miles	Masked Lapwing	0.86	**0.86**	0.98	**0.95**	0.39	0.41
Varanus gouldii	Gould's Goanna	0.93	**0.88**	0.86	**0.94**	0.39	0.45
Varanus rosenbergi	Heath Monitor	0.89	0.77	0.97	0.81	0.10	0.29
Varanus varius	Lace Monitor	0.87	**0.87**	0.99	**0.97**	0.32	0.33
Vermicella annulata	Bandy-bandy	0.84	0.78	0.90	**0.92**	0.26	0.37
Vespadelus darlingtoni	Large Forest Bat	0.87	**0.86**	0.99	**0.95**	0.31	0.34
Vespadelus pumilus	Eastern Forest Bat	0.89	**0.89**	0.99	**0.95**	0.33	0.34
Vespadelus regulus	Southern Forest Bat	0.86	0.84	0.99	**0.96**	0.26	0.30
Vespadelus troughtoni	Eastern Cave Bat	0.80	0.72	0.87	0.81	0.21	0.24
Vespadelus vulturnus	Little Forest Bat	0.82	0.81	1.00	**0.98**	0.26	0.27
Vombatus ursinus	Bare-nosed Wombat	0.88	**0.87**	0.99	**0.95**	0.33	0.35
Vulpes vulpes	Fox	0.79	0.79	0.99	**0.97**	0.28	0.29
Wallabia bicolor	Swamp Wallaby	0.81	0.81	1.00	**0.99**	0.30	0.30
Zoothera heinei	Russet-tailed Thrush	0.92	**0.92**	0.89	**0.92**	0.38	0.35
Zoothera lunulata	Bassian Thrush	0.86	0.84	0.96	**0.85**	0.32	0.36
Zosterops lateralis	Silvereye	0.79	0.79	1.00	**0.98**	0.34	0.34

Table 27. Covariate importance for all 446 fitted Maxent models

Number of models is the number for which each covariate contributed greater than 5%

Covariate	Number of Models	Min Contribution	Mean Contribution	Max Contribution
ce_radann90	88	0	3.5	71.7
COG_2000m90	185	0	5.0	93.3
ct_temp_maxsum90	37	0	1.4	48.1
ct_tempann90	198	0	8.4	63.7
ct_tempmtcp90	262	0	10.7	87.8
ct_tempmtwp90	113	0	4.1	63.5
ct_tempseas90	187	0	8.4	78.9
cw_etaaann90	109	0	3.7	52.4
cw_precipann90	105	0	3.4	68.6
cw_precipdp90	138	0	3.9	32.4
cw_precipseas90	206	0	6.3	48.1
lf_cti90	16	0	0.9	12.7
lf_rough0100_90	311	0	11.2	84.9
NDVI_7median_NS_90	261	0	12.3	77.9
sp_awc_90	13	0	0.6	13.3
sp_cly_90	16	0	1.1	32.8
sp_slt_90	103	0	3.2	40.0
sp_snd_90	18	0	1.4	58.1

7.2.2.1 Impact of the FMIP Baseline Project 2 spatio-temporal filter

A critical factor determining the outcome of Maxent models is the nature of the occurrence data used to fit a model. These data should represent a least-biased sample of the full range of environments in which the taxon is known to occur. Unfortunately, the requirements of the current project necessitated the application of a defined spatial and temporal filter on the available occurrence data for fitting fauna ENMs. A demonstration of the implications of this impact is provided in Appendix 4. The impact of the filtering on numbers of occurrence records available for a given taxon (Figure 20a) varied widely and depended on the fraction of the full distribution found within the current project's geographical domain (the four RFA regions), and the spread of collection dates between 1991 and 1998. The overall trend was for a sharp decline in available records for most taxa, although generally the spatial filter was more constraining. The filter also altered the breadth of the environmental niche captured by the occurrence records (Figure 20b).

7.2.2.2 Fauna BRT models

BRT model fitting had a mixed outcome. Across the six survey methods, 713 prospective models were identified (Table 28). However, using a filter of 0.01 for prevalence (fraction of presence records relative to the total number of records, also referred to as 'naïve occupancy' in the context of presence-absence modelling) reduced the number of potential models to 362. Attempts to fit models were successful for 286 taxon-method combinations, while 76 of the 362 potential models failed to converge to a solution.

Many prospective models for the 427 taxa with some presence records in at least one survey method could not be fitted due to the low number of presence records. Prevalence varied widely from a low of 0.0009 to a high of 1. Very low and very high prevalence or naïve occupancy values presents difficulties for model fitting using the BRT method, frequently leading to a fail to converge to a solution. This is the explanation for the 76 failed fits after a preliminary filtering of data with low prevalence values.

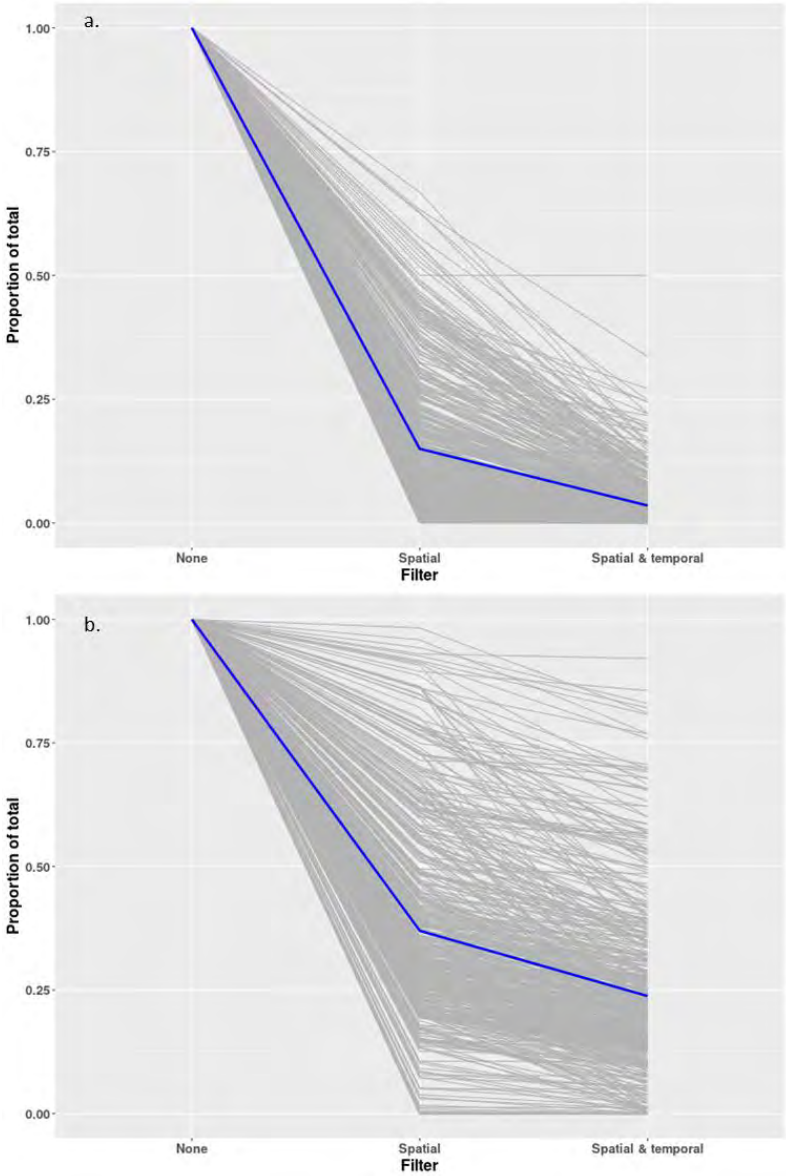


Figure 20. The impact of the filtering on (a) numbers of occurrence records and (b) coverage of environmental conditions in the fauna Maxent models

"None" represents the number of records or environmental coverage of all available records from the Atlas of Living Australia for a taxon. "Spatial" is the fraction of all records or proportion of full environmental coverage remaining when ALA records are restricted to the combined RFA regions forming the spatial extent of this study "Spatial & temporal" refers to the addition of a temporal filter to the spatial filter so that only records from ALA falling within the study extent and collected between 1991 and 1998 are considered

Table 28. Success rate fitting BRT models to fauna species

Potential models were those with at least one presence record for a survey method. Attempted values represent the number of taxa in each survey method with prevalence (naïve occupancy) values > 0.01. Success and Failure values show the number of attempted model fits which converged to a solution and those which did not.

Method	Potential	Attempted	Success	Failure
Diurnal Birds	224	152	147	5
Diurnal Herps	137	58	54	4
Transect Spotlighting	154	74	36	38
Harp Trapping	28	23	18	5
Hair Tubes	39	23	14	9
Nocturnal Owl Call Playback	131	32	17	15
TOTAL	713	362	286	76

Based on AUC scores, fitted BRT models varied widely in quality (minimum AUC of 0.578 to a maximum of 0.994; Table 29). The distribution of Test AUC values varied across the six survey methods (Figure 21). The majority of fitted models returned AUC values greater than 0.75 for Diurnal Bird surveys, Diurnal Herpetofauna surveys, Transect Spotlighting and Harp Trapping. However, models fitted to hair tube and Nocturnal Owl Call Playback data had a majority of models return AUC values less than 0.75.

Our expert team reviewed 281 BRT faunal models representing combinations of species and survey method to determine if they were a good fit to contemporary understanding of the range and habitat suitability of each species in the study region. Only 28% of the species–method model combinations were judged satisfactory or better, and only one amphibian model (6% of 16) was judged satisfactory. Reptile models were scored most highly (47% of model combinations judged satisfactory or better), with mammals (18%) and birds (29%) in between.

Covariate importance for successful BRT models was assessed by counting the number of models for each survey method that returned a covariate importance value greater than 5% (Table 30). The importance of variables was not consistent across all survey methods for a given species. Correlative models such as the BRT models presented here will show different combinations of important covariates whenever the number and distribution of occurrence data change, or different covariates are used. Inferring causality from coefficient values or importance values for correlative models is unsound (Mac Nally 2002). It was therefore not possible to identify any set of covariates as universal prospective 'drivers' of the probability of occurrence computed by this collection of BRT presence–absence models.

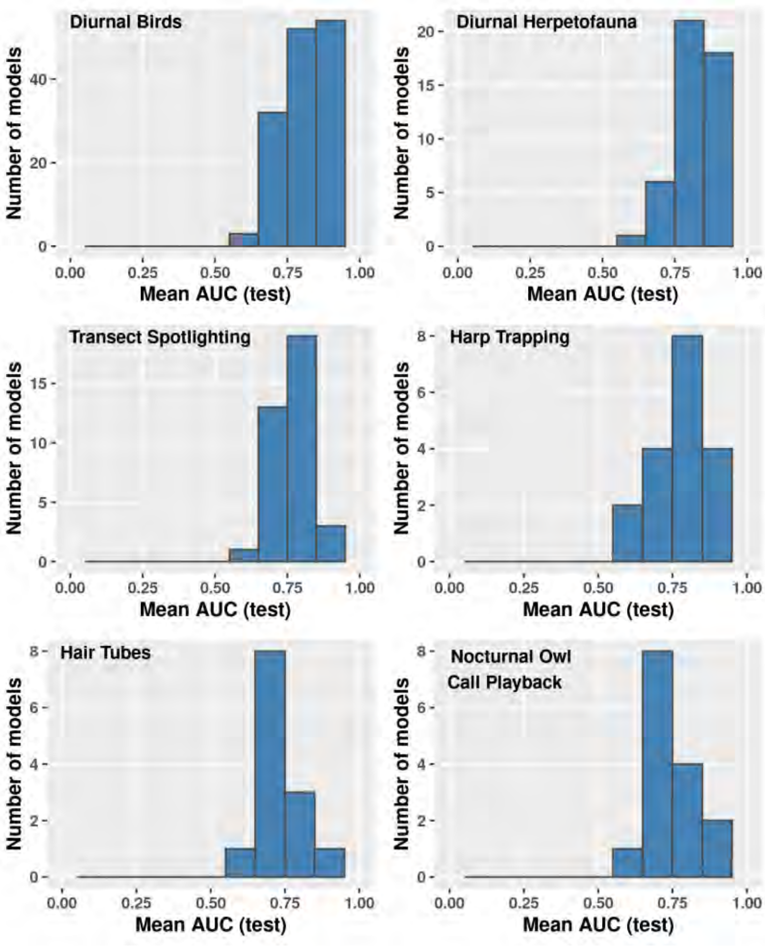


Figure 21. The distribution of Test AUC values for fauna BRT models fitted with records from the six survey methods

Table 29. Mean and standard error (SE) Test AUC scores for BRT models fitted successfully for 252 taxa by survey method

'Herps' = reptiles and frogs; NOCPB = nocturnal call-playback

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Acanthiza pusilla	0.722	0.009	-	-	-	-	-	-	-	-	-	-
Acanthiza reguloides	0.842	0.010	-	-	-	-	-	-	-	-	-	-
Acanthiza lineata	0.715	0.014	-	-	-	-	-	-	-	-	-	-
Acanthiza nana	0.784	0.029	-	-	-	-	-	-	-	-	-	-
Acanthorhynchus tenuirostris	0.746	0.009	-	-	-	-	-	-	-	-	-	-
Accipiter fasciatus	0.703	0.039	-	-	-	-	-	-	-	-	-	-
Accipiter novaehollandiae	0.782	0.029	-	-	-	-	-	-	-	-	-	-
Accipiter cirrocephalus	0.719	0.041	-	-	-	-	-	-	-	-	-	-
Acritoscincus platynotus	-	-	0.798	0.064	-	-	-	-	-	-	-	-
Acrobates pygmaeus	-	-	-	-	0.675	0.045	-	-	-	-	-	-
Adelotus brevis	-	-	0.822	0.034	-	-	-	-	-	-	-	-
Aegotheles cristatus	0.769	0.016	-	-	0.578	0.029	-	-	-	-	-	-
Aepyprymnus rufescens	-	-	-	-	-	-	-	-	0.778	0.047	-	-
Ailuroedus crassirostris	0.852	0.013	-	-	-	-	-	-	-	-	-	-
Alectura lathami	0.819	0.017	-	-	-	-	-	-	-	-	-	-
Alisterus scapularis	0.794	0.011	-	-	-	-	-	-	-	-	-	-
Amalosia lesueurii	-	-	0.991	0.003	-	-	-	-	-	-	-	-
Amphibolurus muricatus	-	-	0.775	0.024	-	-	-	-	-	-	-	-
Anas superciliosa	0.853	0.042	-	-	-	-	-	-	-	-	-	-
Anilios nigrescens	-	-	0.826	0.018	-	-	-	-	-	-	-	-
Anomalopus leuckartii	-	-	0.962	0.017	-	-	-	-	-	-	-	-
Antechinus flavipes	-	-	-	-	-	-	-	-	0.812	0.032	-	-
Antechinus stuartii	-	-	-	-	-	-	-	-	0.860	0.020	-	-
Anthochaera lunulata	0.917	0.016	-	-	-	-	-	-	-	-	-	-
Anthochaera carunculata	0.853	0.009	-	-	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Aquila audax	0.731	0.027	-	-	-	-	-	-	-	-	-	-
Artamus cyanopterus	0.776	0.023	-	-	-	-	-	-	-	-	-	-
Austronomus australis	-	-	-	-	0.832	0.055	0.839	0.057	-	-	-	-
Aviceda subcristata	0.716	0.066	-	-	-	-	-	-	-	-	-	-
Bellatorias major	-	-	0.813	0.049	-	-	-	-	-	-	-	-
Cacatua galerita	0.831	0.016	-	-	-	-	-	-	-	-	-	-
Cacomantis variolosus	0.772	0.022	-	-	-	-	-	-	-	-	-	-
Cacomantis flabelliformis	0.739	0.011	-	-	-	-	-	-	-	-	-	-
Cacomantis pallidus	0.621	0.069	-	-	-	-	-	-	-	-	-	-
Cacophis krefftii	-	-	0.777	0.032	-	-	-	-	-	-	-	-
Caligavis chrysops	0.847	0.010	-	-	-	-	-	-	-	-	-	-
Callocephalon fimbriatum	0.876	0.011	-	-	-	-	-	-	-	-	-	-
Calyptorhynchus lathami	0.734	0.012	-	-	-	-	-	-	-	-	-	-
Zanda funerea	0.703	0.019	-	-	-	-	-	-	-	-	-	-
Calyptotis ruficauda	-	-	0.922	0.008	-	-	-	-	-	-	-	-
Calyptotis scutirostrum	-	-	0.951	0.004	-	-	-	-	-	-	-	-
Canis familiaris	-	-	-	-	-	-	-	-	0.725	0.061	0.860	0.051
Carlia vivax	-	-	0.930	0.034	-	-	-	-	-	-	-	-
Carterornis leucotis	0.919	0.042	-	-	-	-	-	-	-	-	-	-
Centropus phasianinus	0.833	0.019	-	-	-	-	-	-	-	-	-	-
Chalcites lucidus	0.862	0.009	-	-	-	-	-	-	-	-	-	-
Chalcophaps indica	0.853	0.021	-	-	-	-	-	-	-	-	-	-
Chalinolobus dwyeri	-	-	-	-	-	-	0.878	0.030	-	-	-	-
Chalinolobus gouldii	-	-	-	-	-	-	0.628	0.024	-	-	-	-
Chalinolobus morio	-	-	-	-	-	-	0.760	0.012	-	-	-	-
Cinclosoma punctatum	0.757	0.021	-	-	-	-	-	-	-	-	-	-
Climacteris picumnus	0.885	0.034	-	-	-	-	-	-	-	-	-	-
Climacteris erythrops	0.819	0.009	-	-	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Colluricincla harmonica	0.731	0.013	-	-	-	-	-	-	-	-	-	-
Colluricincla megarhyncha	0.936	0.016	-	-	-	-	-	-	-	-	-	-
Columba leucomela	0.896	0.011	-	-	-	-	-	-	-	-	-	-
Concinnia martini	-	-	0.892	0.012	-	-	-	-	-	-	-	-
Concinnia tenuis	-	-	0.794	0.015	-	-	-	-	-	-	-	-
Coracina novaehollandiae	0.688	0.011	-	-	-	-	-	-	-	-	-	-
Coracina papuensis	0.771	0.016	-	-	-	-	-	-	-	-	-	-
Coracina tenuirostris	0.726	0.010	-	-	-	-	-	-	-	-	-	-
Corcorax melanorhamphos	0.801	0.027	-	-	-	-	-	-	-	-	-	-
Cormobates leucophaea	0.874	0.018	-	-	-	-	-	-	-	-	-	-
Corvus coronoides	0.781	0.015	-	-	-	-	-	-	-	-	-	-
Corvus mellori	0.931	0.023	-	-	-	-	-	-	-	-	-	-
Corvus orru	0.857	0.017	-	-	-	-	-	-	-	-	-	-
Corvus tasmanicus	0.885	0.010	-	-	-	-	-	-	-	-	-	-
Cracticus nigrogularis	0.897	0.015	-	-	-	-	-	-	-	-	-	-
Cracticus torquatus	0.725	0.010	-	-	-	-	-	-	-	-	-	-
Crinia signifera	-	-	0.782	0.020	0.689	0.060	-	-	-	-	-	-
Cryptophis nigrescens	-	-	0.668	0.047	-	-	-	-	-	-	-	-
Ctenotus robustus	-	-	0.845	0.039	-	-	-	-	-	-	-	-
Ctenotus taeniolatus	-	-	0.928	0.009	-	-	-	-	-	-	-	-
Dacelo novaeguineae	0.718	0.014	-	-	0.796	0.072	-	-	-	-	-	-
Daphoenositta chrysoptera	0.730	0.010	-	-	-	-	-	-	-	-	-	-
Dasyurus maculatus	-	-	-	-	-	-	-	-	0.730	0.026	-	-
Demansia psammophis	-	-	0.777	0.020	-	-	-	-	-	-	-	-
Dicaeum hirundinaceum	0.725	0.009	-	-	-	-	-	-	-	-	-	-
Dicrurus bracteatus	0.896	0.014	-	-	-	-	-	-	-	-	-	-
Diporiphora nobbi	-	-	0.915	0.020	-	-	-	-	-	-	-	-
Egernia cunninghami	-	-	0.866	0.035	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Egernia mcpheei	-	-	0.745	0.023	-	-	-	-	-	-	-	-
Egernia saxatilis	-	-	0.850	0.035	-	-	-	-	-	-	-	-
Entomyzon cyanotis	0.937	0.024	-	-	-	-	-	-	-	-	-	-
Eopsaltria australis	0.681	0.010	-	-	-	-	-	-	-	-	-	-
Eudynamys orientalis	0.856	0.022	-	-	-	-	-	-	-	-	-	-
Eulamprus heatwolei	-	-	0.961	0.003	-	-	-	-	-	-	-	-
Eulamprus kosciuskoi	-	-	0.976	0.006	-	-	-	-	-	-	-	-
Eulamprus quoyii	-	-	0.797	0.013	-	-	-	-	-	-	-	-
Eurostopodus mystacalis	0.722	0.045	-	-	0.765	0.065	-	-	-	-	-	-
Eurystomus orientalis	0.729	0.030	-	-	-	-	-	-	-	-	-	-
Falco hypoleucos	0.988	0.005	-	-	-	-	-	-	-	-	-	-
Falcunculus frontatus	0.649	0.047	-	-	-	-	-	-	-	-	-	-
Falsistrellus tasmaniensis	-	-	-	-	-	-	0.786	0.020	-	-	-	-
Felis catus	-	-	-	-	0.847	0.041	-	-	0.664	0.076	-	-
Geopelia humeralis	0.893	0.027	-	-	-	-	-	-	-	-	-	-
Geopelia striata	0.912	0.018	-	-	-	-	-	-	-	-	-	-
Gerygone mouki	0.908	0.008	-	-	-	-	-	-	-	-	-	-
Gerygone olivacea	0.838	0.016	-	-	-	-	-	-	-	-	-	-
Glossopsitta concinna	0.842	0.020	-	-	-	-	-	-	-	-	-	-
Gymnorhina tibicen	0.819	0.019	-	-	-	-	-	-	-	-	-	-
Hemiaspis signata	-	-	0.711	0.033	-	-	-	-	-	-	-	-
Hemiergis decresiensis	-	-	0.911	0.041	-	-	-	-	-	-	-	-
Hirundapus caudacutus	0.634	0.018	-	-	-	-	-	-	-	-	-	-
Hirundo neoxena	0.739	0.032	-	-	-	-	-	-	-	-	-	-
Intellagama lesueurii	-	-	0.777	0.052	-	-	-	-	-	-	-	-
Isoodon macrourus	-	-	-	-	-	-	-	-	0.619	0.040	-	-
Lalage leucomela	0.815	0.047	-	-	-	-	-	-	-	-	-	-
Lampropholis amicula	-	-	0.852	0.039	-	-	-	-	-	-	-	-

Taxon	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Lampropholis delicata	-	-	0.766	0.008	-	-	-	-	-	-	-	-
Lampropholis guichenoti	-	-	0.903	0.010	-	-	-	-	-	-	-	-
Lechriodus fletcheri	-	-	-	-	0.847	0.041	-	-	-	-	-	-
Lerista bougainvillii	-	-	0.895	0.019	-	-	-	-	-	-	-	-
Leucosarcia melanoleuca	0.743	0.008	-	-	-	-	-	-	-	-	-	-
Lichenostomus melanops	0.892	0.019	-	-	-	-	-	-	-	-	-	-
Limnodynastes dumerilii	-	-	-	-	0.704	0.060	-	-	-	-	-	-
Limnodynastes peronii	-	-	0.797	0.039	-	-	-	-	-	-	-	-
Liopholis whitii	-	-	0.905	0.032	-	-	-	-	-	-	-	-
Litoria dentata	-	-	0.730	0.059	-	-	-	-	-	-	-	-
Litoria fallax	-	-	0.790	0.059	-	-	-	-	-	-	-	-
Litoria latopalmata	-	-	0.790	0.059	-	-	-	-	-	-	-	-
Litoria lesueuri	-	-	0.802	0.020	0.842	0.027	-	-	-	-	-	-
Litoria peronii	-	-	-	-	0.842	0.027	-	-	-	-	-	-
Litoria verreauxii	-	-	-	-	0.915	0.040	-	-	-	-	-	-
Lopholaimus antarcticus	0.852	0.014	-	-	-	-	-	-	-	-	-	-
Macropus giganteus	-	-	-	-	0.779	0.062	-	-	-	-	-	-
Macropygia phasianella	0.854	0.009	-	-	-	-	-	-	-	-	-	-
Malurus assimilis	0.775	0.006	-	-	-	-	-	-	-	-	-	-
Malurus cyaneus	0.742	0.017	-	-	-	-	-	-	-	-	-	-
Malurus melanocephalus	0.916	0.015	-	-	-	-	-	-	-	-	-	-
Manorina melanophrys	0.841	0.010	-	-	-	-	-	-	-	-	-	-
Manorina melanocephala	0.846	0.020	-	-	-	-	-	-	-	-	-	-
Meliphaga lewinii	0.899	0.005	-	-	-	-	-	-	-	-	-	-
Melithreptus brevirostris	0.825	0.018	-	-	-	-	-	-	-	-	-	-
Melithreptus albogularis	0.947	0.018	-	-	-	-	-	-	-	-	-	-
Melithreptus lunatus	0.688	0.013	-	-	-	-	-	-	-	-	-	-
Menura alberti	0.969	0.012	-	-	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Menura novaehollandiae	0.848	0.007	-	-	-	-	-	-	-	-	-	-
Merops ornatus	0.835	0.029	-	-	-	-	-	-	-	-	-	-
Microeca fascinans	0.836	0.023	-	-	-	-	-	-	-	-	-	-
Miniopterus australis	-	-	-	-	-	-	0.745	0.021	-	-	-	-
Miniopterus orianae	-	-	-	-	-	-	0.836	0.077	-	-	-	-
Mixophyes fasciolatus	-	-	-	-	0.705	0.074	-	-	-	-	-	-
Monarcha melanopsis	0.837	0.008	-	-	-	-	-	-	-	-	-	-
Morethia boulengeri	-	-	0.964	0.011	-	-	-	-	-	-	-	-
Mus musculus	-	-	-	-	-	-	-	-	0.721	0.096	-	-
Myiagra cyanoleuca	0.821	0.023	-	-	-	-	-	-	-	-	-	-
Myiagra rubecula	0.758	0.011	-	-	-	-	-	-	-	-	-	-
Myiagra inquieta	0.841	0.029	-	-	-	-	-	-	-	-	-	-
Myotis macropus	-	-	-	-	-	-	0.859	0.038	-	-	-	-
Myzomela sanguinolenta	0.867	0.009	-	-	-	-	-	-	-	-	-	-
Neochmia temporalis	0.675	0.019	-	-	-	-	-	-	-	-	-	-
Nesoptilotis leucotis	0.885	0.015	-	-	-	-	-	-	-	-	-	-
Ninox connivens	-	-	-	-	-	-	-	-	-	-	0.944	0.029
Ninox novaeseelandiae	0.749	0.046	-	-	0.679	0.045	-	-	-	-	0.669	0.011
Ninox strenua	-	-	-	-	0.679	0.045	-	-	-	-	0.736	0.022
Notamacropus parma	-	-	-	-	0.693	0.124	-	-	-	-	-	-
Notamacropus rufogriseus	-	-	-	-	0.814	0.06	-	-	-	-	-	-
Nyctophilus bifax	-	-	-	-	-	-	0.942	0.016	-	-	-	-
Nyctophilus geoffroyi	-	-	-	-	-	-	0.777	0.016	-	-	-	-
Nyctophilus gouldi	-	-	-	-	-	-	0.648	0.014	-	-	-	-
Oedura tryoni	-	-	0.994	0.002	-	-	-	-	-	-	-	-
Ophioscincus truncatus	-	-	0.885	0.014	-	-	-	-	-	-	-	-
Origma solitaria	0.919	0.020	-	-	-	-	-	-	-	-	-	-
Oriolus sagittatus	0.799	0.013	-	-	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Orthonyx temminckii	0.87	0.010	-	-	-	-	-	-	-	-	-	-
Oryctolagus cuniculus	-	-	-	-	0.765	0.071	-	-	-	-	-	-
Pachycephala rufiventris	0.764	0.008	-	-	-	-	-	-	-	-	-	-
Pachycephala pectoralis	0.809	0.012	-	-	-	-	-	-	-	-	-	-
Pachycephala olivacea	0.902	0.025	-	-	-	-	-	-	-	-	-	-
Pardalotus striatus	0.796	0.013	-	-	-	-	-	-	-	-	-	-
Pardalotus punctatus	0.756	0.008	-	-	-	-	-	-	-	-	-	-
Parvipsitta pusilla	0.839	0.008	-	-	-	-	-	-	-	-	-	-
Perameles nasuta	-	-	-	-	0.765	0.071	-	-	0.750	0.063	0.733	0.020
Petauroides volans	-	-	-	-	0.905	0.018	-	-	-	-	0.839	0.005
Petaurus australis	-	-	-	-	0.763	0.049	-	-	-	-	0.794	0.014
Petaurus breviceps	-	-	-	-	0.824	0.014	-	-	-	-	0.665	0.013
Petrochelidon nigricans	0.897	0.026	-	-	-	-	-	-	-	-	-	-
Petroica rosea	0.833	0.01	-	-	-	-	-	-	-	-	-	-
Petroica phoenicea	0.920	0.006	-	-	-	-	-	-	-	-	-	-
Petroica boodang	0.804	0.031	-	-	-	-	-	-	-	-	-	-
Phaps chalcoptera	0.817	0.043	-	-	-	-	-	-	-	-	-	-
Phaps elegans	0.896	0.021	-	-	-	-	-	-	-	-	-	-
Phascolarctos cinereus	-	-	-	-	0.824	0.014	-	-	-	-	0.664	0.039
Philemon citreogularis	0.777	0.028	-	-	-	-	-	-	-	-	-	-
Philemon corniculatus	0.813	0.012	-	-	-	-	-	-	-	-	-	-
Phylidonyris niger	0.849	0.030	-	-	-	-	-	-	-	-	-	-
Phylidonyris novaehollandiae	0.863	0.010	-	-	-	-	-	-	-	-	-	-
Phylidonyris pyrrhoptera	0.951	0.041	-	-	-	-	-	-	-	-	-	-
Phyllurus platurus	-	-	0.923	0.021	-	-	-	-	-	-	-	-
Pitta versicolor	0.877	0.016	-	-	-	-	-	-	-	-	-	-
Platycercus elegans	0.785	0.013	-	-	-	-	-	-	-	-	-	-
Platycercus adscitus	0.796	0.021	-	-	-	-	-	-	-	-	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Podargus strigoides	0.796	0.021	-	-	0.752	0.044	-	-	-	-	-	-
Pseudechis porphyriacus	-	-	0.595	0.044	-	-	-	-	-	-	-	-
Pseudemoia entrecasteauxii	-	-	0.99	0.002	-	-	-	-	-	-	-	-
Pseudemoia spenceri	-	-	0.944	0.020	-	-	-	-	-	-	-	-
Pseudocheirus peregrinus	-	-	-	-	0.802	0.022	-	-	0.747	0.092	0.715	0.035
Pseudophryne australis	-	-	0.923	0.025	-	-	-	-	-	-	-	-
Pseudophryne coriacea	-	-	0.749	0.023	0.686	0.064	-	-	-	-	-	-
Psophodes olivaceus	0.812	0.009	-	-	-	-	-	-	-	-	-	-
Pteropus poliocephalus	-	-	-	-	0.749	0.056	-	-	-	-	0.815	0.039
Ptilinopus magnificus	0.935	0.008	-	-	-	-	-	-	-	-	-	-
Ptilinopus regina	0.940	0.015	-	-	-	-	-	-	-	-	-	-
Ptilonorhynchus violaceus	0.792	0.011	-	-	-	-	-	-	-	-	-	-
Ptiloris paradiseus	0.923	0.008	-	-	-	-	-	-	-	-	-	-
Pycnoptilus floccosus	0.908	0.015	-	-	-	-	-	-	-	-	-	-
Rankinia diemensis	-	-	0.930	0.024	-	-	-	-	-	-	-	-
Rattus fuscipes	-	-	-	-	-	-	-	-	0.725	0.018	-	-
Rattus lutreolus	-	-	-	-	-	-	-	-	0.665	0.089	-	-
Rhinolophus megaphyllus	-	-	-	-	-	-	0.721	0.022	-	-	-	-
Rhipidura rufifrons	0.818	0.006	-	-	-	-	-	-	-	-	-	-
Rhipidura albiscapa	0.852	0.012	-	-	-	-	-	-	-	-	-	-
Rhipidura leucophrys	0.905	0.018	-	-	-	-	-	-	-	-	-	-
Saiphos equalis	-	-	0.796	0.010	-	-	-	-	-	-	-	-
Saproscincus challengeri	-	-	0.844	0.017	-	-	-	-	-	-	-	-
Saproscincus mustelinus	-	-	0.893	0.008	-	-	-	-	-	-	-	-
Saproscincus rosei	-	-	0.781	0.038	-	-	-	-	-	-	-	-
Scoteanax rueppellii	-	-	-	-	-	-	0.701	0.043	-	-	-	-
Scotorepens orion	-	-	-	-	-	-	0.703	0.038	-	-	-	-
Scythrops novaehollandiae	0.804	0.017	-	-	-	-	-	-	-	-	-	-

Taxon	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sericornis magnirostra	0.909	0.007	-	-	-	-	-	-	-	-	-	-
Sericornis citreogularis	0.838	0.007	-	-	-	-	-	-	-	-	-	-
Sericornis frontalis	0.722	0.008	-	-	-	-	-	-	-	-	-	-
Sericulus chrysocephalus	0.904	0.022	-	-	-	-	-	-	-	-	-	-
Silvascincus murrayi	-	-	0.875	0.009	-	-	-	-	-	-	-	-
Smicrornis brevirostris	0.969	0.014	-	-	-	-	-	-	-	-	-	-
Sphecotheres vieilloti	0.935	0.014	-	-	-	-	-	-	-	-	-	-
Strepera versicolor	0.895	0.028	-	-	-	-	-	-	-	-	-	-
Strepera graculina	0.737	0.013	-	-	-	-	-	-	-	-	-	-
Symposiachrus trivirgatus	0.897	0.017	-	-	-	-	-	-	-	-	-	-
Thylogale thetis	-	-	-	-	0.749	0.056	-	-	-	-	-	-
Todiramphus sanctus	0.718	0.015	-	-	-	-	-	-	-	-	-	-
Tregellasia capito	0.898	0.007	-	-	-	-	-	-	-	-	-	-
Trichoglossus chlorolepidotus	0.892	0.011	-	-	-	-	-	-	-	-	-	-
Trichoglossus haematodus	0.855	0.009	-	-	-	-	-	-	-	-	-	-
Trichosurus caninus	-	-	-	-	0.86	0.022	-	-	-	-	0.807	0.024
Trichosurus vulpecula	-	-	-	-	0.797	0.027	-	-	0.965	0.02	0.700	0.027
Tyto novaehollandiae	0.681	0.09	-	-	0.733	0.048	-	-	-	-	0.649	0.002
Tyto tenebricosa	-	-	-	-	0.692	0.069	-	-	-	-	0.726	0.020
Vanellus miles	0.888	0.054	-	-	-	-	-	-	-	-	-	-
Varanus varius	-	-	0.733	0.018	-	-	-	-	-	-	-	-
Vespadelus darlingtoni	-	-	-	-	-	-	0.813	0.012	-	-	-	-
Vespadelus pumilus	-	-	-	-	-	-	0.806	0.018	-	-	-	-
Vespadelus regulus	-	-	-	-	-	-	0.849	0.014	-	-	-	-
Vespadelus vulturnus	-	-	-	-	-	-	0.864	0.013	-	-	-	-
Vombatus ursinus	-	-	-	-	0.795	0.072	-	-	-	-	-	-
Vulpes vulpes	-	-	-	-	0.694	0.083	-	-	-	-	-	-
Wallabia bicolor	-	-	-	-	0.783	0.057	-	-	0.741	0.023	-	-

	Diurnal Birds		Diurnal Herps		Transect Spotlight		Harp Trap		Hair Tubes		NOCPB	
Taxon	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Zoothera heinei	0.883	0.039	-	-	-	-	-	-	-	-	-	-
Zoothera lunulata	0.750	0.040	-	-	-	-	-	-	-	-	-	-
Zosterops lateralis	0.731	0.009	-	-	-	-	-	-	-	-	-	-

Table 30. Counts of covariate importance for BRT presence–absence models

Models were fitted for each species and range of survey methods for which sufficient presence records were found. Counts represent the number of models in which a covariate had a reported variable importance of more than 5%.

Survey method						
	Diurnal bird survey	**Diurnal herpetofauna survey**	**Transect spotlighting**	**Harp trapping**	**Hair tubes**	**Nocturnal call playback**
Number of models	**147**	**54**	**36**	**18**	**14**	**17**
Covariate						
ce_radann	71	24	18	4	5	9
COG_2000	54	29	16	8	4	13
ct_temp_maxsum	44	19	7	2	4	5
ct_tempann	64	23	11	12	6	5
ct_tempmtcp	58	19	14	6	4	10
ct_tempmtwp	45	22	9	5	3	5
ct_tempseas	62	24	16	8	6	10
cw_etaaann	73	34	20	11	12	10
cw_precipann	64	23	14	9	4	7
cw_precipdp	47	14	7	8	8	5
cw_precipseas	97	29	15	13	6	7
lf_cti	23	15	8	8	2	4
lf_rough0100	36	26	13	6	2	5
NDVI_7median_NS	109	33	10	6	4	12
sp_awc	29	10	16	4	7	0
sp_cly	29	15	13	5	7	7
sp_slt	63	19	10	7	5	7
sp_snd	45	15	15	5	4	4

7.2.2.3 Maxent flora models

Maxent yielded good quality environmental niche models for almost all flora species, with Test AUC (area under the receiver operating curve) values > 0.75 (Table 31), the threshold for potentially useful models (Elith 2000; Phillips *et al.* 2006). The exception was *Themeda triandra*, with Test AUC = 0.720. Although the model fit between the predicted habitat suitability and the spatio-temporally filtered input occurrences was judged satisfactory or better for all native species (Table 31), and the models were statistically robust (with the exception of *T. triandra* noted above), about a third of the models did not accurately reflect the respective species' distributions based on all ALA occurrences (Table 31), due to the spatio-temporal filter applied (i.e. the use of corporate data collected within 10 km of the RFA study region from 1987–2000 for systematic records and 1991–1998 for ALA occurrences). For many of the introduced weed species, the fit between predicted habitat suitability and input occurrences was also judged less than satisfactory, for two reasons: (1) the small number of occurrences for most species, and (2) the fact that many of the priority weed species had not expanded to fill their potential niche in eastern NSW forests in the period 1987–2000. Reports of all Maxent flora species models are given in Appendix 11a.

Table 31. AUC metrics and goodness of fit for Maxent models of priority flora species

Reason for priority status: C = climate change; F = fire; M = Myrtle Rust; O = old growth; P = Phytophthora, and W = weed. '–' = not rated.

Species	Priority	AUC Training	AUC Test	Goodness of fit	
				Input points	All ALA points
Acacia concurrens	C	0.9623	0.9459	–	Poor–ok
Acacia dealbata	C F	0.8971	0.8904	Good	Ok–good
Acacia irrorata	F	0.8845	0.8722	Ok–good	Ok–good
Acacia mearnsii	C	0.9425	0.9368	–	Poor–ok
Acacia melanoxylon	F	0.8217	0.8125	Ok–good	Ok–good
Acacia obtusifolia	F O	0.9390	0.9330	Ok	Ok
Acacia terminalis	C	0.9044	0.8943	–	Ok
Acmena smithii	F O	0.8912	0.8863	Good	Ok
Acrothamnus hookeri	C	0.9660	0.9518	–	Ok–good
Adiantum hispidulum	O	0.9044	0.8961	Ok–good	Ok
Alectryon subcinereus	O	0.9152	0.9057	Ok–good	Ok–good
Alpinia caerulea	C	0.9548	0.9505	–	Ok
Angophora costata	C	0.9220	0.9133	–	Ok
Angophora subvelutina	C	0.9276	0.9148	–	Ok
Angophora woodsiana	C	0.9844	0.9772	–	Ok–good
Anredera cordifolia	W	0.9353	0.7597	Poor–ok	Ok–good
Archirhodomyrtus beckleri	F M	0.9564	0.9513	Good	Ok–good
Archontophoenix cunninghamiana	F	0.9550	0.9515	Ok	Poor
Aristida ramosa	C	0.8493	0.8264	–	Ok
Asparagus aethiopicus	W	0.9851	0.9762	Poor–ok	Poor
Asparagus asparagoides	W	0.9647	0.8986	Poor–ok	Poor–ok
Asperula scoparia	C	0.9392	0.9323	–	Ok–good
Asplenium australasicum	F	0.9271	0.9217	Ok–good	Ok
Astroloma humifusum	P	0.9311	0.9110	Ok	Poor–ok
Backhousia leptopetala	M	0.9652	0.9256	Ok	Ok
Banksia oblongifolia	C	0.9675	0.9613	–	Ok–good
Banksia spinulosa	F O	0.8780	0.8693	Good	Ok
Bedfordia arborescens	C	0.9771	0.9743	–	Ok
Blechnum cartilagineum	F	0.8680	0.8629	Ok–good	Ok
Boronia parviflora	P	0.9507	0.9145	Ok–good	Ok–good
Bossiaea cinerea	P	Insufficient records			
Bossiaea neo-anglica	C	0.9780	0.9566	–	Ok
Brunoniella pumilio	C	0.9406	0.9034	–	Good
Caldcluvia paniculosa	F O	0.9452	0.9420	Good	Ok–good
Cassinia aculeata	F O	0.9076	0.8983	Ok	Poor–ok
Cassinia trinerva	C	0.9613	0.9371	–	Poor–ok
Ceratopetalum apetalum	F O	0.9447	0.9342	Ok	Ok
Chrysanthemoides monilifera subsp. *monilifera*	W	Insufficient records			
Chrysanthemoides monilifera subsp. *rotundata*	W	0.9863	0.9821	Poor–ok	Poor
Chrysocephalum apiculatum	C	0.8502	0.8391	–	Ok
Cissus hypoglauca	F	0.8697	0.8651	Good	Good
Coprosma hirtella	C	0.9736	0.9679	–	Ok–good
Correa lawrenceana	P	Insufficient records			

Species	Priority	AUC Training	AUC Test	Goodness of fit	
				Input points	All ALA points
Correa reflexa	C	0.9036	0.8921	–	Ok
Corymbia maculata	O	0.8774	0.8690	Good	Ok
Croton verreauxii	C	0.9471	0.9355	–	Ok
Cyathea australis	F O	0.9037	0.8976	Ok–good	Poor–ok
Cytisus scoparius	W	0.9310	0.8976	Poor–ok	Ok
Daviesia wyattiana	P	0.9673	0.9155	Ok–good	Ok–good
Decaspermum humile	M	0.9884	0.9739	Good	Ok
Dendrobium pugioniforme	O	0.9565	0.9492	Ok	Poor–ok
Denhamia bilocularis	C	0.9664	0.9597	–	Ok
Dillwynia glaberrima	P	0.9642	0.9295	Ok	Poor–ok
Dillwynia sericea	P	0.9109	0.8618	Ok–good	Poor–ok
Dodonaea triquetra	C	0.9110	0.8988	–	Ok
Dolichandra unguis-cati	W	Insufficient records			
Echinopogon ovatus	F O	0.7931	0.7793	Ok–good	Poor–ok
Embelia australiana	F O	0.9487	0.9412	Ok–good	Ok–good
Epacris impressa	C P	0.9713	0.9683	–	Poor–ok
Epacris paludosa	P	0.9776	0.9570	Ok–good	Ok–good
Eragrostis leptostachya	C	0.8659	0.8480	–	Ok
Eremophila debilis	C	0.9406	0.9222	–	Ok
Eucalyptus agglomerata	C	0.9308	0.9220	–	Poor–ok
Eucalyptus biturbinata	C	0.8538	0.8364	–	Ok
Eucalyptus brunnea	C	0.9671	0.9576	–	Poor–ok
Eucalyptus caliginosa	C	0.9477	0.9440	–	Ok–good
Eucalyptus cameronii	C	0.9528	0.9454	–	Ok
Eucalyptus campanulata	C	0.9337	0.9299	–	Good
Eucalyptus cypellocarpa	C	0.9468	0.9450	–	Ok
Eucalyptus dalrympleana	C	0.9193	0.9110	–	Ok–good
Eucalyptus elata	C	0.9689	0.9652	–	Poor–ok
Eucalyptus fastigata	C O P	0.9630	0.9573	Ok–good	Ok–good
Eucalyptus fraxinoides	P	0.9925	0.9900	Good	Ok–good
Eucalyptus imlayensis	P	Insufficient records			
Eucalyptus laevopinea	C	0.9353	0.9268	–	Ok–good
Eucalyptus longifolia	C	0.9823	0.9777	–	Ok
Eucalyptus macrorhyncha	C	0.9267	0.9201	–	Ok
Eucalyptus melliodora	C	0.8513	0.8041	–	Ok–good
Eucalyptus moluccana	C	0.8969	0.8794	–	Ok
Eucalyptus muelleriana	C	0.9701	0.9679	–	Ok
Eucalyptus obliqua	C	0.9427	0.9396	–	Good
Eucalyptus paniculata	C	0.9477	0.9398	–	Ok–good
Eucalyptus pauciflora	C	0.9051	0.8966	–	Good
Eucalyptus pilularis	O	0.9085	0.9017	Ok–good	Ok
Eucalyptus planchoniana	C	0.9809	0.9654	–	Poor–ok
Eucalyptus propinqua	C F	0.9222	0.9123	Good	Ok–good
Eucalyptus radiata	C	0.8996	0.8929	–	Ok–good
Eucalyptus robertsonii	C O	0.9685	0.9639	Good	Good
Eucalyptus saligna	F	0.8974	0.8918	Ok–good	Ok
Eucalyptus sieberi	C F O	0.9452	0.9424	Ok	Poor–ok

Species	Priority	AUC Training	AUC Test	Goodness of fit	
				Input points	All ALA points
Eucalyptus smithii	C P	0.9791	0.9731	–	Poor–ok
Eucalyptus viminalis	C	0.8805	0.8626	–	Ok–good
Euroschinus falcatus var. *falcatus*	C	0.9490	0.9397	–	Poor
Genista monspessulana	W	0.9379	0.8780	Ok	Ok
Glochidion ferdinandi	C	0.9112	0.9041	–	Ok–good
Gompholobium latifolium	C	0.9138	0.8989	–	Good
Gompholobium pinnatum	C	0.9656	0.9512	–	Poor
Goodenia ovata	F O	0.9141	0.9012	Ok	Poor–ok
Goodenia rotundifolia	C	0.9323	0.9174	–	Poor–ok
Goodia lotifolia	F	0.9353	0.9234	Ok	Ok
Gossia acmenoides	M	0.9866	0.9740	Ok–good	Ok
Gossia fragrantissima	M	0.9951	0.9921	Good	Ok
Gossia hillii	M	0.9909	0.9796	Ok–good	Ok
Grevillea irrasa subsp. *irrasa*	P	0.9989	0.9978	–	Good
Grevillea obtusiflora	P	Insufficient records			
Grevillea victoriae	P	0.9663	0.9366	Ok	Ok
Haloragodendron lucasii	P	Insufficient records			
Hibbertia calycina	P	0.9754	0.9574	Good	Ok–good
Hibbertia circinata	P	Insufficient records			
Hibbertia vestita	C	0.9631	0.9538	–	Poor–ok
Hibbertia virgata	P	Insufficient records			
Hierochloe rariflora	C	0.9730	0.9692	–	Ok–good
Hybanthus stellarioides	C	0.9445	0.9329	–	Poor–ok
Imperata cylindrica	F	0.8133	0.8088	Ok–good	Poor–ok
Lantana camara	W	0.9040	0.9001	Ok–good	Poor–ok
Lenwebbia prominens	M	0.9987	0.9937	Good	Ok–good
Lepidosperma urophorum	C	0.9418	0.9318	–	Ok
Leptinella filicula	C	0.9802	0.9629	–	Good
Leptospermum trinervium	M	0.8798	0.8703	Good	Ok–good
Leucopogon ericoides	P	0.9256	0.8861	Ok	Poor–ok
Lomandra spicata	F O	0.9450	0.9384	Ok–good	Ok–good
Lomatia ilicifolia	C F O	0.9585	0.9546	Good	Ok
Lophostemon suaveolens	C	0.9785	0.9717	–	Poor–ok
Macrozamia communis	C F	0.9398	0.9334	Ok–good	Ok
Mallotus philippensis	C	0.9418	0.9324	–	Ok
Melaleuca nodosa	M	0.9739	0.9668	Ok–good	Ok
Melaleuca quinquenervia	M	0.9775	0.9732	Ok–good	Ok
Melaleuca squamea	P	Insufficient records			
Melichrus procumbens	C	0.9342	0.9085	–	Ok
Monotoca glauca	P	Insufficient records			
Nematolepis rhytidophylla	P	Insufficient records			
Nematolepis squamea	P	0.9650	0.9406	Ok	Poor–ok
Notelaea venosa	O	0.9186	0.9093	Ok–good	Ok
Olearia argophylla	C	0.9687	0.9574	–	Ok
Oreomyrrhis eriopoda	C	0.9248	0.9121	–	Ok–good
Orites excelsus	F O	0.9680	0.9636	Good	Good
Oxylobium ellipticum	P	0.9580	0.9442	Good	Ok

Species	Priority	AUC Training	AUC Test	Goodness of fit	
				Input points	All ALA points
Ozothamnus argophyllus	C	0.9720	0.9598	–	Ok
Ozothamnus cuneifolius	C	0.9887	0.9852	–	Ok–good
Panicum effusum	C	0.8313	0.8099	–	Ok
Parsonsia straminea	F	0.8737	0.8652	Ok–good	Ok
Pereskia aculeata	W	Insufficient records			
Persoonia chamaepeuce	C	0.9619	0.9475	–	Ok
Persoonia cornifolia	P	0.9532	0.9448	Ok	Poor–ok
Persoonia oleoides	C	0.9705	0.9627	–	Ok–good
Persoonia silvatica	C P	0.9824	0.9756	–	Ok–good
Persoonia stradbrokensis	C	0.9632	0.9584	–	Ok–good
Pimelea axiflora	C	0.9774	0.9736	–	Ok
Platycerium bifurcatum	F	0.9238	0.9196	Ok–good	Poor–ok
Platylobium formosum	C P	0.9190	0.9032	–	Ok–good
Platysace ericoides	C	0.9233	0.9130	–	Ok
Poa ensiformis	C	0.9752	0.9675	–	Poor–ok
Poa meionectes	C	0.9119	0.9084	–	Ok
Pomaderris aspera	C	0.9479	0.9392	–	Ok
Prostanthera lasianthos	C	0.9412	0.9218	–	Ok–good
Psychotria daphnoides	C P	0.9874	0.9814	–	Poor–ok
Pultenaea altissima	P	0.9142	0.8147	Ok	Poor–ok
Pultenaea baeuerlenii	P	Insufficient records			
Pultenaea benthamii	P	0.9962	0.9884	Ok–good	Ok–good
Pultenaea daphnoides	C P	0.9614	0.9509	–	Poor–ok
Pultenaea juniperina	P	0.9621	0.9537	Ok	Ok–good
Pultenaea paleacea	P	Insufficient records			
Pultenaea parrisiae	P	Insufficient records			
Pultenaea villosa	C	0.9454	0.9328	–	Ok–good
Pyrrosia rupestris	F	0.8920	0.8851	Ok–good	Ok
Rhodamnia argentea	M	0.9654	0.9196	Ok	Poor–ok
Rhodamnia maideniana	M	0.9865	0.9660	–	Good
Rhodamnia rubescens	F M O	0.9241	0.9180	Good	Ok–good
Rhodamnia whiteana	M	Insufficient records			
Rhodomyrtus psidioides	M	0.9525	0.9327	Ok–good	Ok
Rubus fruticosus aggregate	W	0.8640	0.8380	Ok	Poor–ok
Rubus moluccanus	O	0.9096	0.9018	Ok–good	Ok
Sarcochilus falcatus	F O	0.9431	0.9315	Ok	Poor–ok
Scleria mackaviensis	C	0.9210	0.8817	–	Poor–ok
Solanum hapalum	F O	0.9568	0.9477	Good	Ok–good
Solanum pungetium	F O	0.9402	0.9256	Ok–good	Poor–ok
Sorghum leiocladum	C	0.8806	0.8671	–	Poor–ok
Sprengelia incarnata	P	0.9779	0.9520	Ok	Poor–ok
Stephania japonica	F O	0.8812	0.8671	Ok–good	Ok
Syzygium anisatum	M	0.9963	0.9934	Ok	Ok
Syzygium hodgkinsoniae	M	0.9898	0.9879	Ok–good	Poor–ok
Tasmannia purpurascens	P	0.9965	0.9956	Good	Good
Tetrarrhena juncea	C F	0.9604	0.9515	Ok	Poor–ok
Tetratheca bauerifolia	C	0.9702	0.9591	–	Ok–good

Species	Priority	AUC Training	AUC Test	Goodness of fit	
				Input points	All ALA points
Tetratheca subaphylla	P	0.9982	0.9929	Ok–good	Ok
Themeda triandra	F	0.7253	0.7199	Ok–good	Poor–ok
Trochocarpa laurina	F	0.9016	0.8971	Ok–good	Ok
Ulex europaeus	W	Insufficient records			
Xanthorrhoea australis	P	0.9428	0.9090	Ok	Poor
Xanthorrhoea concava	F	0.9733	0.9587	Good	Ok–good
Xanthorrhoea glauca	P	0.9244	0.8929	Ok	Poor–ok
Xanthorrhoea latifolia	C F	0.9508	0.9400	Ok	Poor–ok

One use of a large number of environmental niche models, as presented in Appendix 11a, from a monitoring design perspective is to 'stack' the model surfaces to reveal the parts of the study region that vary in cumulative habitat suitability for the selected species. Figure 22 shows the results of stacking the ENM models for the 81 priority flora species chosen for their likely sensitivity to climate change. Stacking shows that the UNE forests, and the coastal and high-elevation forests fringing the south-eastern and southern margins of the Northern Tablelands have high cumulative habitat suitability for potentially climate-sensitive species. However, the lowland subcoastal forest between Kempsey, Gloucester and Muswellbrook (e.g. Mt Boss, Dingo, Avon River and Masseys Creek State Forests), the central parts of Wollemi National Park and the largely agricultural country west of Armidale, Nundle and Murrurundi offer less suitable habitat for these species. In southern NSW, the South Coast and South-Western Slopes forests provide high-quality habitat, while forests on the lower slopes between Albury and Gundagai, and in Kosciuszko National Park, the Byadbo wilderness and in the agricultural country around Cooma and Bowral are less suitable habitat for these priority species.

Detailed examples of environmental niche modelling using Maxent for two priority flora species, Kangaroo Grass (*Themeda triandra*) and Blackbutt (*Eucalyptus pilularis*), are provided below.

Kangaroo Grass (*Themeda triandra*)

Some 3,032 occurrence points were used to model *Themeda triandra* habitat suitability in relation to the environmental covariate layers in Table 6: 1,478 points were from systematic surveys and 2,840 came from ALA (Table 10), with the duplicate points automatically eliminated by Maxent.

The receiver operating characteristic curve is shown in Figure 23; the average test Area Under the Curve (AUC) for ten replicate runs was 0.720 (standard deviation, 0.013). As already noted, this was below the accepted threshold (0.75) for a potentially useful model, and so the quality of the *Themeda triandra* model was unsatisfactory.

Table 32 shows the relative contributions of each environmental covariate to the Maxent model. Values > 5 are regarded as important, and in the case of *Themeda triandra*, the first six covariates had values > 5: cw_etaaann90, cog_100m90, cw_precipseas, ct_tempseas90, ndvi_7median_ns_90, and sp_slt_90. Average annual actual evaporation was clearly the most important environmental covariate in the model, but candidate old growth, coefficient of variation (CV) of seasonal precipitation, CV of seasonal temperature, NDVI and the fraction of silt were also important influences. The relationship between these covariates and *Themeda triandra* occurrence can be displayed in two ways: firstly, as the modelled relationship between each environmental variable by itself and *T. triandra* habitat suitability, and secondly, the effect of each environmental variable on the Maxent prediction while allowing for the effect of each of the other covariates. Figure 24 shows these two sets of curves for each of the six important environmental variables in the *Themeda triandra* model.

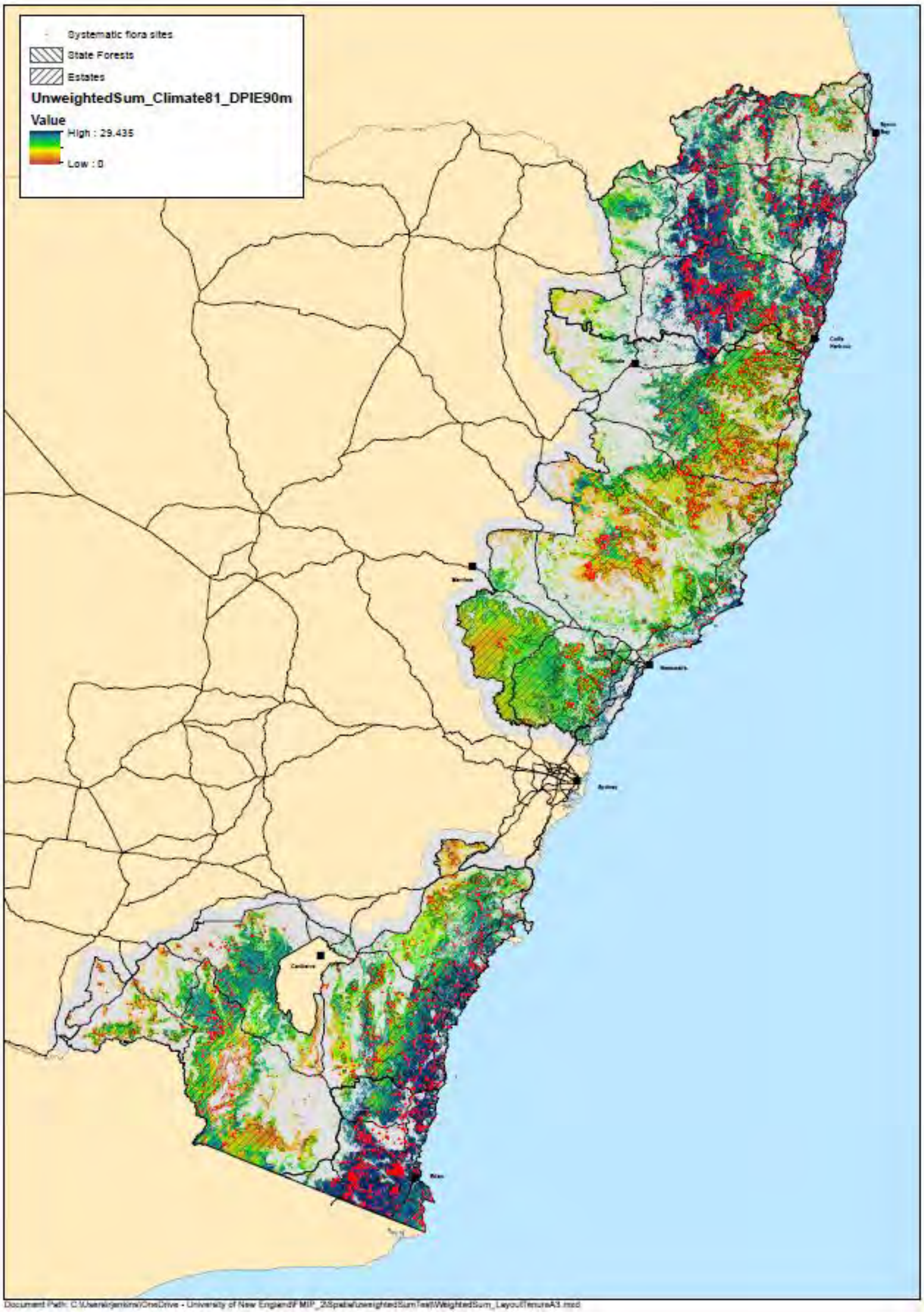


Figure 22. Stacked set of ENM Maxent models for the 81 climate-sensitive priority flora species

Shows the range in cumulative habitat suitability from high to low across the study region for the stack of 81 species, with non-forest vegetation masked out

Finally, Figure 25 shows the point-wise mean and standard deviation of the 10 modelled output surfaces of *Themeda triandra* habitat quality across the study region. *T. triandra* habitat quality was predicted to be greatest in the central ranges of the UNE, on the Far North Coast and parts of the LNE coast and South Coast, with lower suitability in the upper Richmond and Clarence valleys, the tablelands west of Armidale, the high country around Nundle, Tuggolo and Barrington Tops, central Wollemi, the South-West Slopes between Tumbarumba and Tumut, and Kosciuszko National Park. In fact, *Themeda triandra* has a semi-continuous distribution throughout the study region (Atlas of Living Australia; PlantNET: NSW Flora Online) and the modelled variations in habitat suitability may be an artefact of imperfect sampling and recording within the confines of the spatio-temporal (1990s RFA) filter applied to the occurrence records. An alternative view of this same spatial Maxent model for *T. triandra* in relation to the survey points is shown in Figure 26. The many *Themeda triandra* occurrences in modelled lower-quality habitat in the western part of the study region help explain the low Test AUC value and the unsatisfactory nature of the model.

Blackbutt (*Eucalyptus pilularis*)

The Blackbutt (*Eucalyptus pilularis*) Maxent model used 886 points, selected from the 452 points from systematic surveys and 832 points from ALA (Table 10). The ROC curve (Figure 27) shows an AUC = 0.902 ± 0.010 (mean ± s.d.), indicating the model was statistically robust.

Table 33 shows the relative contributions of each environmental covariate to the *Eucalyptus pilularis* Maxent model. The first five covariates had values > 5: cw_precipann_90, ct_tempann90, ct_tempseas90, ndvi_7median_ns_90, and cw_etaaann90. Annual precipitation, annual mean temperature and CV of temperature seasonality were the most important environmental covariates in the model, but NDVI and average annual actual evaporation were also important influences. The modelled relationships between these covariates and *E. pilularis* occurrence are shown in Figure 28.

The point-wise mean and standard deviation of the 10 modelled output surfaces of *E. pilularis* habitat quality underscored the quality of this model (Figure 29a, b). The modelled habitat quality of *E. pilularis* across the study region highlighted the species' coastal distribution in NSW, and was a fair representation of all known occurrences of the species (Table 31) as well as of the input points used in the modelling (Figure 30).

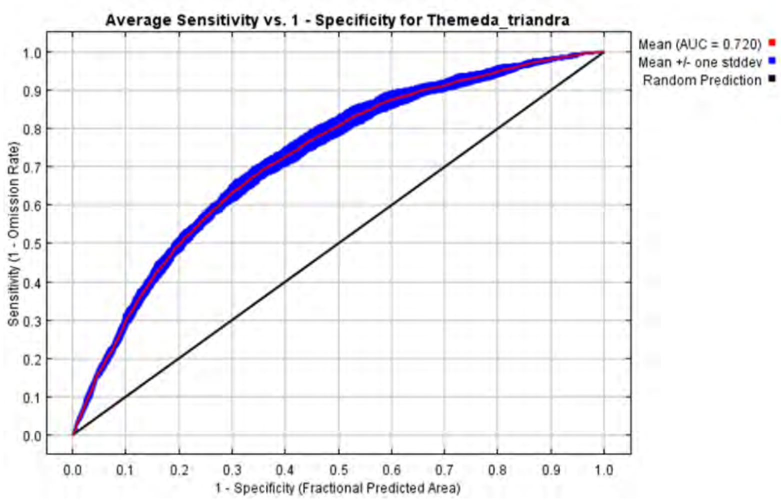
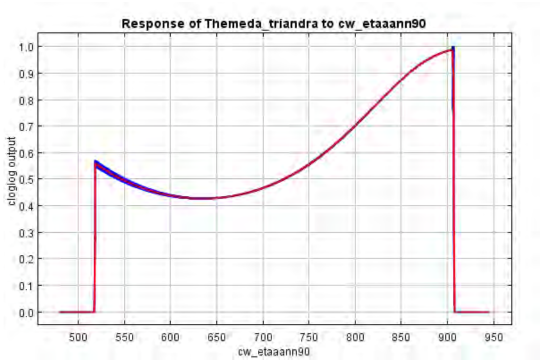
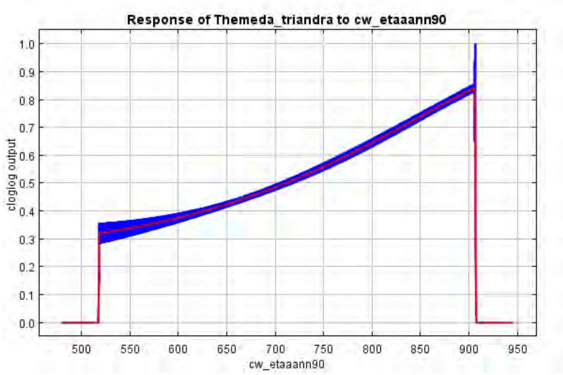


Figure 23. The receiver operating characteristic (ROC) curve for the Maxent Themeda triandra *model, averaged over 10 replicate runs*

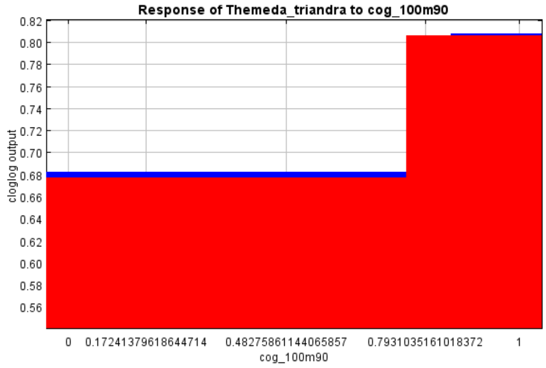
(a)


Response of Themeda_triandra to cw_etaaann90
cloglog output
cw_etaaann90

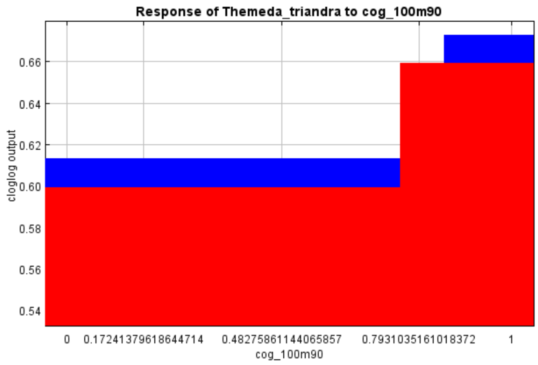
(b)


Response of Themeda_triandra to cw_etaaann90
cloglog output
cw_etaaann90

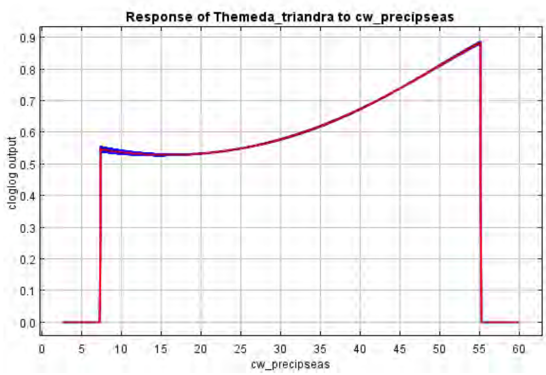
(c)


Response of Themeda_triandra to cog_100m90
cloglog output
0 0.17241379618644714 0.48275861144065857 0.7931035161018372 1
cog_100m90

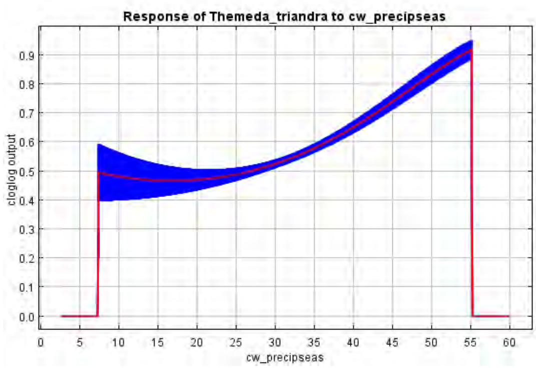
(d)


Response of Themeda_triandra to cog_100m90
cloglog output
0 0.17241379618644714 0.48275861144065857 0.7931035161018372 1
cog_100m90

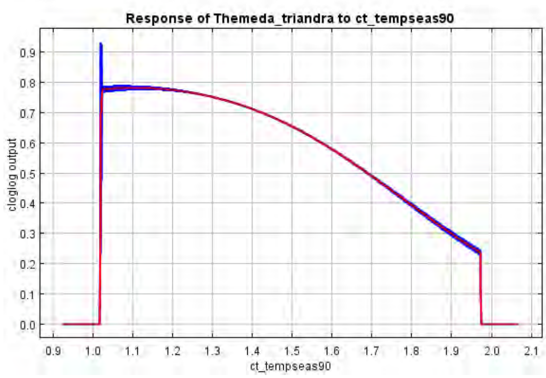
(e)


Response of Themeda_triandra to cw_precipseas
cloglog output
cw_precipseas

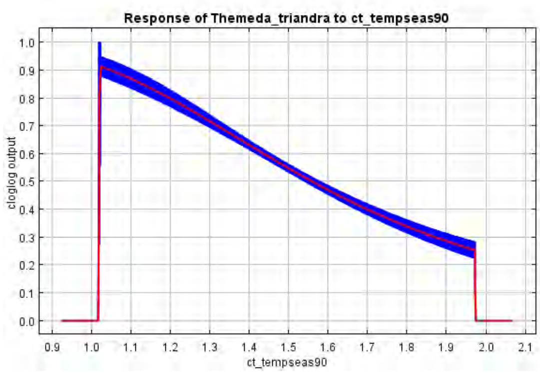
(f)


Response of Themeda_triandra to cw_precipseas
cloglog output
cw_precipseas

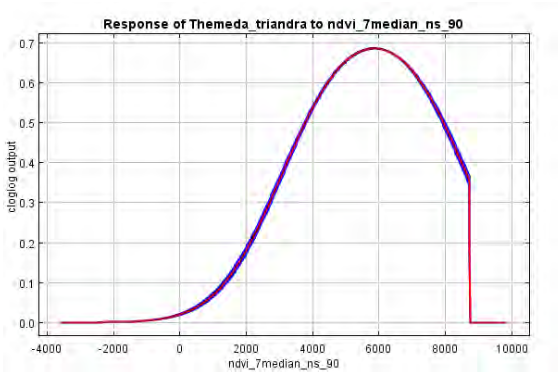
(g)


Response of Themeda_triandra to ct_tempseas90
cloglog output
ct_tempseas90

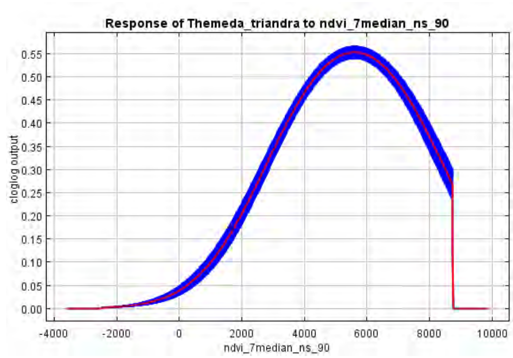
(h)


Response of Themeda_triandra to ct_tempseas90
cloglog output
ct_tempseas90

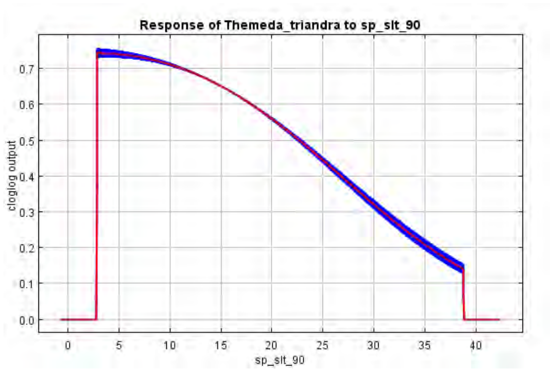
(i)



(j)



(k)



(l)

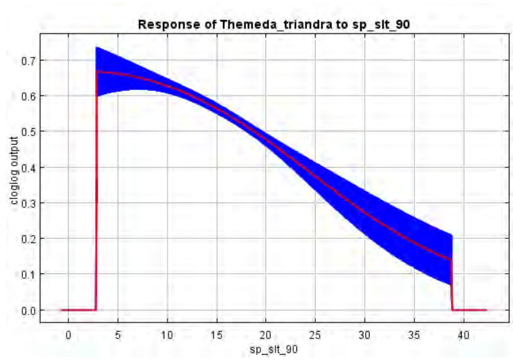


Figure 24. The relationship between modelled Themeda triandra *habitat suitability and the six important environmental variables influencing the Maxent prediction*

(a, b) Average annual actual evaporation, cw_etaaann90, (c, d) candidate old growth, cog_100m90; (e, f) CV of seasonal precipitation, cw_precipseas; (g, h) CV of seasonal temperature, ct_tempseas90; (I, j) NDVI, ndvi_7median_ns_90, and (k, l) the fraction of silt, sp_slt_90. (a, c, e, g, i) The relationship between the environmental covariate alone and predicted T. triandra *suitability, and (b, d, f, h, j, l) the marginal response curve for each environmental variable, showing how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.*

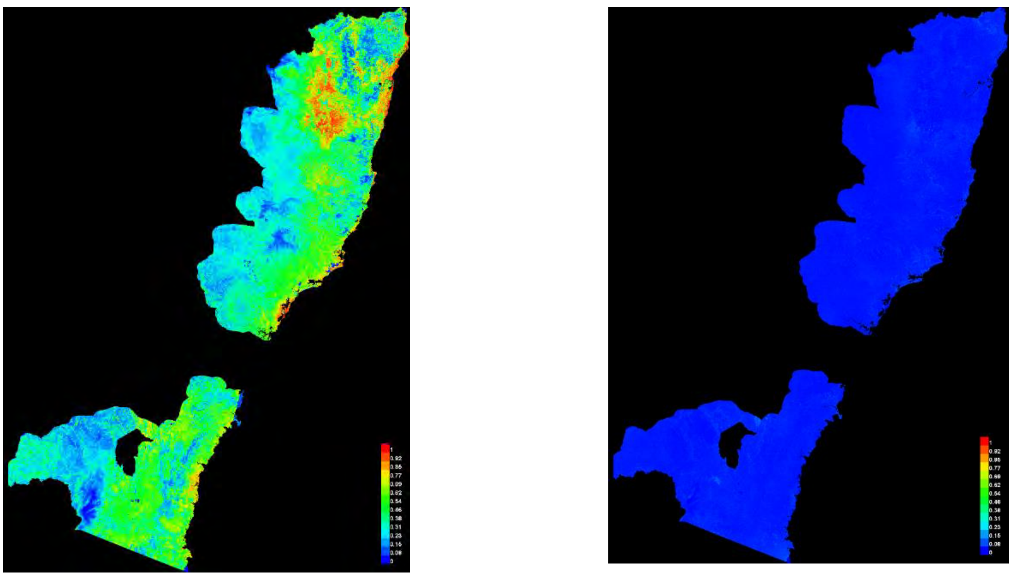


Figure 25. The point-wise (a) mean and (b) standard deviation of the 10 output grids of the T. triandra *model*

Table 32. Estimates of the relative contribution of environmental covariates to the Themeda triandra *Maxent model*

Values shown are averages over 10 replicate runs

Environmental covariate	Percent contribution (%)
cw_etaaann90	37.7
cog_100m90	8.1
cw_precipseas	6.9
ct_tempseas90	6.9
ndvi_7median_ns_90	6.3
sp_slt_90	5.1
sp_awc90	4.0
fire_62_91_bool90	4.0
ct_tempann90	3.9
lf_rough0100_90	3.5
cw_precipdp90	3.2
lf_tpi0250_90	2.7
ce_radann90	2.3
sp_snd_90	1.8
sp_cly_90	1.6
lf_cti90	1.1
cw_precipann_f90	0.9
Sum	100.0

Table 33. Estimates of the relative percent contribution of each covariate to the Eucalyptus pilularis *Maxent model*

Values shown are averages over 10 replicate runs

Variable	Percent contribution (%)
cw_precipann_f90	22.7
ct_tempann90	21.9
ct_tempseas90	18.7
ndvi_7median_ns_90	7.2
cw_etaaann90	6.7
ce_radann90	4.4
cw_precipdp90	3.1
fire_62_91_bool90	3.1
cw_precipseas	2.5
sp_slt_90	2.2
sp_cly_90	1.7
sp_awc90	1.5
lf_tpi0250_90	1.3
cog_100m90	0.9
sp_snd_90	0.9
lf_cti90	0.7
lf_rough0100_90	0.6
Sum	100.1

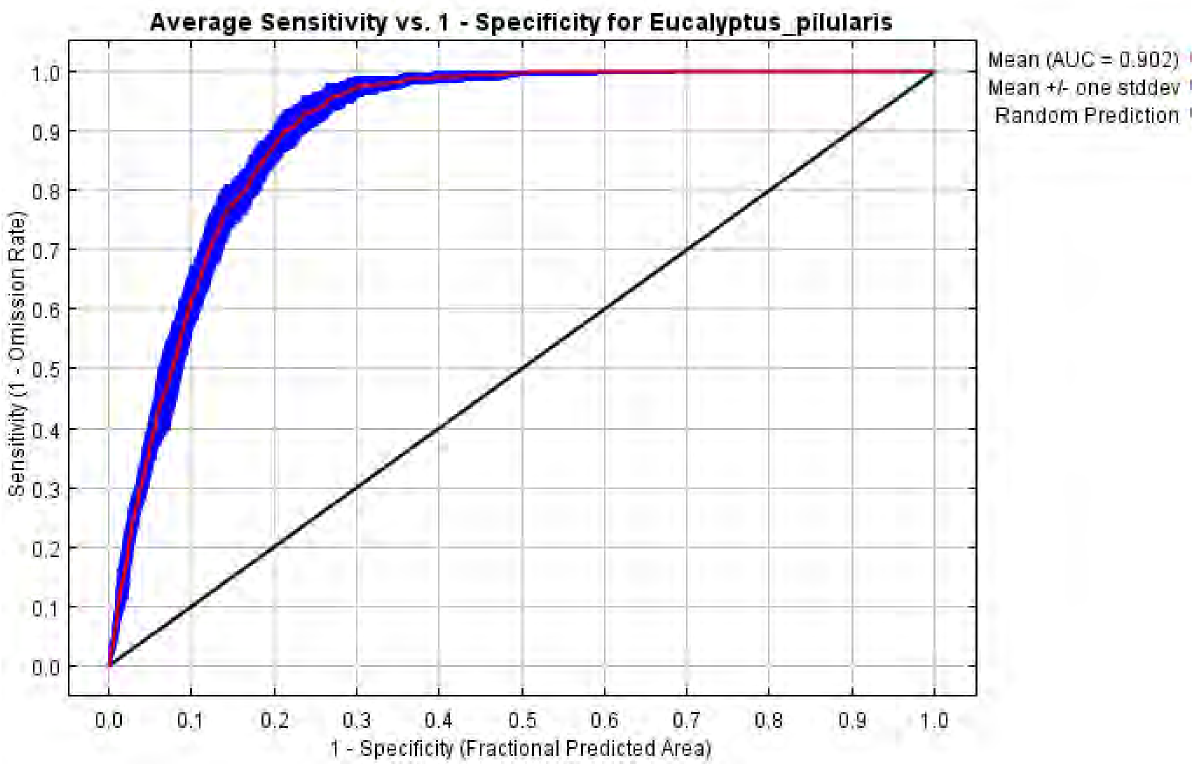


Figure 26. The receiver operating characteristic (ROC) curve for the Maxent E. pilularis *model, averaged over 10 replicate runs*

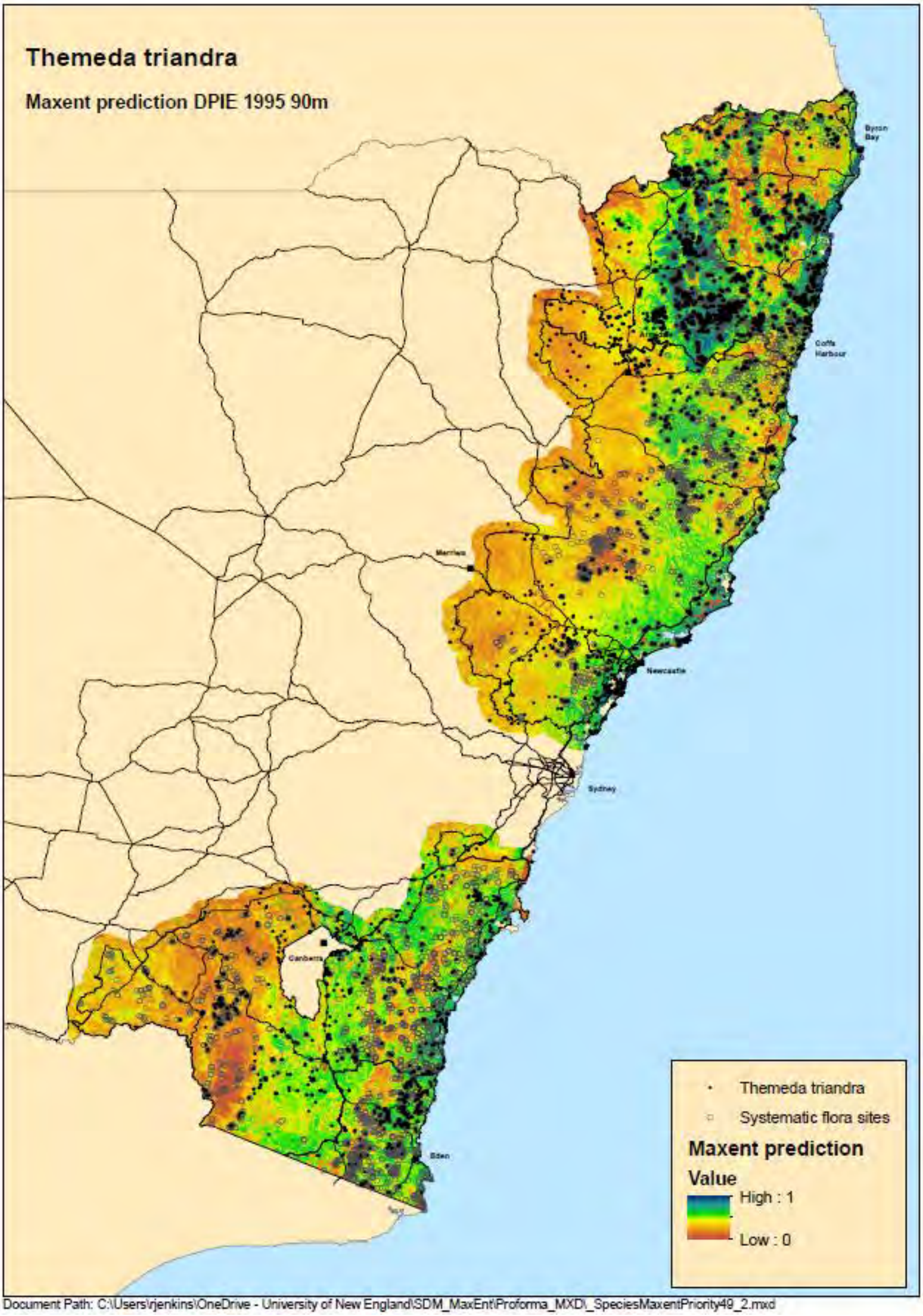
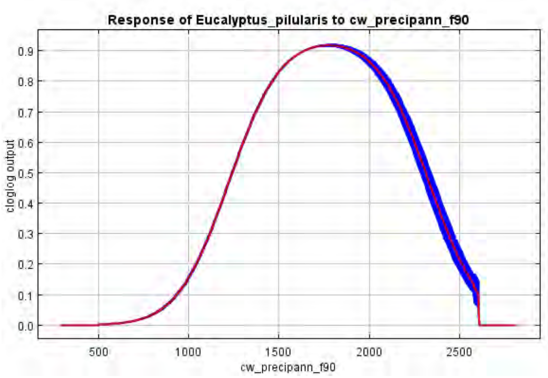
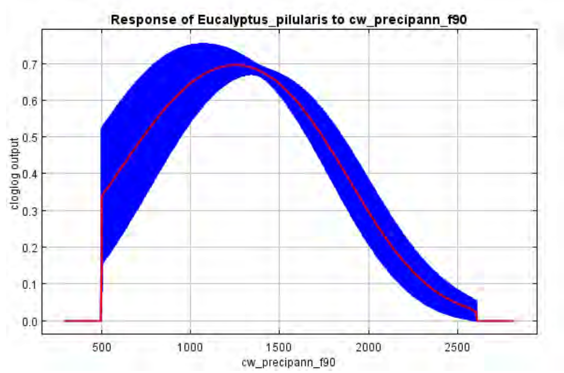


Figure 27. The Maxent model of Themeda triandra *habitat quality in relation to the locations of all input occurrences (black dots) and systematic flora sites (open circles)*

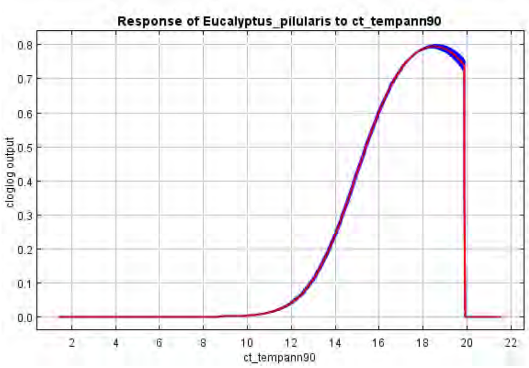
(a)


Response of Eucalyptus_pilularis to cw_precipann_f90
cloglog output
cw_precipann_f90

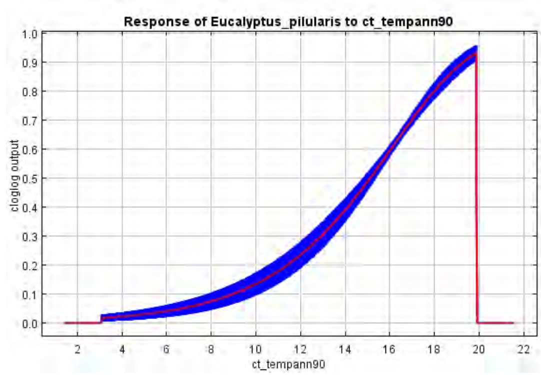
(b)


Response of Eucalyptus_pilularis to cw_precipann_f90
cloglog output
cw_precipann_f90

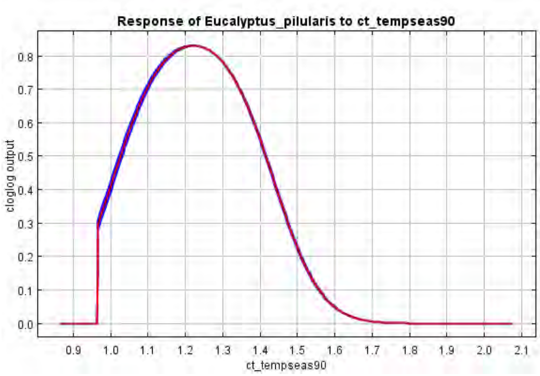
(c)


Response of Eucalyptus_pilularis to ct_tempann90
cloglog output
ct_tempann90

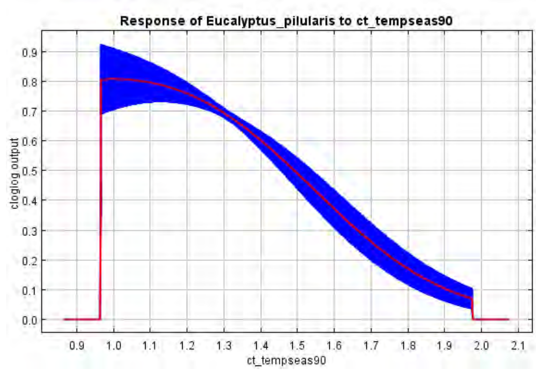
(d)


Response of Eucalyptus_pilularis to ct_tempann90
cloglog output
ct_tempann90

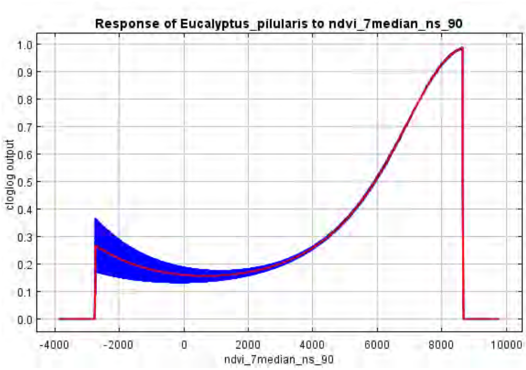
(e)


Response of Eucalyptus_pilularis to ct_tempseas90
cloglog output
ct_tempseas90

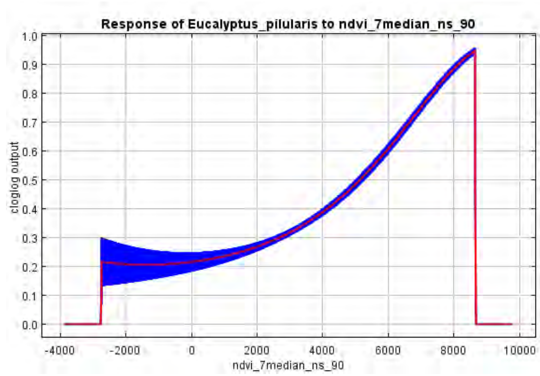
(f)


Response of Eucalyptus_pilularis to ct_tempseas90
cloglog output
ct_tempseas90

(g)


Response of Eucalyptus_pilularis to ndvi_7median_ns_90
cloglog output
ndvi_7median_ns_90

(h)


Response of Eucalyptus_pilularis to ndvi_7median_ns_90
cloglog output
ndvi_7median_ns_90

(i) (j)

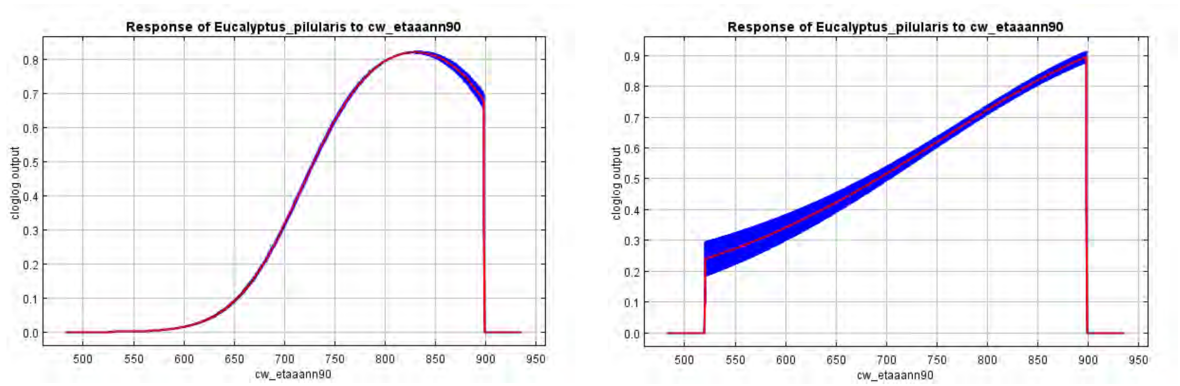


Figure 28. The relationship between modelled E. pilularis *habitat suitability and the six important environmental variables influencing the Maxent prediction*

(a, b) Annual precipitation, cw_precipann_f90; (c, d) annual mean temperature, ct_tempann90; (e, f) CV of seasonal temperature, ct_tempseas90; (g, h) NDVI, ndvi_7median_ns_90, and (i, j) average annual actual evaporation, cw_etaaann90. (a, c, e, g, i) The relationship between the environmental covariate alone and predicted E. pilularis suitability, and (b, d, f, h, j) the marginal response curve for each environmental variable, showing how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value.

(a) (b)

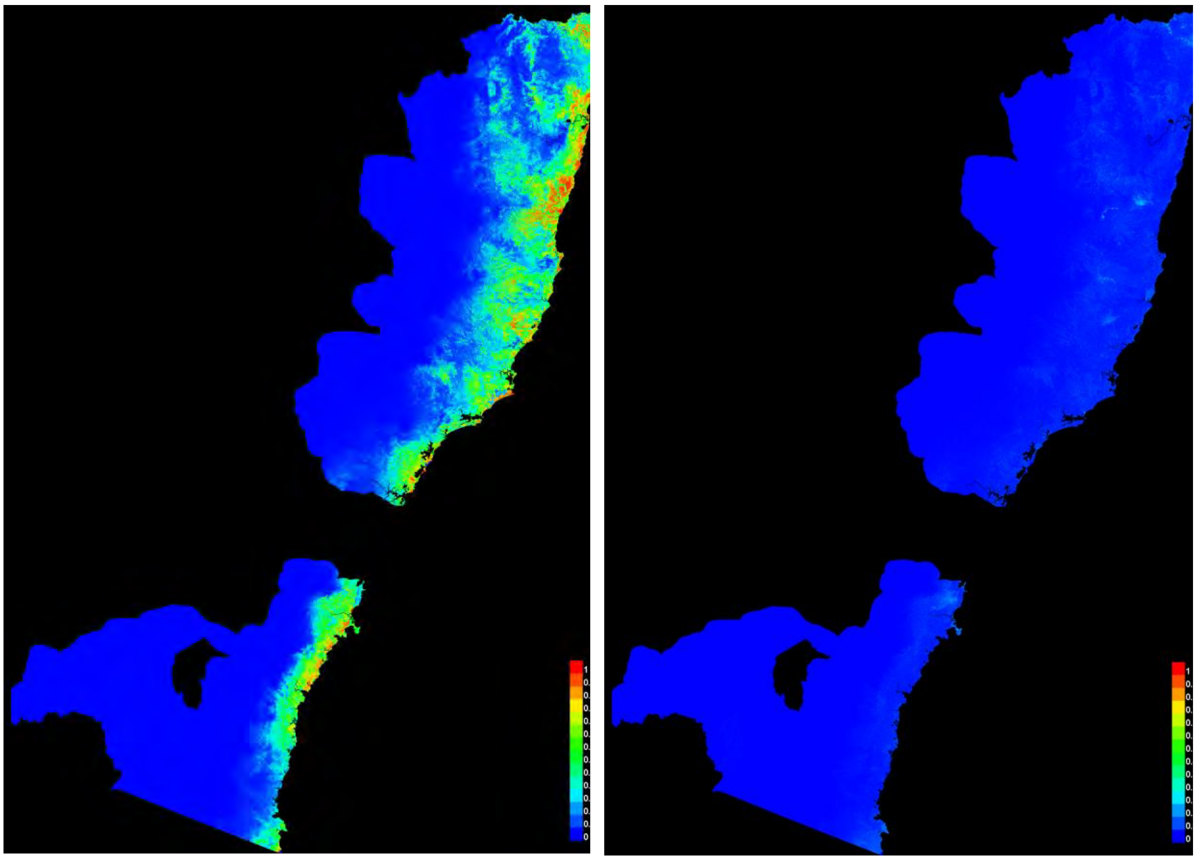


Figure 29. The point-wise (a) mean and (b) standard deviation of the 10 output grids of the E. pilularis *model*

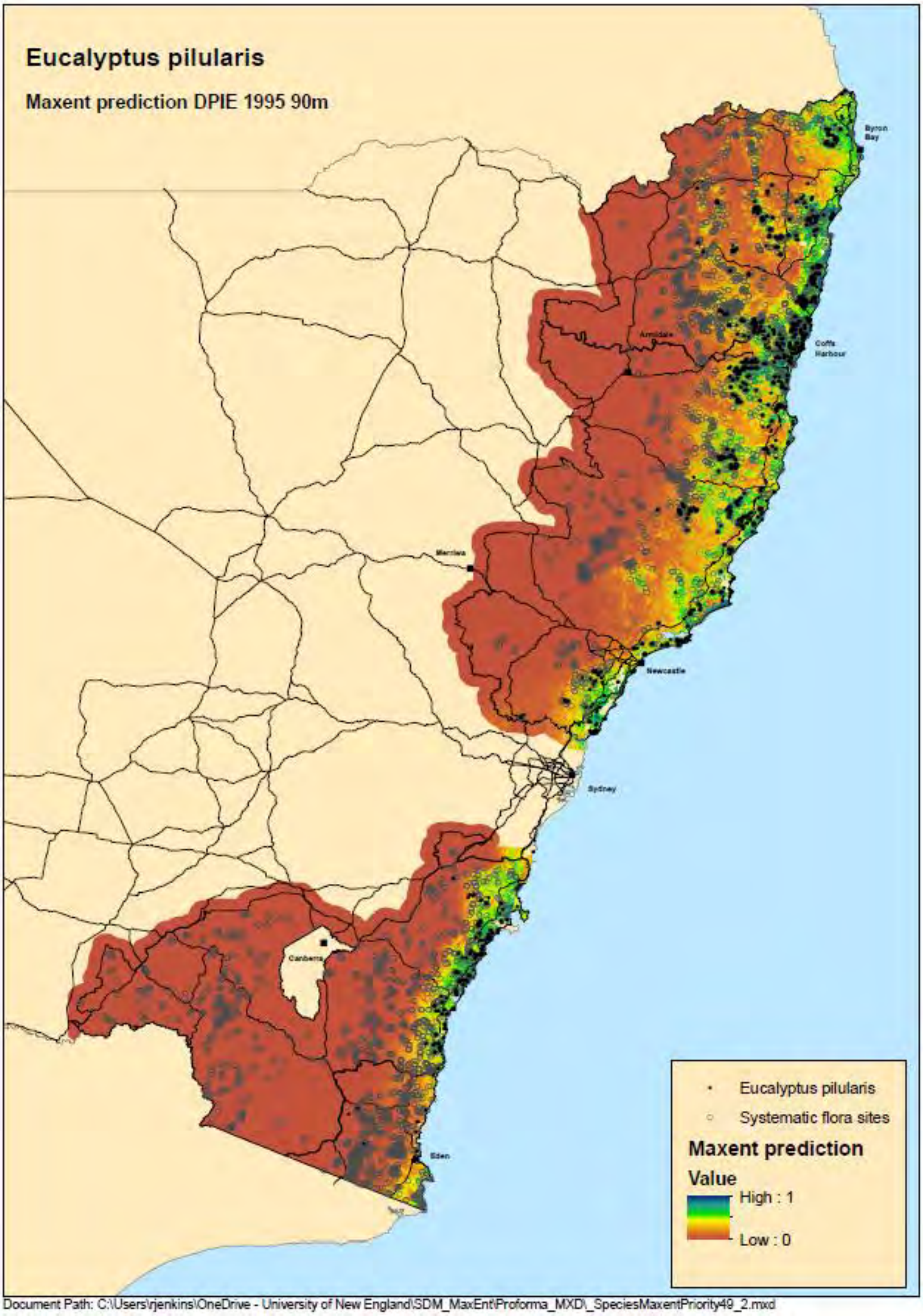


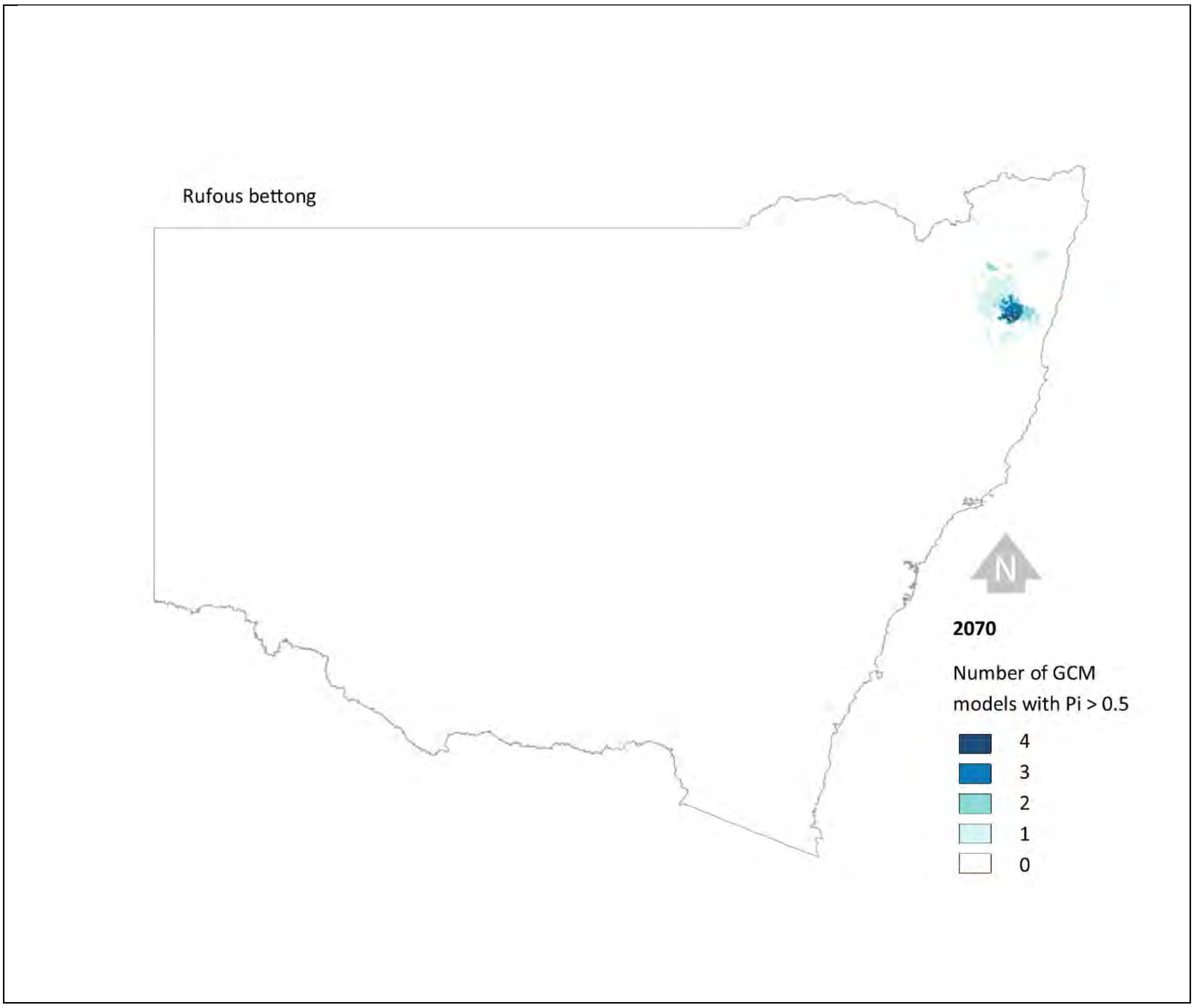
Figure 30. The Maxent model of Eucalyptus pilularis *habitat quality in relation to the locations of all input occurrences (black dots) and systematic flora sites (open circles)*

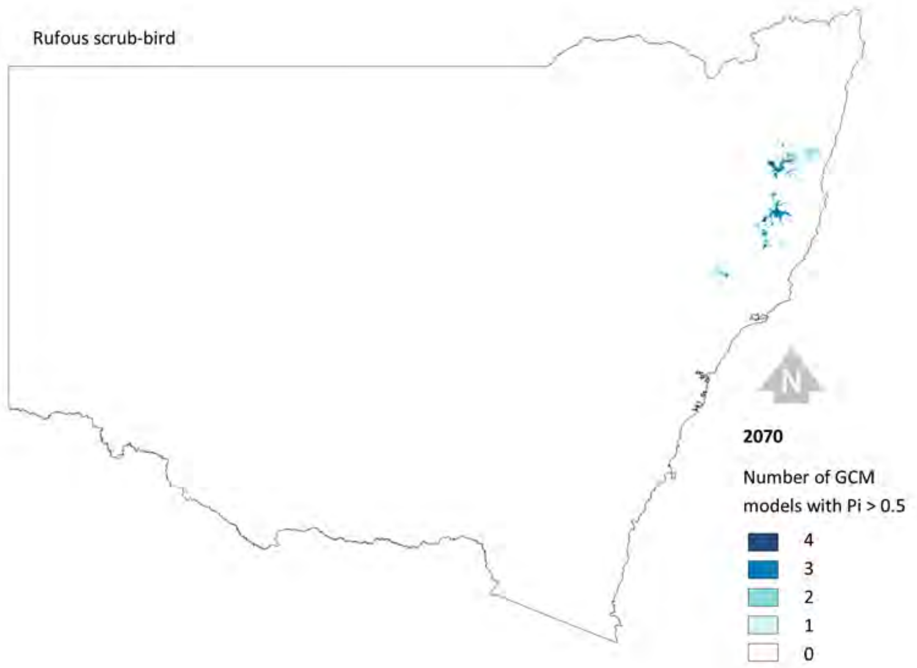
7.3 Climate projections

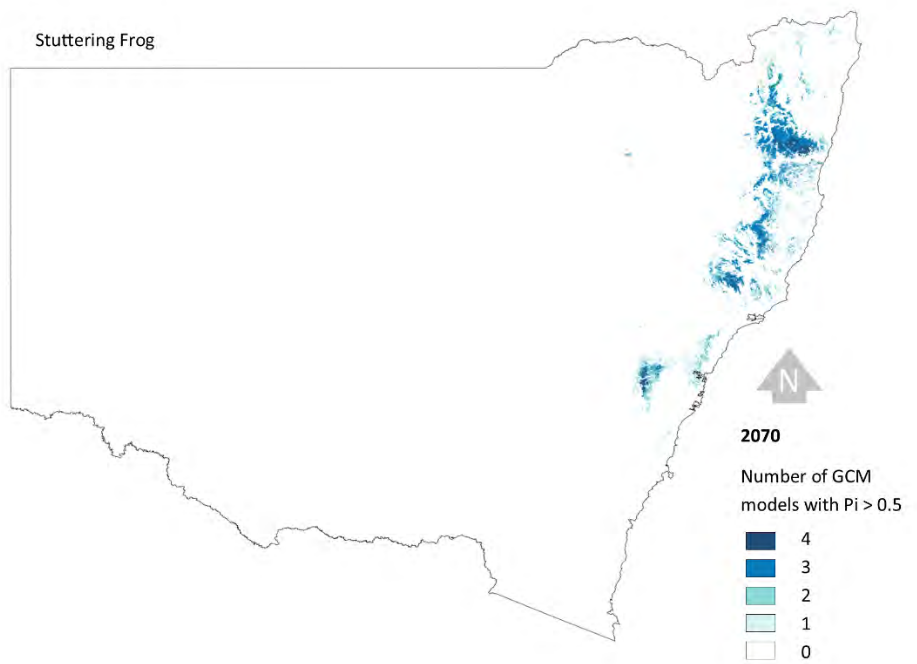
7.3.1 PLP fauna ENM and REMP models

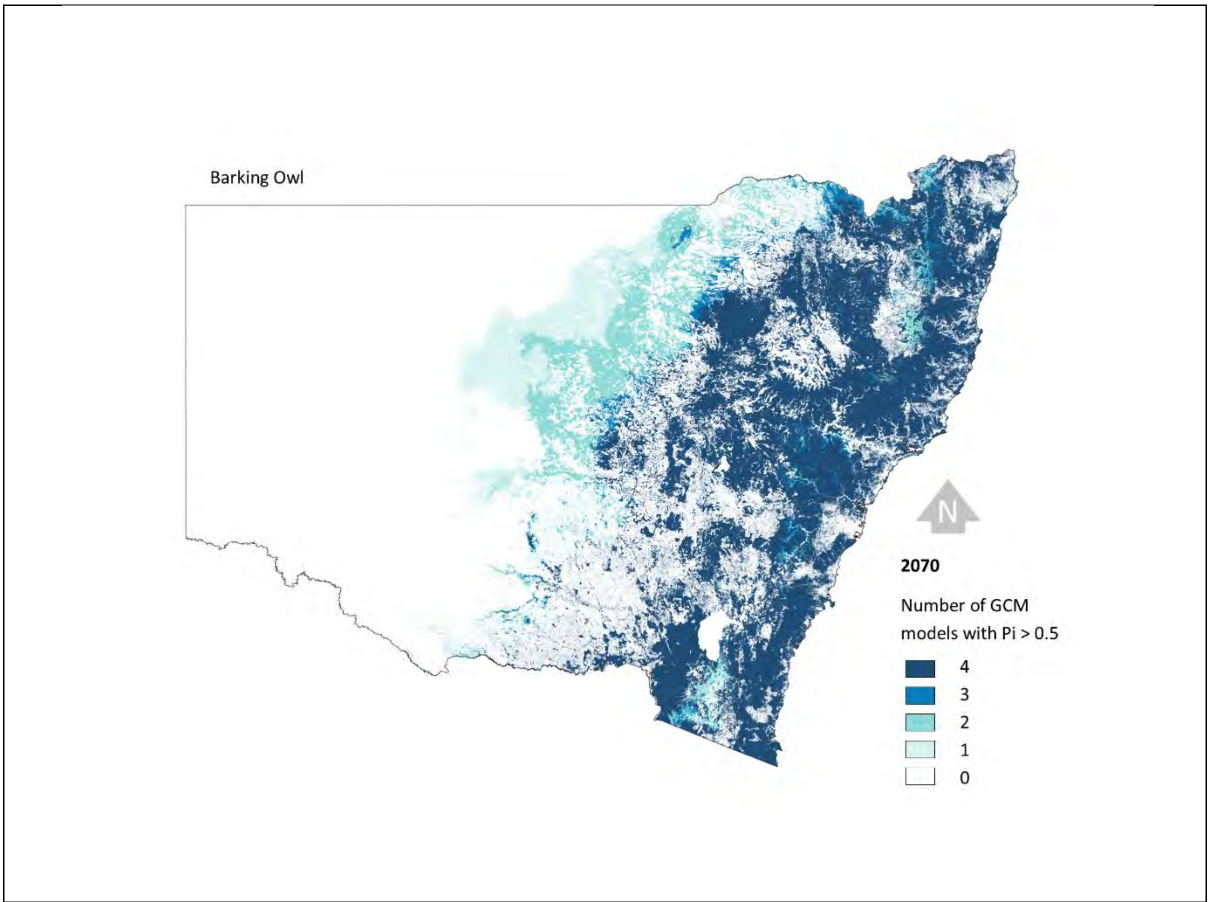
Model reports for each of the PLP Maxent ENM models are provided in Appendix 8. AUC scores indicate generally good fit of the models to the species records. The fauna model outputs were aggregated into consensus models for each species. The value in each consensus model is the number of climate scenarios (of the four GCMs) for which the species model predicted Pi values above a threshold of 0.5 (out of a range of 0 to 1). Thus, the consensus map synthesises information about both likely presence of landscape capacity and agreement among climate scenarios. The consensus maps are presented below in Figure 31.

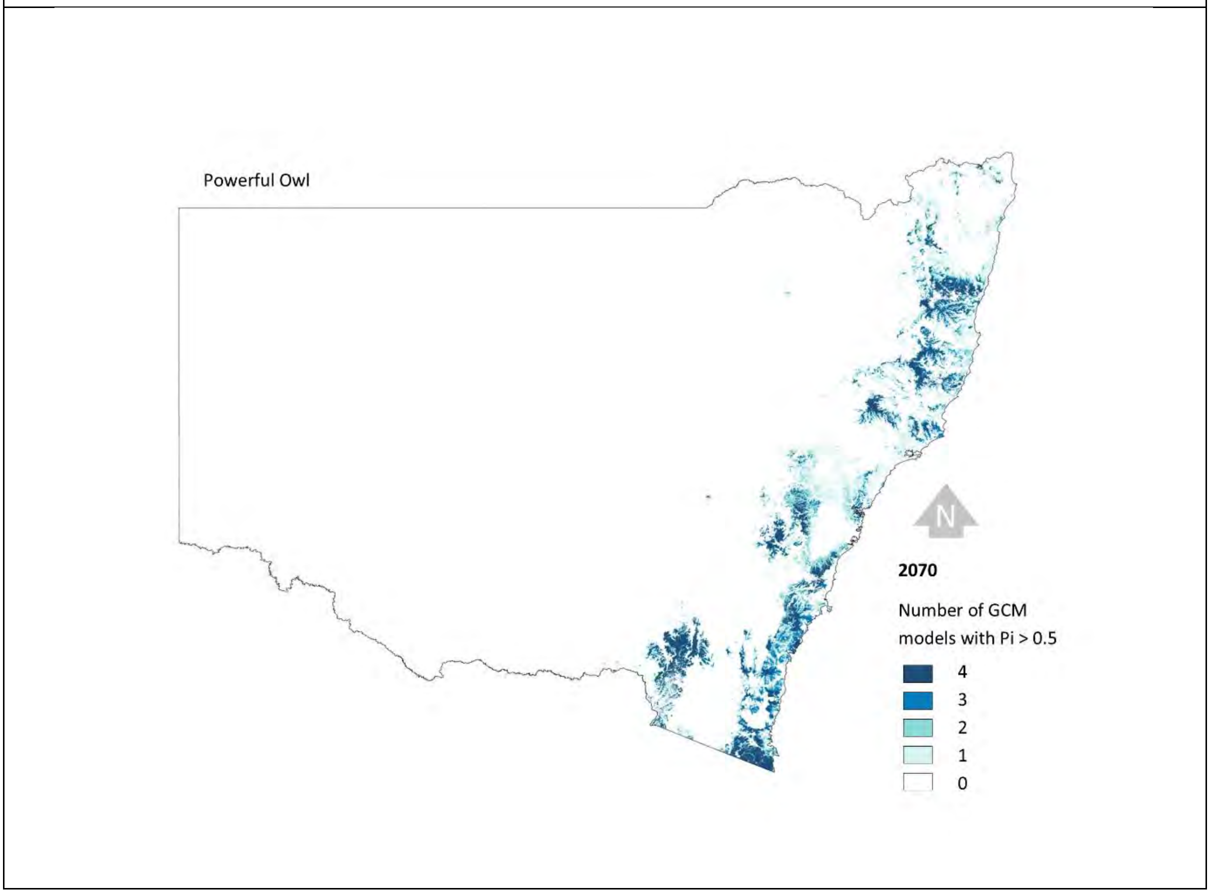
Summaries of species forecasts for the preferred model (ENM or REMP) for each of the seven species are provided in Table 34. The seven species models forecast moderate (−7%) to dramatic (−80%) reductions in landscape capacity from 2000–2070.

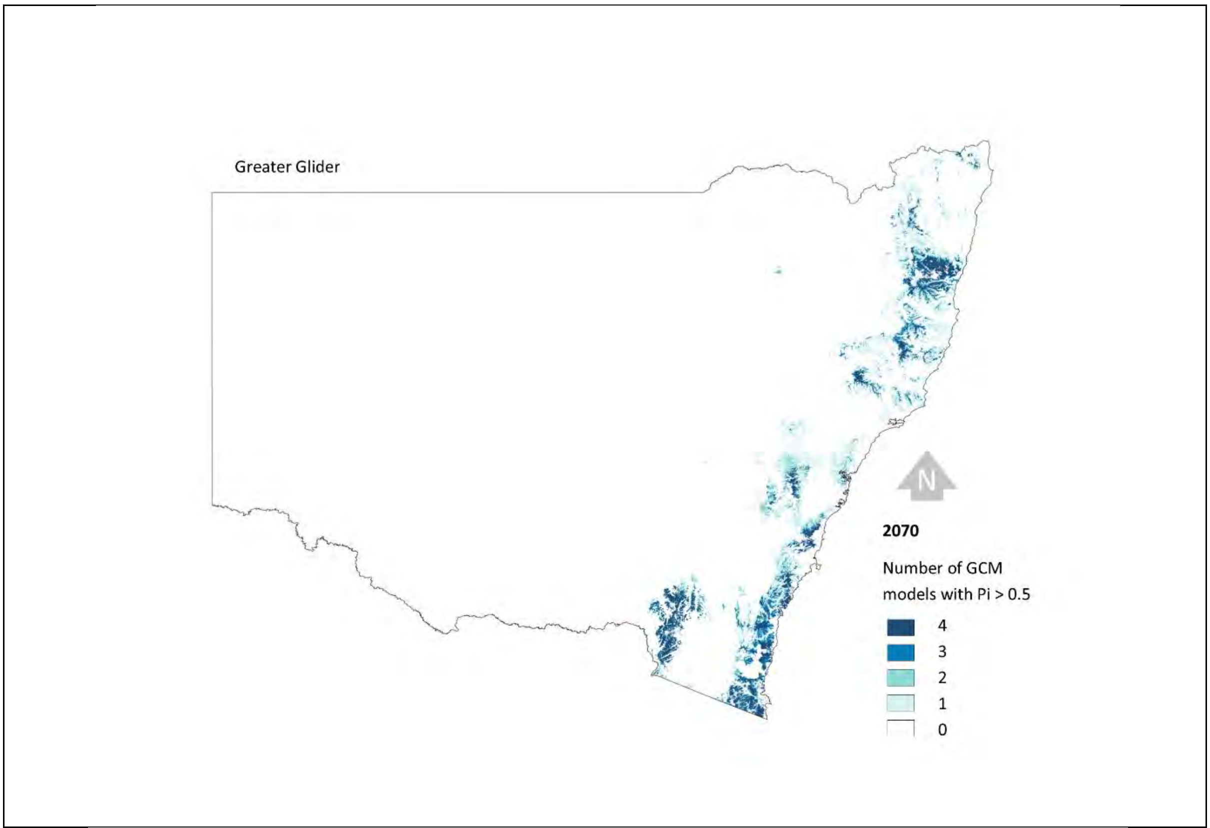



Rufous scrub-bird
N
2070
Number of GCM
models with Pi > 0.5
4
3
2
1
0


Stuttering Frog
N
2070
Number of GCM
models with Pi > 0.5
4
3
2
1
0


Barking Owl
N
2070
Number of GCM models with Pi > 0.5
4
3
2
1
0


Powerful Owl
N
2070
Number of GCM models with Pi > 0.5
4
3
2
1
0



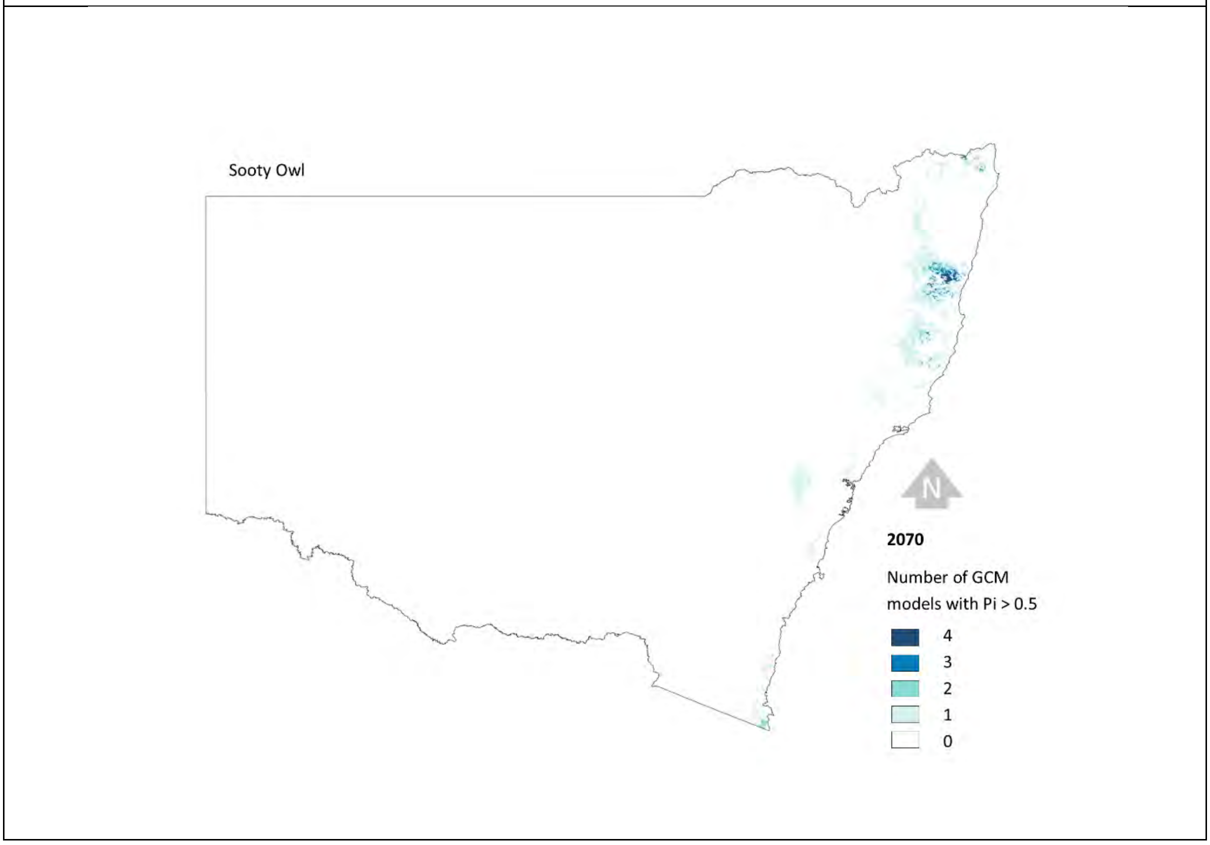


Figure 31. Consensus maps of landscape capacity for seven focus species

Each map indicates the number of NARCliM GCMs (averaged across RCMs) that lead to a potential occupancy of greater than 0.5 (out of a potential range of 0–1.0) for the species at 2070. Thus, a location with a value of 4 suggests relatively high landscape capacity at 2070, with full concensus across the climate projections.

Table 34. Change in Pi between 2000 and 2070 epochs, summed across NSW for seven priority fauna species

PLP_ID	Species	Common name	Habitat remaining 2000 (%)	Habitat remaining 2030 (%)	Habitat remaining 2070 (%)	Change 2000–2070 (%)
71	*Aepyprymnus rufescens*	Rufous Bettong	49	22	10	−80
11	*Atrichornis rufescens*	Rufous Scrub-bird	95	49	47	−51
78	*Mixophyes balbus*	Stuttering Frog	63	66	57	−9
21	*Ninox connivens*	Barking Owl	68	63	63	−7
68	*Ninox strenua*	Powerful Owl	49	41	36	−27
88	*Petauroides volans*	Greater Glider	56	49	40	−28
8	*Tyto tenebricosa*	Sooty Owl	60	44	34	−44

Some of the expected contractions in landscape capacity are dramatic, with the Rufous Bettong already listed as vulnerable in NSW, expected to lose nearly 80% of 2000 landscape capacity by 2070. The average change among the seven species was −35.21%, with a median change of −28.57%. This signals a significant projected loss due solely to climate change across these species.

Figure 32 charts the trajectories for the seven species as well as for the full set of 78 PLP models (based on refined version 3 PLP modelling for the seven species, and version 2 for the full 78 species). Note that the full PLP species set is biased towards the forested area of NSW, but does include some non-forest species as well. Although the full set includes more extreme outliers, notably *Macropus dorsalis*, which is only found west of the Great Dividing Range in NSW (increase of over 500% in landscape capacity), the mean (−18.0) and median (−31.4) are similar to those of the seven species, meaning in general terms the seven species are good indicator species of climate risk for all landscape-managed threatened species in the SoS program, and therefore may be considered good candidates for ongoing forest monitoring.

The 78 species models were combined into a combined climate refugia map by aggregating all of the species surfaces across each epoch (2000, 2030 and 2070). More weight was given to species under greater threat (according to NSW listings) and to 2070 than 2030 predictions, and less weight to 2000 surfaces. More weight was also given to geographically constrained species than widespread species (Drielsma *et al.* in prep.). Figure 33 shows the change in landscape capacity across NSW based on the 78 species. The map shows a loss (red) of weighted landscape capacity in the west (where the severity of climate change is expected to be greatest) and from the coast (where the severity of climate change is less, but there are more species to begin with). Large intact areas of native vegetation at cooler, higher altitudes, where the velocity of climate change is less, tend to remain stable or can increase in overall landscape capacity as these areas become suitable to species formerly found in areas that will become unsuitable due to rising temperatures, mostly on the coast and to the west of the dividing range. Note, the magnitude of change (roughly ± 2.0) does not indicate the predicted overall impact to species across NSW as each location is relevant to different sets of species, so the number of species affected is much greater. Full details of the PLP methods can be found in Drielsma *et al.* (in prep.).

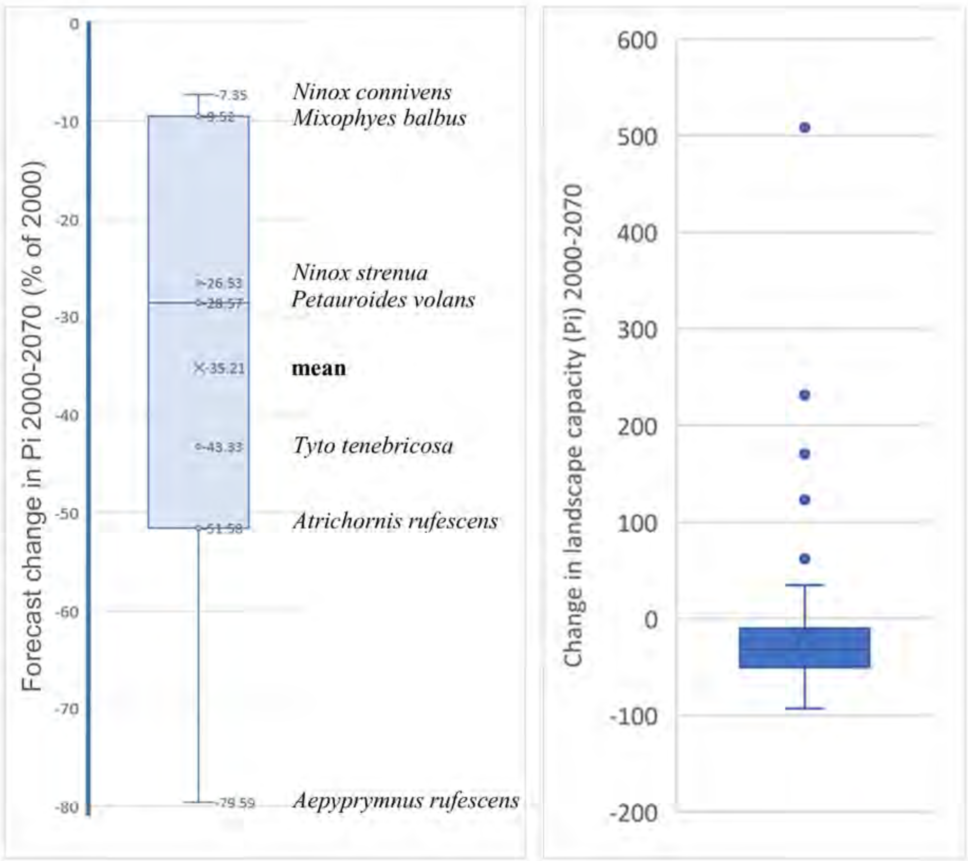


Figure 32. Predicted percentage change in Pi between 2000 and 2070 for seven selected forest species (left) and 78 landscape landscape-managed NSW-listed threatened species (right)

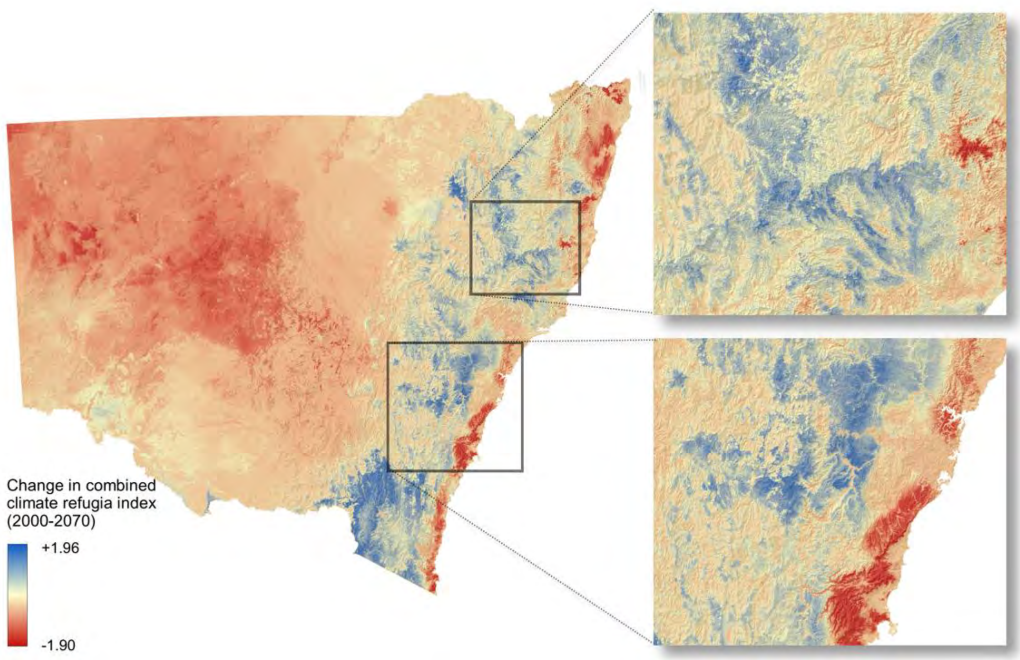


Figure 33. Change in combined climate refugia index, from 2000-only analysis to 2000–2070 analysis (source: Drielsma et al. *in prep.)*

7.3.2 Flora ENM models

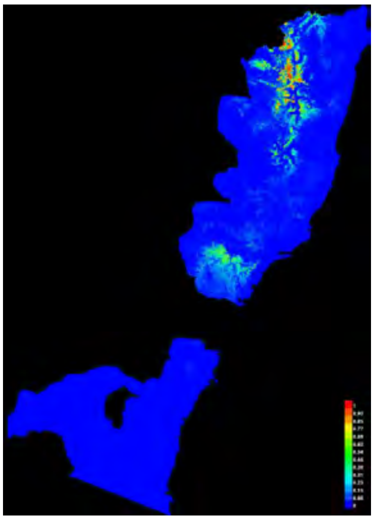
Maxent was used to project the 1990s baseline ENM surfaces of habitat suitability for 81 climate-change priority flora species using the NARCliM base climatic covariates (2000) to 2030 and 2070. The 2000 climate models were judged largely satisfactory or better in terms of accurately reflecting all ALA occurrences of each species (Table 35). Only 12 models were judged less than satisfactory in this regard and even these models predicted > 50% of all known occurrences of the respective species as suitable habitat, and so were retained for climate projections. Reports of all of the Maxent flora species climate projections are given in Appendix 11b.

Maxent performed well statistically in projecting habitat suitability under the 2030 and 2070 NARCliM climate scenarios for these climate-sensitive species, with all Test AUC values > 0.75 (Table 35). The largest group of species (42%) showed a projected reduction in habitat of medium or greater (> 0.45) suitability between 2000 and 2030 (Table 35), an extreme example being *Eucalyptus brunnea*, which is projected to lose basically all habitat of medium or better suitability in the study region by 2030 (Figure 34a, b). More typical were species such as *Persoonia oleoides* (Figure 34c, d) and *Acrothamnus hookeri* (Figure 34e, f), for which projected habitat suitability declined to a marked or minor degree. A third of species showed the reverse trend, with greater predicted habitat suitability in 2030 than 2000, to a lesser or greater degree, respectively, such as *Acacia mearnsii* (Figure 34g, h) and *Leptinella filicula* (Figure 34i, j). A further quarter of species showed no change in the projected extent of habitat of medium or higher suitability between 2000 and 2030, *Angophora woodsiana* being an example (Figure 34k, l).

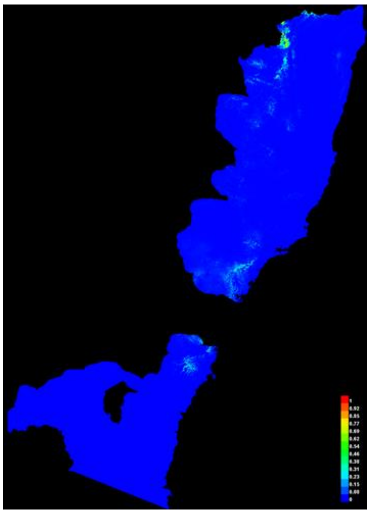
The 2000 to 2070 climatic projections produced more consistent change in species' habitat suitability, with only three species showing no projected change in medium to high habitat suitability extent, *Euroschinus falcatus* being an example (Figure 35a, b). The largest group of species (59%) was projected to have a reduced extent of habitat of medium to high suitability by 2070, to a lesser or greater degree, examples being *Denhamia bilocularis* (Figure 35c, d) and *Eucalyptus pauciflora* (Figure 35e, f), respectively. Remaining species (37%) were projected to have a greater extent of medium to high habitat suitability due to climate change, either to a minor or marked degree: *Gompholobium latifolium* (Figure 35g, h) and *Brunoniella pumilio* (Figure 35i, j), respectively.

Several trends were evident in the 2070 projections: (1) areas of medium to high habitat suitability of several species with North Coast distributions were projected to extend further south by 2070, an example being *Angophora costata* (Figure 35k, l); (2) the high elevation forests around Point Lookout and Barrington Tops are projected to have medium to high habitat suitability for many southern NSW species by 2070, even though these species are not currently known from northern NSW, an example being *Poa ensiformis* (Figure 35m, n); (3) suitable habitat for some higher elevation species is projected to shrink further upslope by 2070, an example being *Eucalyptus obliqua* (Figure 35o, p). More general trends by 2070 were that: (1) the extent of suitable habitat of most of the priority canopy-dominant eucalypts will have declined by 2070; (2) most species distributed on the North Coast or North and South Coast will enjoy an increase in suitable habitat, whereas (3) most species with South Coast, northern ranges and or southern ranges distributions will suffer reductions in suitable habitat in the study region. Given that the global climate model (MIROC3.2) used for these climate projections predicts a warmer wetter future climate, and that three other equally likely GCMs predict hotter or drier climates, or both, the level of predicted change in habitat suitability of climate-sensitive flora species, outlined above, is a best-case scenario in terms of heat waves and drought (although not necessarily in terms of storm damage, inundation or weeds). These findings point to the need for future biodiversity monitoring to focus on climate-sensitive species and those parts of the eastern forests of NSW likely to come under greatest pressure from climate change.

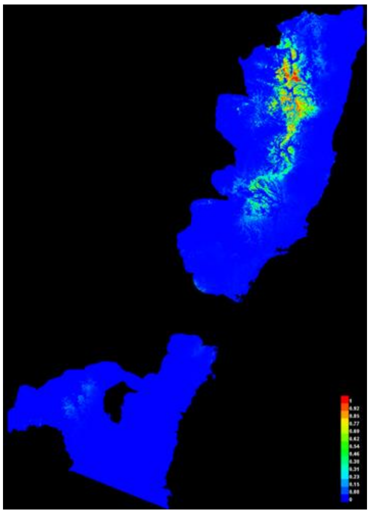
(a)



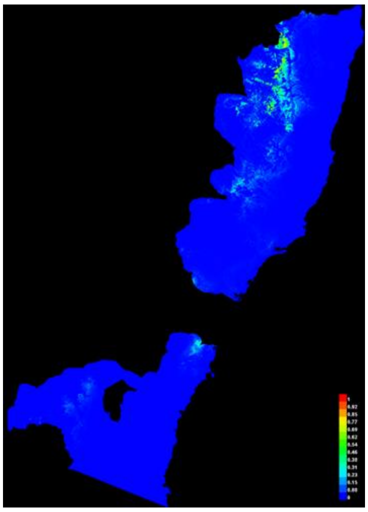
(b)



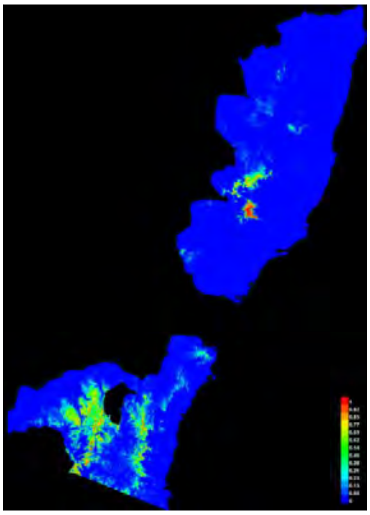
(c)



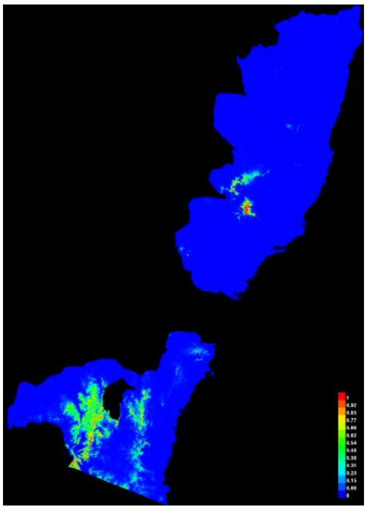
(d)



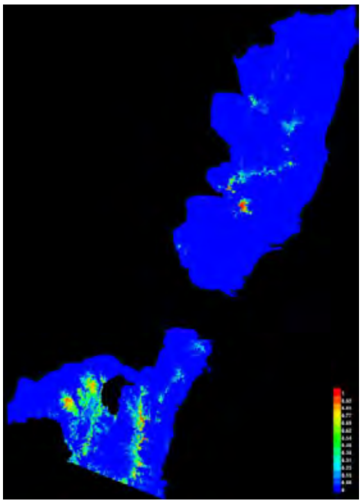
(e)



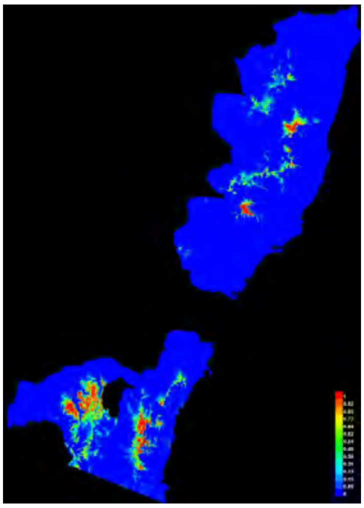
(f)



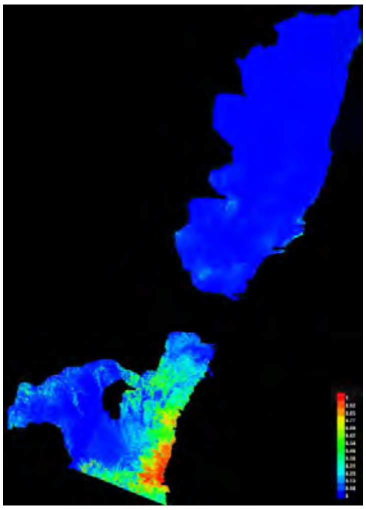
(g)



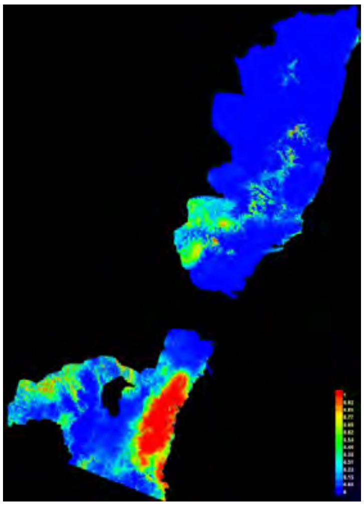
(h)



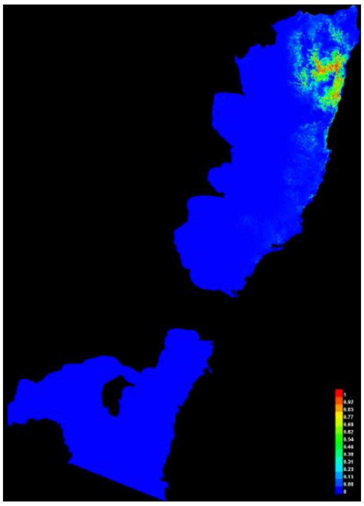
(i)



(j)



(k)



(l)

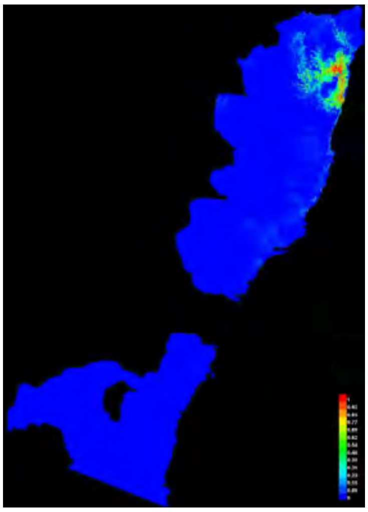
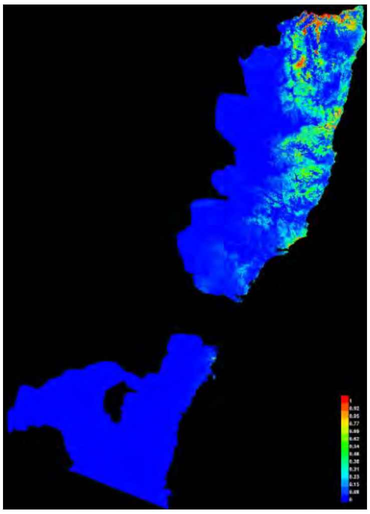


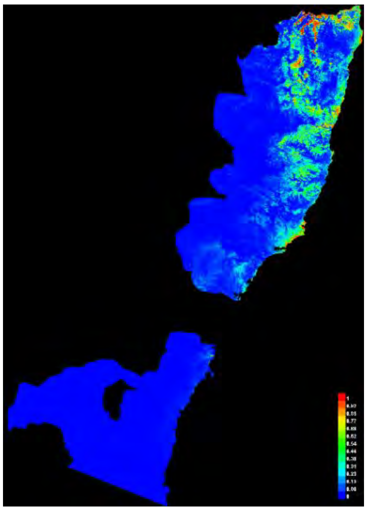
Figure 34. Maxent projections of the habitat suitability of selected climate-sensitive flora species

Maxent projections of the habitat suitability of selected climate-sensitive flora species in (a, c, e, g, h) 2000 and (b, d, f, h, j) 2030: (a, b) Eucalyptus brunnea*; (c, d)* Persoonia oleoides*; (e, f) Acrothamnus hookeri; (g, h)* Acacia mearnsii*; (i, j)* Leptinella filicula*, and (k, l)* Angophora woodsiana

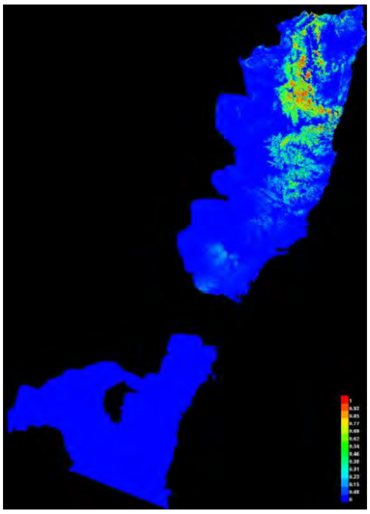
(a)



(b)



(c)



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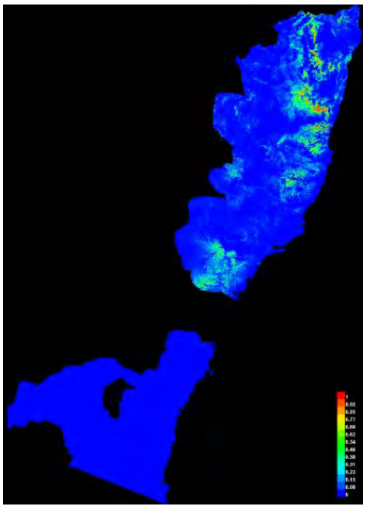
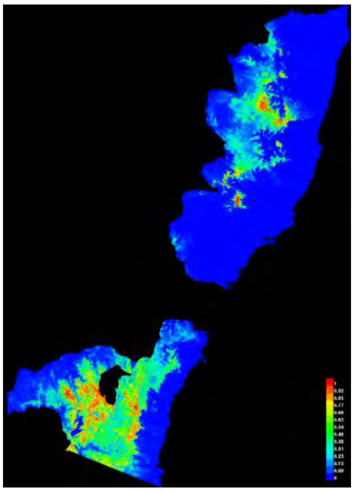
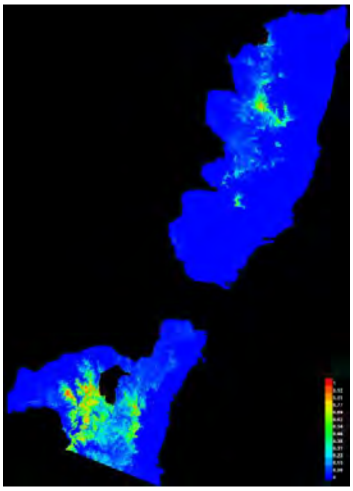


(e)



(f)



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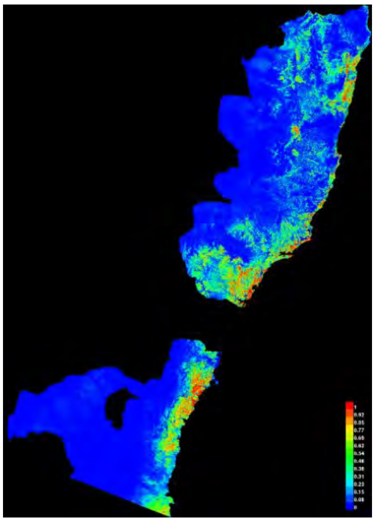

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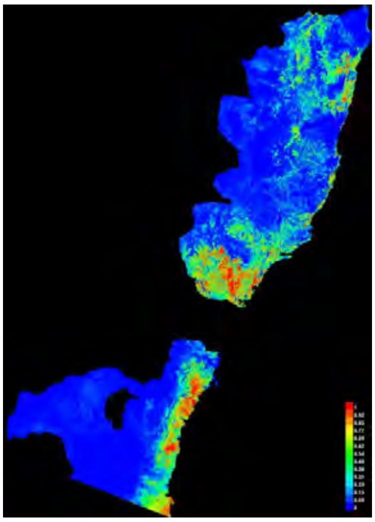

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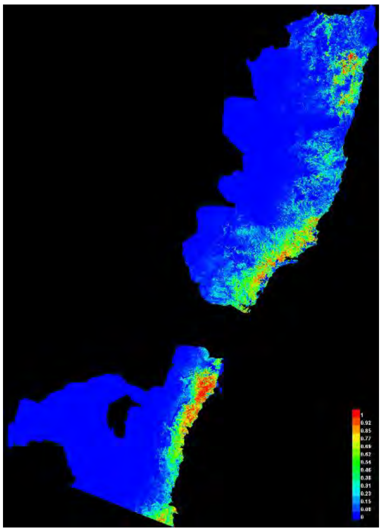

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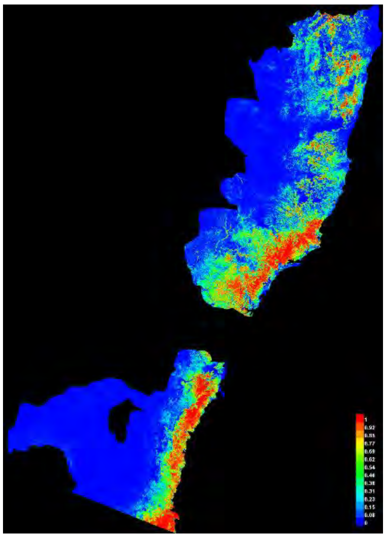
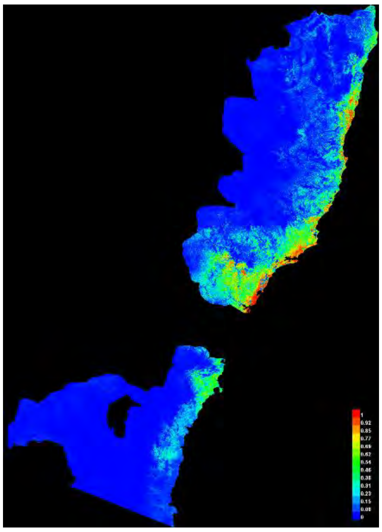
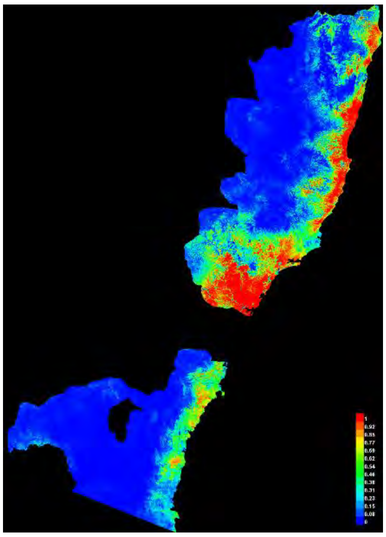


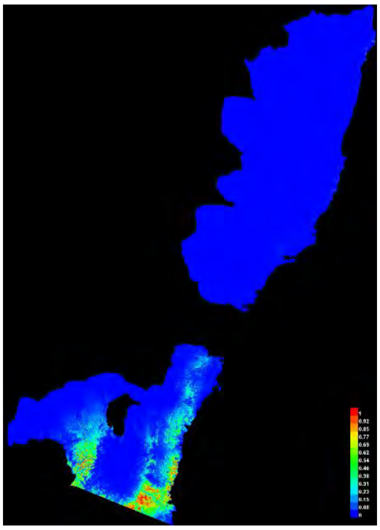
(k)



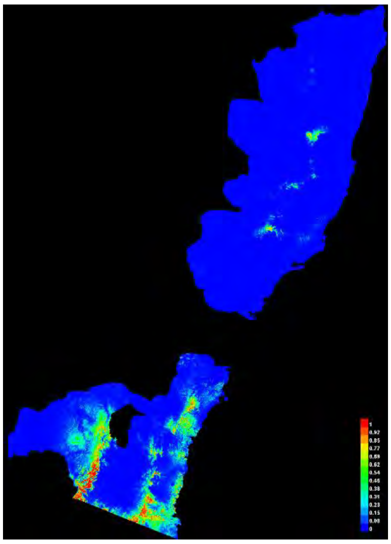
(l)



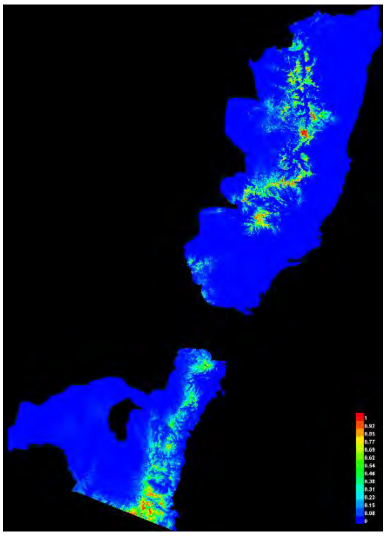
(m)



(n)



(o)



(p)

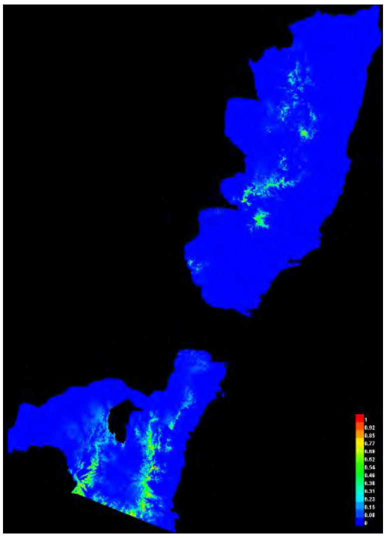


Figure 35. Maxent projections of the habitat suitability of selected climate-sensitive flora species

Maxent projections of the habitat suitability of selected climate-sensitive flora species in (a, c, e, g, i, k, m) 2000 and (b, d, f, h, j, l, n) 2070: (a, b) Euroschinus falcatus *var.* falcatus*; (c, d)* Denhamia bilocularis*; (e, f)* Eucalyptus pauciflora*; (g, h)* Gompholobium latifolium*; (i, j)* Brunoniella pumilio*; (k, l)* Angophora costata*; (m, n)* Poa ensiformis*; (o, p)* Eucalyptus obliqua*.*

Table 35. The goodness of fit, AUC scores and outcomes of Maxent models of 81 climate-sensitive flora species and climate projections from 2000 to 2030 and from 2000 to 2070

The goodness of fit of Maxent habitat suitability surfaces modelled with 2000 NARCliM climatic co-variates were judged in relation to all ALA occurrences. Change in habitat suitability (Δ Hab. suit.) was judged visually, comparing 2000 surfaces with 2030 and 2070 projections, respectively. Key: 'nc' = no change; '+' = projected increase in medium to high habitat suitability; '–' = projected decrease in medium to high habitat suitability

Species	Goodness of fit of 2000 model	2030 projection			2070 projection		
		AUC Train	AUC Test	Δ Hab. suit.	AUC Train	AUC Test	Δ Hab. suit.
Acacia concurrens	Ok	0.9608	0.9493	–	0.9595	0.9496	+
Acacia mearnsii	Ok	0.9376	0.9351	+	0.9375	0.9327	+
Acacia terminalis	Ok	0.9120	0.9061	–	0.9116	0.9051	+
Acrothamnus hookeri	Good	0.9662	0.9560	–	0.9660	0.9608	–
Alpinia caerulea	Ok	0.9530	0.9499	nc	0.9543	0.9514	+
Angophora costata	Ok	0.9221	0.9173	nc	0.9181	0.9129	+
Angophora subvelutina	Ok–good	0.9169	0.9081	+	0.9171	0.9086	+
Angophora woodsiana	Good	0.9783	0.9736	nc	0.9786	0.9728	+
Aristida ramosa	Ok	0.8467	0.8333	–	0.8485	0.8375	–
Asperula scoparia	Ok–good	0.9378	0.9338	nc	0.9366	0.9305	–
Banksia oblongifolia	Ok–good	0.9666	0.9633	+	0.9651	0.9617	+
Bedfordia arborescens	Ok	0.9730	0.9703	nc	0.9730	0.9704	–
Bossiaea neo-anglica	Ok	0.9762	0.9713	nc	0.9762	0.9707	–
Brunoniella pumilio	Ok–good	0.9326	0.9100	+	0.9301	0.9040	+
Cassinia trinerva	Ok	0.9570	0.9447	+	0.9578	0.9463	+
Chrysocephalum apiculatum	Ok	0.8365	0.8282	nc	0.8358	0.8255	–
Coprosma hirtella	Ok	0.9687	0.9640	+	0.9680	0.9626	–
Correa reflexa	Ok	0.9039	0.8952	–	0.9038	0.8976	–
Croton verreauxii	Ok	0.9402	0.9322	–	0.9413	0.9344	+
Denhamia bilocularis	Ok	0.9573	0.9515	–	0.9566	0.9502	–
Dodonaea triquetra	Ok	0.9101	0.9015	–	0.9093	0.8985	+
Epacris impressa	Poor–ok	0.9719	0.9705	+	0.9717	0.9705	–
Eragrostis leptostachya	Poor–ok	0.8634	0.8483	+	0.8630	0.8490	–
Eremophila debilis	Ok	0.9317	0.9231	–	0.9340	0.9231	–
Eucalyptus agglomerata	Ok	0.9276	0.9209	–	0.9303	0.9224	–
Eucalyptus biturbinata	Ok–good	0.8477	0.8391	–	0.8522	0.8445	–
Eucalyptus brunnea	Ok	0.9675	0.9578	–	0.9660	0.9591	–
Eucalyptus caliginosa	Ok	0.9445	0.9407	nc	0.9425	0.9369	–
Eucalyptus cameronii	Poor–ok	0.9512	0.9460	–	0.9503	0.9451	–
Eucalyptus campanulata	Ok–good	0.9311	0.9281	–	0.9318	0.9298	–
Eucalyptus cypellocarpa	Ok	0.9492	0.9477	nc	0.9470	0.9456	–
Eucalyptus dalrympleana	Ok–good	0.9142	0.9097	+	0.9150	0.9106	–
Eucalyptus elata	Ok	0.9663	0.9625	–	0.9674	0.9643	nc
Eucalyptus laevopinea	Ok	0.9268	0.9225	–	0.9275	0.9209	–
Eucalyptus longifolia	Ok	0.9788	0.9743	–	0.9812	0.9771	–
Eucalyptus macrorhyncha	OK	0.9248	0.9190	nc	0.9254	0.9183	–
Eucalyptus melliodora	Ok	0.8491	0.8302	–	0.8484	0.8375	–
Eucalyptus moluccana	Ok–good	0.8854	0.8717	–	0.8901	0.8780	nc
Eucalyptus muelleriana	Ok	0.9679	0.9661	nc	0.9673	0.9650	–

Species	Goodness of fit of 2000 model	2030 projection			2070 projection		
		AUC Train	AUC Test	Δ Hab. suit.	AUC Train	AUC Test	Δ Hab. suit.
Eucalyptus obliqua	Ok	0.9422	0.9404	–	0.9421	0.9408	–
Eucalyptus paniculata	Ok	0.9432	0.9357	–	0.9445	0.9391	+
Eucalyptus pauciflora	Ok–good	0.9032	0.8964	–	0.9037	0.8971	–
Eucalyptus planchoniana	Good	0.9805	0.9733	–	0.9794	0.9724	+
Eucalyptus radiata	Good	0.8947	0.8897	+	0.8962	0.8919	–
Eucalyptus smithii	Ok	0.9719	0.9615	–	0.9724	0.9656	–
Eucalyptus viminalis	Ok	0.8764	0.8659	+	0.8737	0.8625	–
Euroschinus falcatus	Ok	0.9451	0.9385	nc	0.9421	0.9343	nc
Glochidion ferdinandi	Good	0.9100	0.9045	+	0.9093	0.9041	+
Gompholobium latifolium	Ok–good	0.9152	0.9037	nc	0.9139	0.9020	+
Gompholobium pinnatum	Ok–good	0.9634	0.9556	+	0.9651	0.9546	+
Goodenia rotundifolia	Ok	0.9300	0.9195	–	0.9291	0.9177	+
Hibbertia vestita	Ok	0.9583	0.9497	nc	0.9578	0.9484	+
Hierochloe rariflora	Ok	0.9751	0.9727	+	0.9750	0.9726	–
Hybanthus stellarioides	Ok	0.9409	0.9313	–	0.9412	0.9340	+
Lepidosperma urophorum	Ok	0.9386	0.9314	+	0.9395	0.9344	–
Leptinella filicula	Good	0.9791	0.9654	+	0.9791	0.9638	–
Lophostemon suaveolens	Poor–ok	0.9785	0.9739	nc	0.9789	0.9743	+
Mallotus philippensis	Ok	0.9343	0.9273	+	0.9325	0.9265	+
Melichrus procumbens	Ok–good	0.9314	0.9145	–	0.9316	0.9105	+
Olearia argophylla	Ok–good	0.9620	0.9497	nc	0.9624	0.9498	–
Oreomyrrhis eriopoda	Ok–good	0.9217	0.9129	–	0.9189	0.9105	–
Ozothamnus argophyllus	Ok	0.9736	0.9652	+	0.9741	0.9664	–
Ozothamnus cuneifolius	Ok	0.9880	0.9860	+	0.9873	0.9847	+
Panicum effusum	Ok	0.8262	0.8095	+	0.8239	0.8083	–
Persoonia chamaepeuce	Ok	0.9595	0.9519	nc	0.9602	0.9529	–
Persoonia oleoides	Ok–good	0.9691	0.9647	–	0.9701	0.9629	–
Persoonia silvatica	Ok	0.9801	0.9777	+	0.9809	0.9761	–
Persoonia stradbrokensis	Ok	0.9677	0.9653	–	0.9656	0.9629	+
Pimelea axiflora	Ok	0.9767	0.9724	+	0.9769	0.9737	+
Platylobium formosum	Poor–ok	0.9233	0.9171	+	0.9219	0.9144	+
Platysace ericoides	Ok	0.9088	0.8989	–	0.9078	0.8982	–
Poa ensiformis	Ok	0.9106	0.9080	+	0.9067	0.9047	+
Poa meionectes	Poor–ok	0.9687	0.9611	+	0.9673	0.9609	–
Pomaderris aspera	Poor–ok	0.9407	0.9341	+	0.9414	0.9342	+
Prostanthera lasianthos	Poor–ok	0.9272	0.9129	nc	0.9250	0.9083	–
Psychotria daphnoides	Poor–ok	0.9836	0.9745	–	0.9858	0.9786	–
Pultenaea daphnoides	Poor–ok	0.9610	0.9544	–	0.9623	0.9579	–
Pultenaea villosa	Ok	0.9436	0.9358	nc	0.9400	0.9315	+
Scleria mackaviensis	Poor–ok	0.9245	0.8961	+	0.9236	0.8882	–
Sorghum leiocladum	Poor–ok	0.8769	0.8666	nc	0.8737	0.8655	–
Tetratheca bauerifolia	Ok	0.9654	0.9549	–	0.9658	0.9564	–

7.4 Species trend analyses

Data on trends of forest species are limited but we present examples from different taxa based on occupancy analyses or alternative approaches to capturing trends (Table 36). While occupancy analyses will be relevant for tracking trends in most species, other indicators may also be appropriate for some taxa (e.g. activity for bats; Law *et al.* 2021). Assessment of these data will provide context for interpreting future monitoring of forest species.

It is important to understand that each of the studies reported below were conducted in dynamic landscapes in which habitat suitability for the focal species may be changing due to a range of factors, including time since fire, logging, plantation establishment, and climate (e.g. drought). A brief description of the relevant landscape context is provided in the sections below.

7.4.1 Owls, gliders and possums

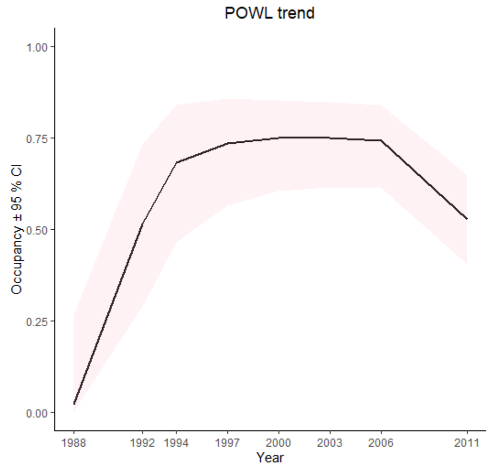
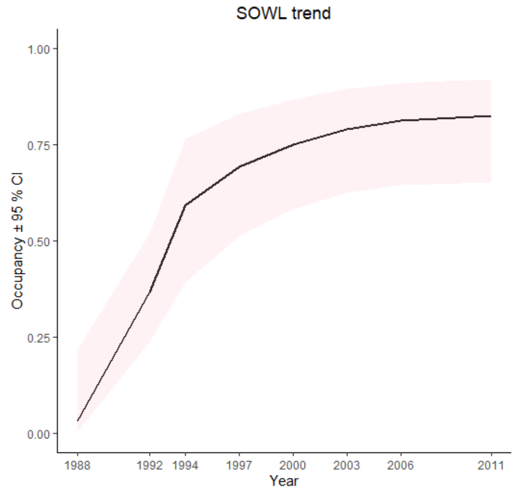
One hundred and one (101) sites across approximately 100,000 ha of forest, including state forests and a national park and a nature reserve south of Eden, were surveyed between 1988–2011 using listening, call-playback and spotlighting techniques (Kavanagh *et al.* unpub. data). The study was conducted in a landscape that was affected by significant recent disturbances, and aimed to monitor changes in the distribution, abundance and rate of recovery of an assemblage of nocturnal, forest-dependent fauna. Major wildfires burnt large portions of the study area in the early 1950s, 1970s and 1980s, and intensive logging began in the late 1960s gradually impacting most areas of state forest during the study. Unlogged forest was retained only in several wide creek reserves, or as narrow strips along creeks, or in alternate uncut coupes (which were progressively harvested), and in the national park and nature reserve. This fire and logging history negatively affected the occurrence of several species of nocturnal, forest-dependent fauna at the start of the study.

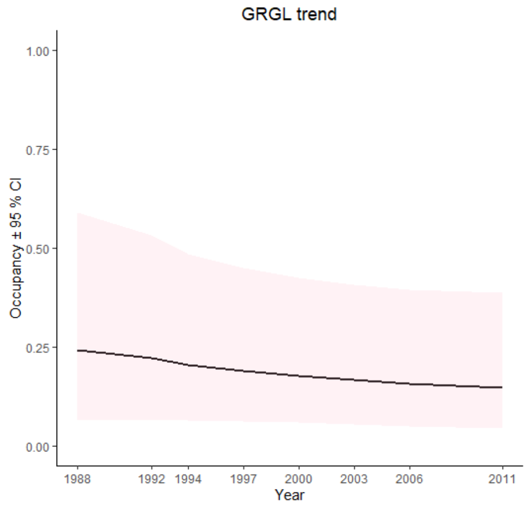
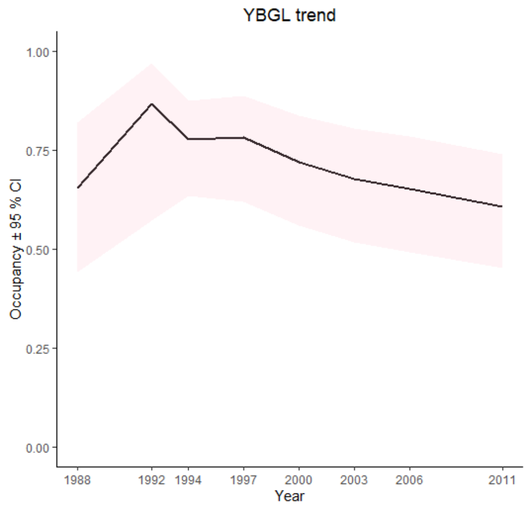
Initial occupancy in 1988 was very low for the two large forest owls, the Powerful Owl (*Ninox strenua*) and Sooty Owl (*Tyto tenebricosa*), and for two arboreal marsupials, the Mountain Brushtail Possum (*Trichosurus caninus*) and Common Brushtail Possum (*T. vulpecula*) (Table 37). Over the following two decades, the Powerful Owl and the Sooty Owl increased dramatically in their distribution and abundance throughout the study area. The principal prey species for both of these owls is the Common Ringtail Possum (*Pseudocheirus peregrinus*) (Kavanagh 2002) which was initially widespread and abundant (occupancy 0.88). Over time, the Common Ringtail Possum declined in occupancy, partly in response to increased predation pressure. Extinction probability for this species was more likely at sites with recent (< 10 years) harvesting and recent fire history, whereas colonisation probability was increased at sites which had not burnt for several decades. A significant habitat feature for the Common Ringtail Possum in these forests are well-developed stands of the Black She-Oak (*Allocasuarina littoralis*) which provide important shelter and food resources for this Possum. *A. littoralis* is known to be killed by wildfire but forms dense stands in long unburnt forest (Lunt 1998).

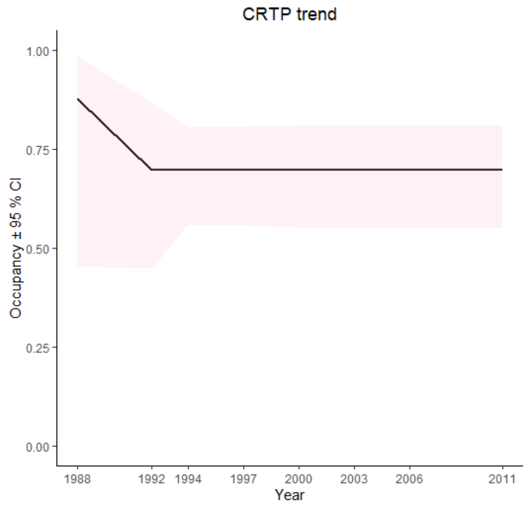
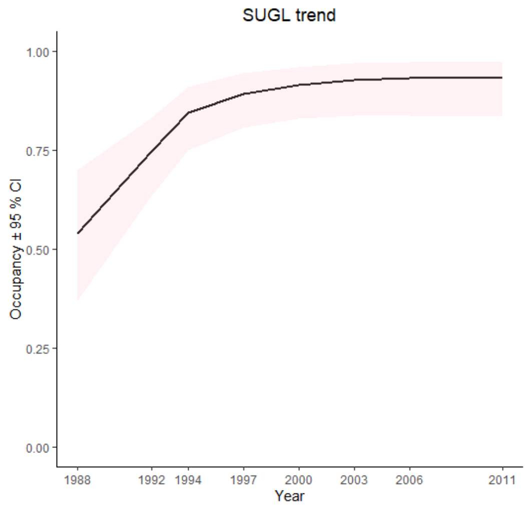
The Greater Glider (*Petauroides volans*) is of concern in these forests because its occupancy was in steady decline (Table 37). The distribution of this species was strongly associated with the extent of rainforest (i.e. wetter, more productive sites), but its extinction probability was increased by logging, thinning and fire disturbance in the landscape. The colonisation probability of this species was associated with greater proportions of unlogged forest in the landscape – a feature that was also in steady decline in the study area. Note that at a broader regional scale, mean annual temperature was the most influential covariate, in our analyses, but different covariates are important at different scales.

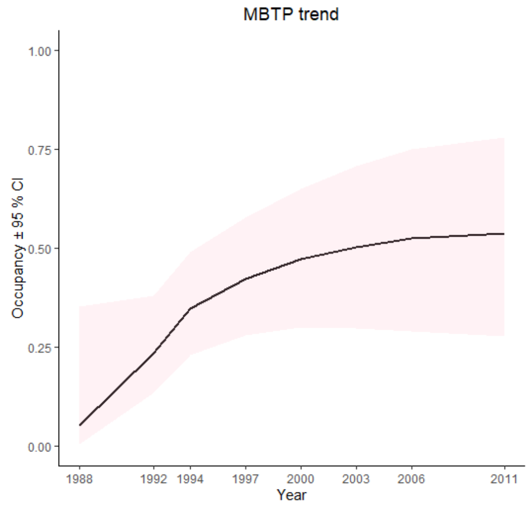
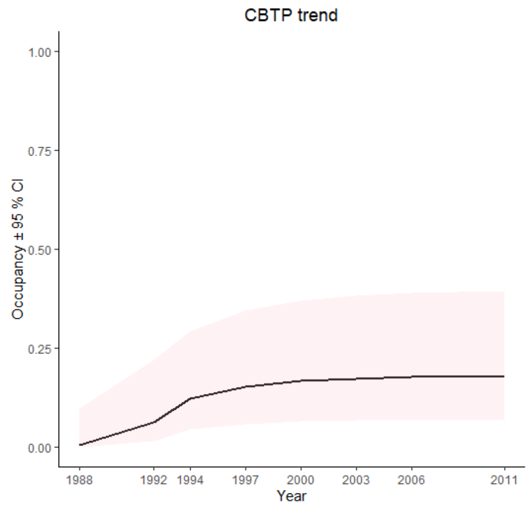
Table 36. Summary of species occupancy trends

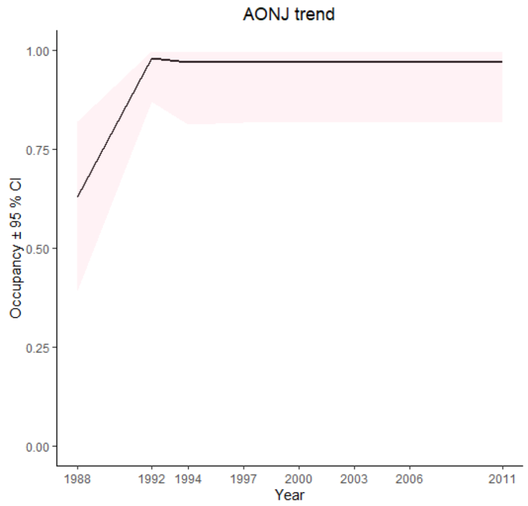
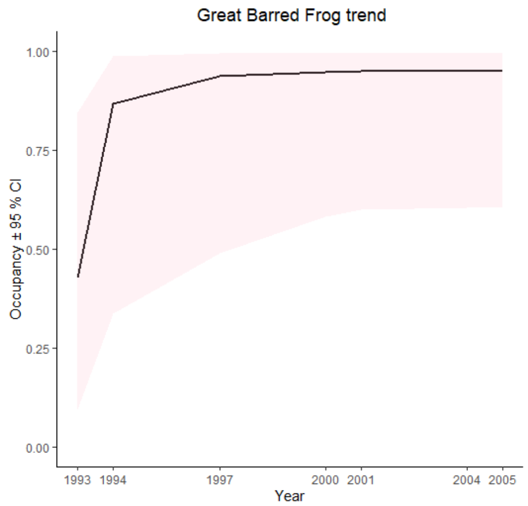
See subsequent sections below for details

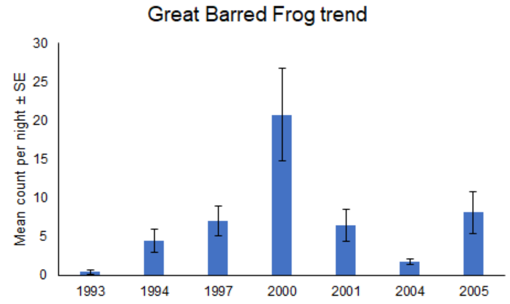
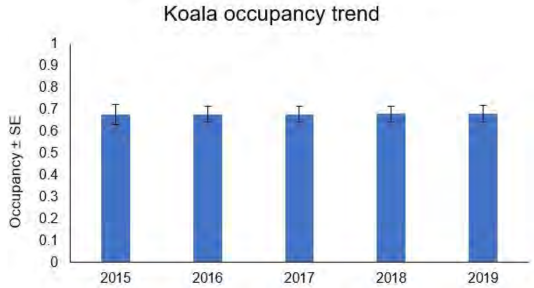
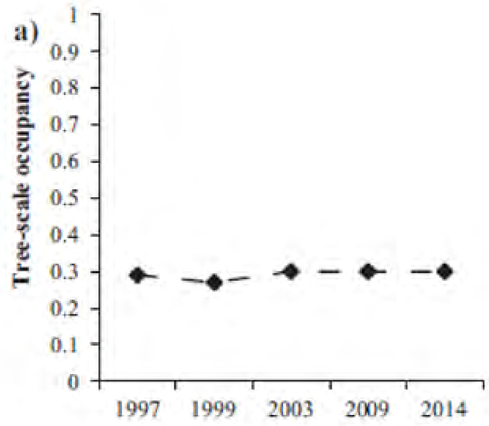
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Powerful Owl	Eden	Kavanagh	1988 – 2011	Occupancy	Variable; increasing then decline	
Sooty Owl	Eden	Kavanagh	1988 – 2011	Occupancy	Positive	

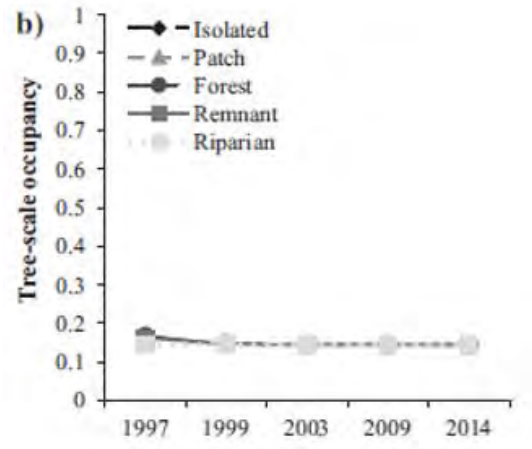
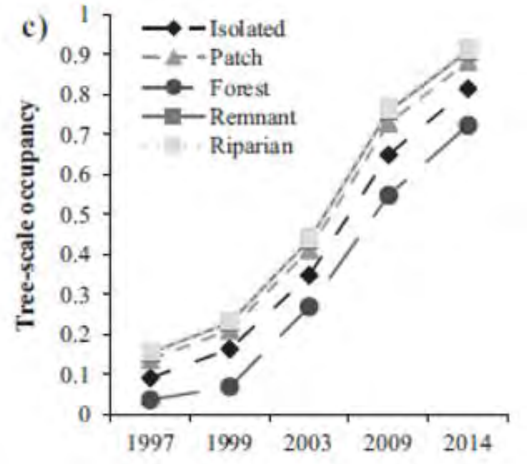
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Greater Glider	Eden	Kavanagh	1988 – 2011	Occupancy	Steady decline	
Yellow-bellied Glider	Eden	Kavanagh	1988 – 2011	Occupancy	Stable, or slight decline	

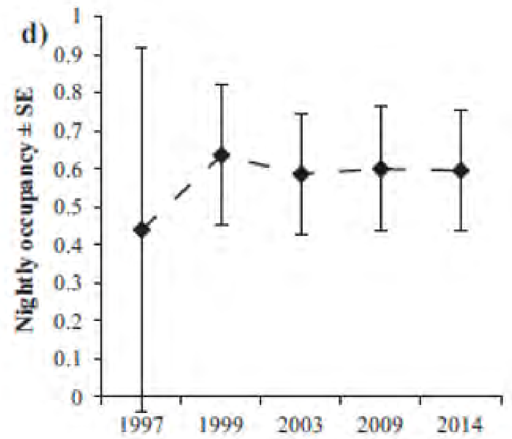
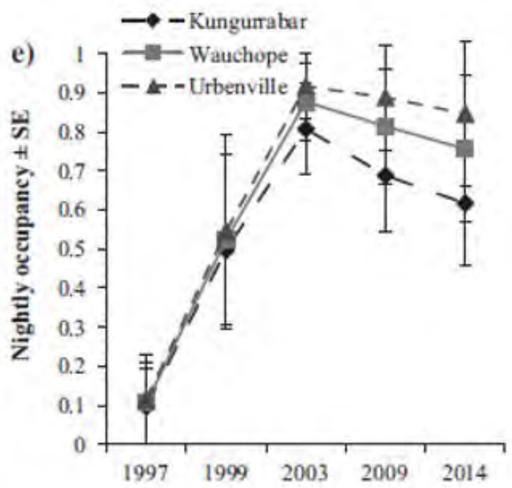
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Common Ringtail Possum	Eden	Kavanagh	1988 – 2011	Occupancy	Decline, then stable	
Sugar Glider	Eden	Kavanagh	1988 – 2011	Occupancy	Positive	

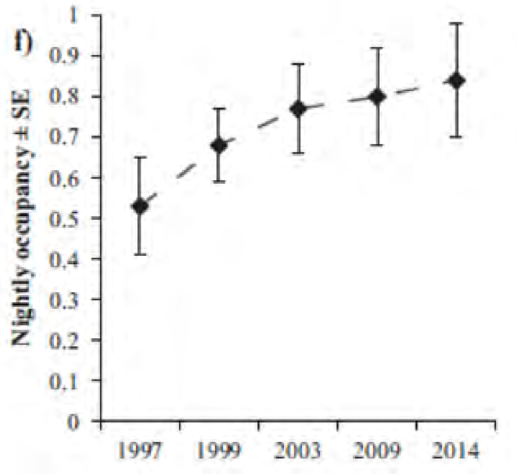
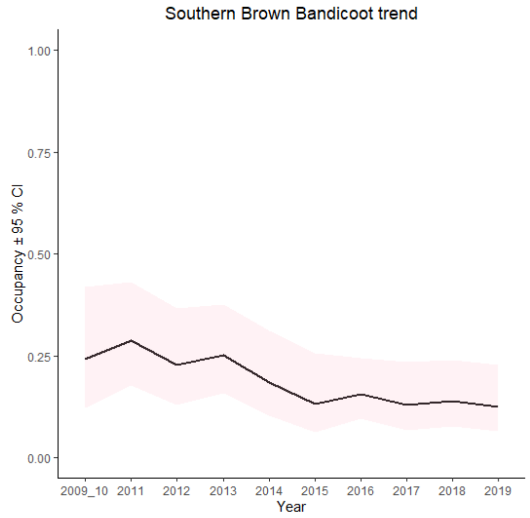
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Mountain Brushtail Possum	Eden	Kavanagh	1988 – 2011	Occupancy	Positive	
Common Brushtail Possum	Eden	Kavanagh	1988 – 2011	Occupancy	Positive	

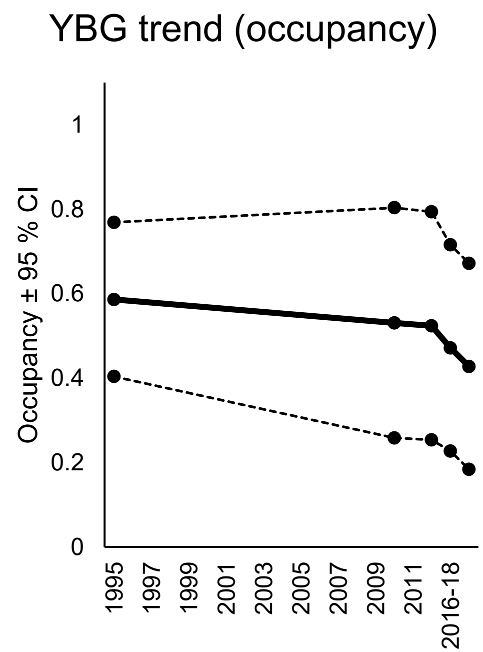
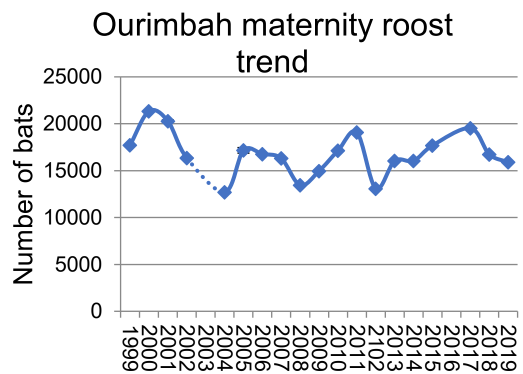
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Australian Owlet Nightjar	Eden	Kavanagh	1988 – 2011	Occupancy	Increase, then stable	
Great Barred Frog	Chaelundi	Lemckert	1993 – 2005	Occupancy	Positive	

Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Great Barred Frog	Chaelundi	Lemckert	1993 – 2005	Activity (calling)	Fluctuating	
Koala	Northeast Hinterland	Law	2015 – 2019	Occupancy	Stable	
Sugar/Squirrel Gliders	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (tree-level)	Stable	

Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Tawny Frogmouth	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (tree-level)	Stable	
Common Brushtail Possum	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (tree-level)	Positive	

Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Koala	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (plantation-level)	Stable	
Southern Boobook	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (plantation-level)	Positive	

Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Australian Owlet nightjar	Northern NSW Plantations (Wauchope, Grafton, Urbenville)	Law	1997-2014	Occupancy (plantation-level)	Positive	
Southern Brown Bandicoot	Eden	Bilney	2009/10-2019	Occupancy	Negative	

Species	**Region**	**Data source**	**Monitoring period**	**Metric**	**Trend**	**Figure**
Yellow-bellied Glider	Bago-Maragle	Bilney	1995-2018	Occupancy	Negative	
Eastern Horseshoe Bat	Ourimbah	Law	1999-2019	Abundance	Fluctuating	

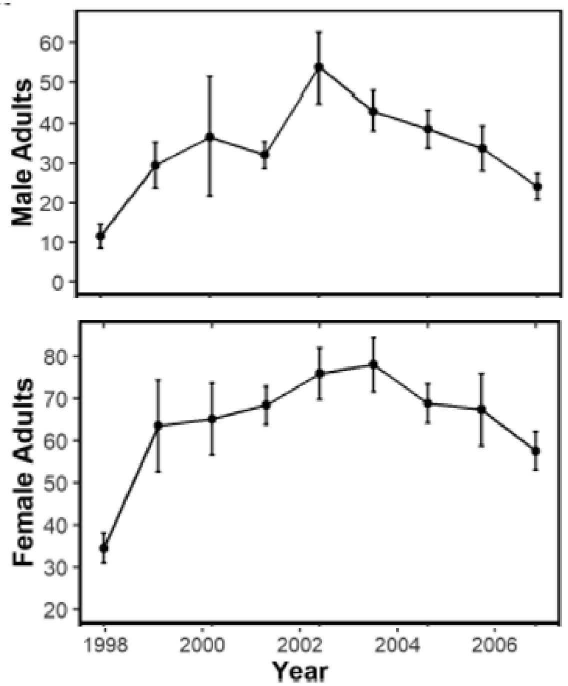
Species	Region	Data source	Monitoring period	Metric	Trend	Figure
Large-footed Myotis	Upsalls Creek	Law	1998-2006	Abundance	Fluctuating; decline	

Table 37. Species occupancy metrics for nocturnal birds and arboreal marsupials surveyed between 1988–2011 in the forests south of Eden

Methods are described in Section 6.3

Species	Detection probability (median) single visit	Initial occupancy (median)	Extinction probability (median)	Colonisation probability (median)	Trend in occupancy (1988–2011)
Powerful Owl	0.49	0.02	0.16	0.38	0.02-0.53
Sooty Owl	0.44	0.03	0.07	0.37	0.03-0.82
Greater Glider	0.14	0.24	0.12	0.01	0.24-0.15
Yellow-bellied Glider	0.67	0.66	0.20	0.61	0.66-0.61
Common Ringtail Possum	0.35	0.88	0.12	0.48	0.88-0.70
Sugar Glider	0.59	0.54	0.03	0.49	0.54-0.94
Mountain Brushtail Possum	0.20	0.05	0.15	0.19	0.05-0.54
Common Brushtail Possum	0.10	0.005	0.19	0.09	0.01-0.18
Australian Owlet-nightjar	0.52	0.63	0.03	0.99	0.63-0.97

Occupancy for two other gliders with larger home-ranges, the Yellow-bellied Glider (*Petaurus australis*) and the Sugar Glider (*P. breviceps*), were either stable or slightly declining, or increasing throughout the study. Initial occupancy for both species was related to the extent of unlogged forest in the landscape. Extinction probability for the Yellow-bellied Glider was associated with the extent of burnt forest, whereas for the Sugar Glider it was the extent of thinned forest. Colonisation probability for both species was associated with the extent of unlogged forest, or less disturbed forest, in the landscape.

Occupancy by the Mountain Brushtail Possum, which was strongly related to the extent of rainforest, continued to increase during the study in the least disturbed parts of the landscape. The Common Brushtail Possum showed a more modest increase in occupancy over time, but again mostly in the least disturbed parts of the landscape. The Australian Owlet-nightjar (*Aegotheles cristatus*) initially occurred on about half of the sites but continued to increase until it occupied almost all of the sites by the end of the study. This species responded negatively to the increasing extent of thinning and recent harvesting, but positively to fire disturbance in the landscape.

In summary, the extent of unlogged forest and a lack of recent fire had the most important influences accounting for species occupancy and rates of recovery following disturbance for most species of forest owls and arboreal marsupials.

7.4.2 Koalas

DPI Forest Science has monitored annually the Koala metapopulation of the hinterland forests of northeast New South Wales since 2015 (https://www.dpi.nsw.gov.au/forestry/science/koala-research).

The study uses passive acoustic methods to record Koala bellows and site occupancy at 171 sites across a variety of forest types in state forests and national parks. An extensive area (1.7 million ha) of better-quality Koala habitat was targeted for surveys using a model derived for the study area. About 50 sites were sampled immediately after the extensive bushfires in 2019 and a larger complement was completed in 2020 (not yet analysed). The program comprises 4 years of pre-fire data representing a strong baseline for ongoing Koala monitoring and an assessment of the impacts and recovery from the 2019 fires in these forests.

Occupancy analysis of these data identified a stable trend in Koala occupancy for the north-east metapopulation over 5 years from 2015 to 2019 (Figure 36). Occupancy remained high throughout this period with at least one bellowing Koala occupying about 68% of survey sites. The occupancy modelling process assessed the effects of sensor type, elevation, modelled habitat suitability, site productivity (NDVI) and the extent of mapped low and high severity fire. Koala occupancy was found to decline with elevation and increase with modelled habitat suitability. The occupancy estimate was derived by accounting for the different elevations and modelled habitat suitability that were assessed and so it represents median site conditions. Unexpectedly, there was no signal of a decline in Koala occupancy in 2018 during the recent NSW drought or immediately after the 2019 wildfires.

It is important to point out that stable occupancy of a metapopulation can include increasing and decreasing subpopulations, whereby connected populations that go extinct can be recolonised. Monitoring over such a regional scale is important for assessing the changing status of species together with monitoring that focuses intensively on individual populations. Also, in North East NSW, many Koala subpopulations are under threat along the coast from increasing urbanisation. These coastal populations are not part of the hinterland forests monitored in this study.

The continued stable trend in occupancy after fire needs to be interpreted carefully. Firstly, monitoring attempted to be representative of the fire extent on Koala habitat. Given about 30% of modelled Koala habitat burnt on the North Coast, we accordingly monitored Koalas at 16 burnt sites (33% of all sites monitored in 2019) with varying degrees of severity and fire extent, which we assessed in a 1-km radius around each site using Fire Extent and Severity Mapping (FESM; Department of Planning, Industry and Environment 2021b). Ten sites mostly experienced high-severity fire and six mostly experienced low-severity fire.

Overall, Koalas were detected at 81% of the 16 burnt sites sampled, which was equivalent to the detection rate at unburnt, but drought-afflicted sites, in 2019. All three high-severity fire sites without Koala detections had high-severity fire extents of > 50% of their surroundings. At other burnt sites where Koalas were detected, refuge areas occurred in the surrounding landscape (i.e. high fire severity covered < 50% of the surrounding landscape) or fire severity was lower.

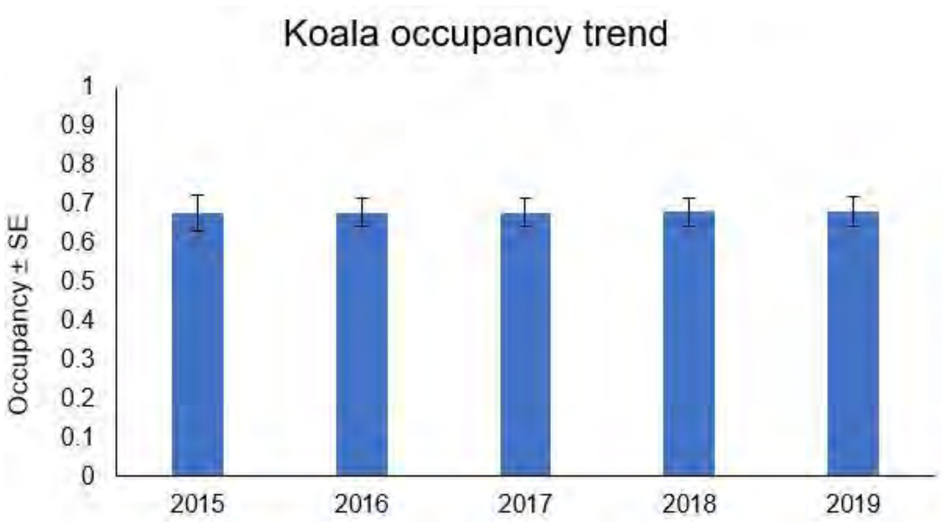


Figure 36. Column graph illustrating a stable trend in Koala occupancy

Column graph illustrating a stable trend in Koala occupancy after accounting for the influence of elevation and habitat suitability of monitoring sites. Estimates for each year assume median values (i.e. an elevation of 756 m ASL and habitat suitability of 0.56).

7.4.3 Southern Brown Bandicoot

FCNSW monitored Southern Brown Bandicoots (*Isoodon obesulus*) in a local rather than region-wide study near Eden using camera traps from 2009 to 2019 at 40 sites (two cameras per site) (R. Bilney unpublished data). Multi-season occupancy analysis of the data set was completed by Gonsalves and Law (2021a). Assuming median topographic position of the monitoring sites (lower slopes/gully), occupancy was relatively low over the period (2009–2019) of monitoring and has decreased by ~46% from 0.24 in 2009–10 to 0.13 in 2019 (Figure 37). Occupancy fluctuated between years but was relatively stable between 2009–10 and 2013 before showing a decline in 2014 and 2015 and then stabilising to a low level in subsequent years. Colonisation and extinction probability were associated with 12-monthly rainfall in the calendar year preceding surveys and the extent of fire of different ages, respectively. Timber harvesting did not influence the trend. A moderate level of precision is evident for the trend and additional sites would be needed to increase precision. Trends monitoring of Southern Brown Bandicoots in nearby coastal national parks revealed similar occupancy levels, though no declining trend was observed over the same period (Claridge *et al.* 2019)

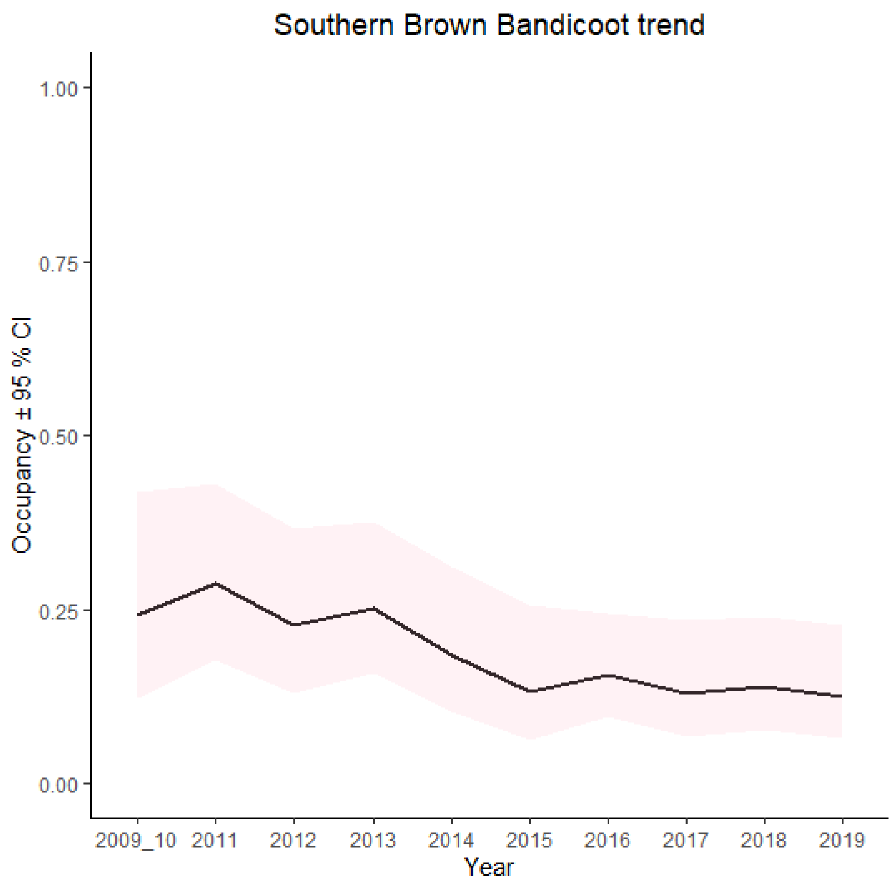


Figure 37. The trend for Southern Brown Bandicoot multi-season occupancy between 2009 and 2019

The trend for Southern Brown Bandicoot multi-season occupancy between 2009 and 2019. Dashed lines are 95% confidence intervals. Trends are calculated assuming median topographic position (equivalent to lower slopes/gully) when calculating initial occupancy

7.4.4 Yellow-bellied Gliders at Bago-Maragle State Forests

The Forestry Commission of NSW monitored Yellow-bellied Gliders (*Petaurus australis*) in a study near Tumut using spotlighting and call-playback techniques (R. Bilney unpub. data). The monitoring built on initial assessments in 1995 (Kavanagh and Stanton 1998) and resumed annually from 2010. A rotating panel design was implemented from 2013 onwards such that three panels of ~40 sites were sampled each year, with no subset of sites sampled in all three rotations (i.e. annual sites). Multi-season occupancy analysis of the data set was completed by Gonsalves and Law (2021b). Yellow-bellied Glider occupancy decreased by 16% between 1995 and 2019, with the decline most notable after 2015, though confidence intervals were relatively wide (Figure 38). This imprecision reflects low detection probability due to few site repeat visits within each year for this method. Modelling of dynamic parameters, colonisation and extinction, revealed that colonisation probability was positively associated with the abundance of hollow trees at a site, whereas extinction probability was relatively stable.

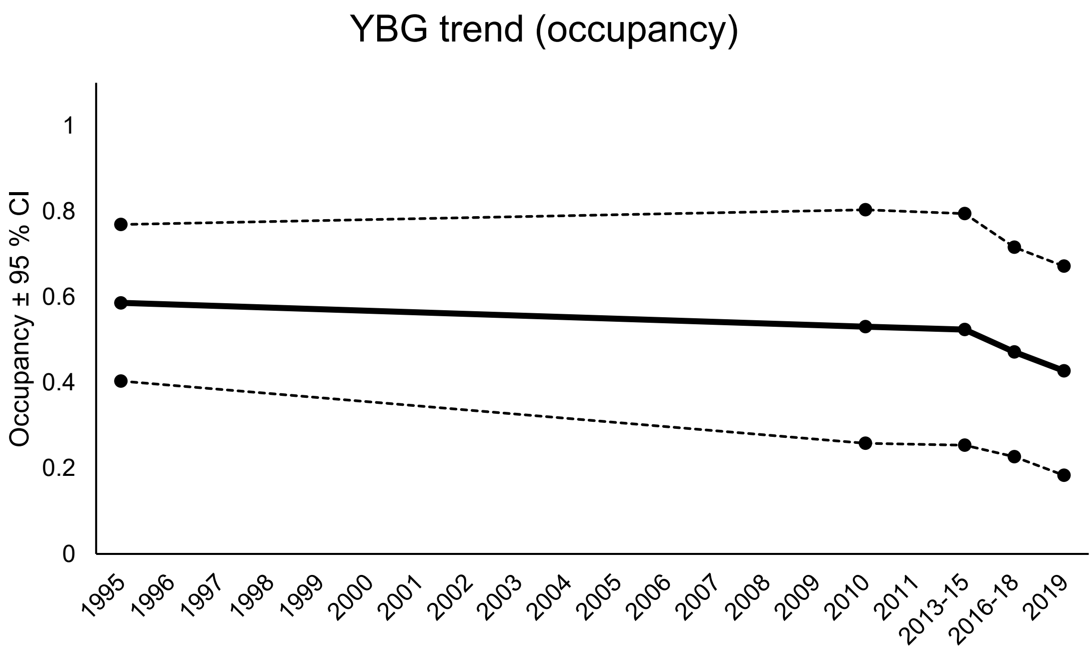


Figure 38. The trend for Yellow-bellied Glider occupancy between 1995 and 2019

Dashed lines are 95% confidence intervals.

7.4.5 Bats

Initial trends in occupancy and activity of bats have been published for bats in the Pilliga forests, providing an example of how such data can effectively track changes for bats over time in relation to environmental and disturbance regimes (Law *et al.* 2020). Such data are unavailable for coastal forests, though long-term data-sets for individual study locations or experiments have been reviewed elsewhere (Law 2018). An example from this review is presented below.

Caves are potentially ideal sites for describing trends in bat populations. In contrast to tree-hollow roosting bats, populations of cave bats concentrate at just a few locations during the maternity season, so it is potentially straightforward to count and monitor populations of cave bats (e.g. breeding females) compared to hollow-dependent bats that are dispersed between different tree roosts throughout the forest. Annual counts over a 17-year period of a large maternity population of Eastern Horseshoe Bats (*Rhinolophus megaphyllus*) in a sandstone cave in Ourimbah State Forest near Wyong revealed a relatively stable population in the absence of major perturbations (Figure 39). When systematic monitoring began in 1999, we estimated 17,712 ± 2,273 bats (n = 3 nights). In 2019, 20 years after monitoring began, the census counted 15,899 bats (n = 1 night), similar to the estimates when the study began. Despite the fact that the population has been through a number of peaks and troughs in the last 17 years, the population has remained relatively stable (Figure 39).

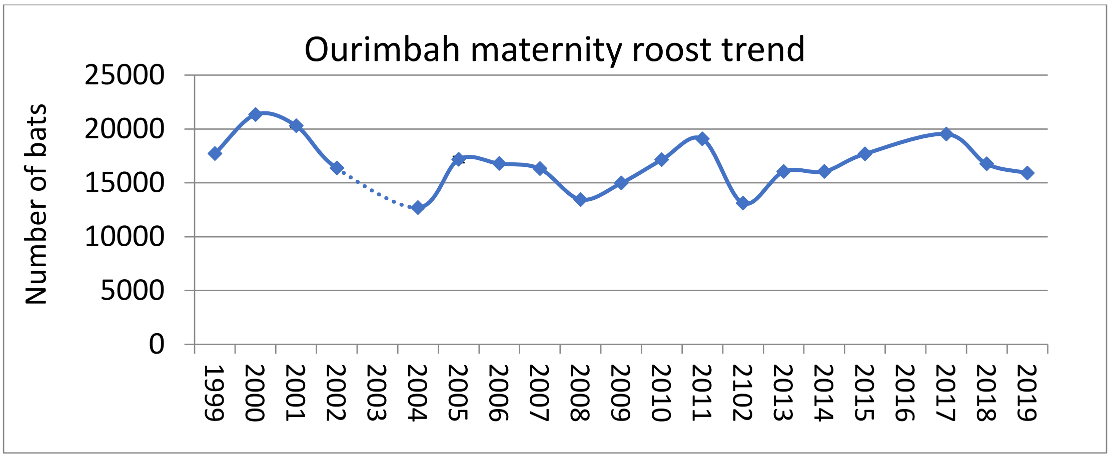


Figure 39. Maternity roost population count of Eastern Horseshoe Bats at Ourimbah State Forest each December

Where estimates of the roost population were made over multiple nights the values given are means with a standard error bar (n = 3–4 nights)

In another bat study, trends in population dynamics were described by banding Large-footed Myotis (*Myotis macropus*) annually at one roost exposed to timber harvesting and another that was unharvested (Law *et al.* 2021). Bats were caught and banded annually at two roosts over 14 years with 529 individuals banded and a 45% recapture rate. Mark-recapture analyses allowed for investigation of the dependence of survival on time, sex, and age at marking. The study spanned extreme El Niño and La Niña weather events, but there was little variation in survival, although recruitment was lower during drought. Survival of adults (~0.70) and population size of adult females was similar between the two sites, suggesting that neither timber harvesting with retained riparian buffers nor eutrophication from farming influenced survival. Survival of adult males and females was similar, but survival of juveniles was less than half that of adults, probably due to a combination of mortality and dispersal. Abundance of *M. macropus* varied considerably across the study period. At Upsalls Creek, there was an initial increase in abundance of adults, following peaks in abundance of subadults (Figure 40). There was some support for the initial increase to be recovery from a major flood event in 1995. Total abundance then peaked at about 140 bats, stabilised briefly and then declined towards the end of banding. Abundance of subadults declined from early peaks to a minimum in 2002, with a recovery apparent at the end of the study.

7.4.6 Trends in fauna in eucalypt plantations

Trends in occupancy have been modelled for selected mammals and nocturnal birds during a 17-year or more longitudinal study on three large-scale plantations of locally indigenous eucalypts in northern NSW. The study began in a farmland mosaic and has continued to track occupancy after the establishment of eucalypt plantations within the paddock areas. Accordingly, the trends describe the change from cleared paddocks with scattered remnant vegetation to a young plantation. Surveys were undertaken at focal trees located in different classes of remnant vegetation that became embedded within the plantations as well as in the plantation matrix itself. Reference sites were also sampled in adjacent blocks of forest.

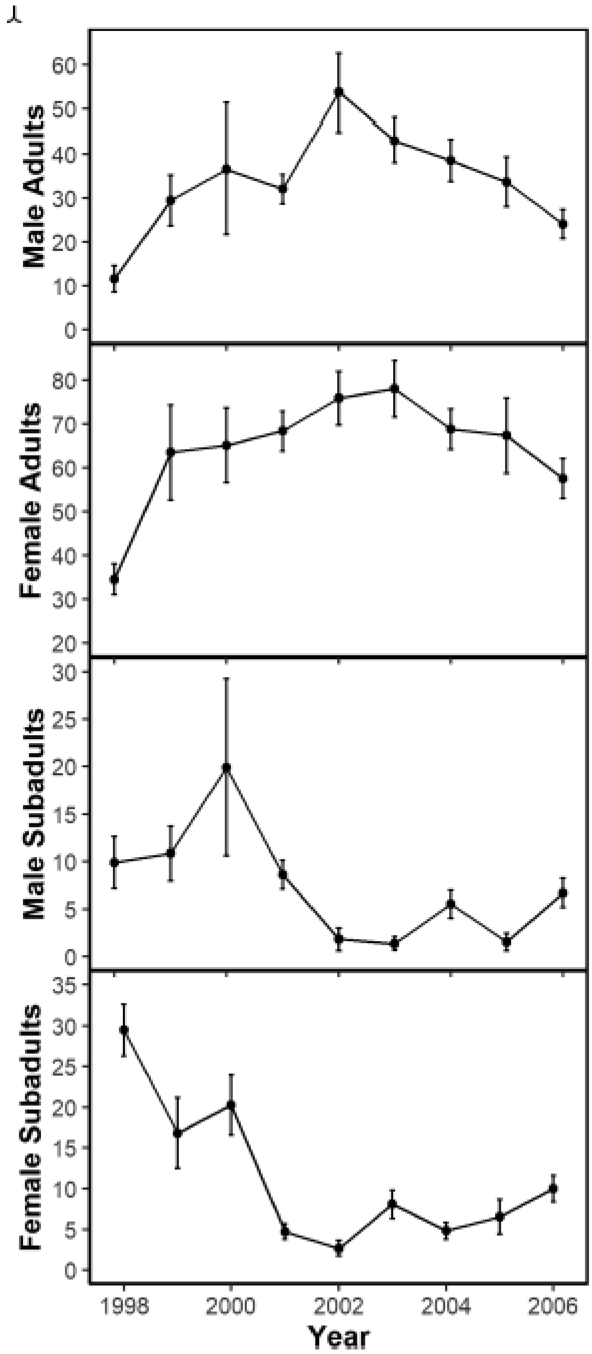


Figure 40. Trends in modelled abundance of Myotis macropus *at a roost in Kerewong State Forest*

Note possible mortality and recovery after an intense rainfall and flooding event in 1995 immediately prior to the study.

Nine species of arboreal mammals and eight species of nocturnal birds were recorded during focal tree watches. Multi-season, multi-scale occupancy analyses revealed most species were stable over time and, among mammals, a large temporal increase was most notable for Common Brushtail Possum (*Trichosurus vulpecula*) (Figure 41). Among nocturnal birds, both Southern Boobook (*Ninox* *novaeseelandiae*) and Australian Owlet-nightjar (*Aegotheles cristatus*) increased in occupancy over time. Increasers tended to be widespread species with generalist attributes, while stable or decreasing species were more likely to be specialists. While few negative effects due to change in land-use to plantation were recorded, limited increase in occupancy for most species contrasts with overall positive trends reported previously for diurnal bird species (Law *et al.* 2014).

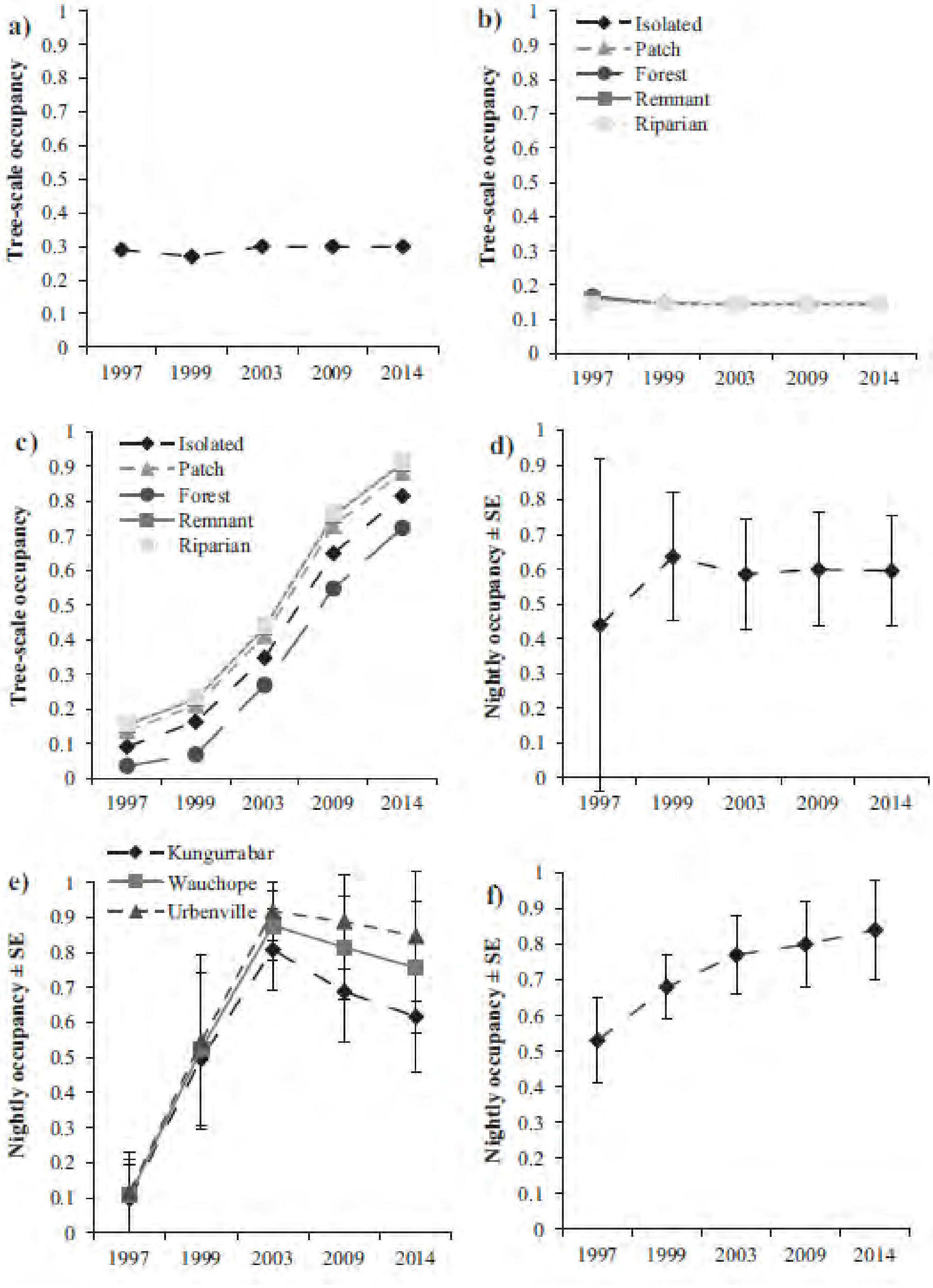


Figure 41. Temporal trends in occupancy of various fauna species in eucalypt plantations

Plots illustrating temporal trends in occupancy for (a) Sugar/Squirrel Gliders (tree-level), (b) Tawny Frogmouths (tree-level), (c) Common Brushtail Possums (tree-level), (d) Koalas (large-scale – plantation), (e) Southern Boobook owls (large-scale – plantation) and (f) Australian Owlet-nightjars (large-scale – plantation). Standard errors are not calculated for small-scale (tree-scale) occupancy estimates. More details in Law et al. *(2017)*

7.4.7 Frogs in Chaelundi State Forest

Data sets allowing for an assessment of trends in occupancy and populations are much more difficult to obtain for frogs due to the highly variable nature of their activity patterns and the standard method of survey. Frog counts are typically undertaken by recording the number of calling males occupying a breeding site (e.g. Lemckert and Morse 1999; Lemckert *et al.* 2006; Lemckert and Mahony 2008) and the number of male frogs detectable at any given time is highly dependent on season and weather conditions (e.g. Penman *et al.* 2006; Lemckert and Grigg 2010) and can vary widely even between nights. Furthermore, the chorusing behaviour of multiple males at a breeding site makes accurate counts of the number of males increasingly difficult as the number of males calling increases and choruses of 20 or more frogs can be very hard to accurately measure and are usually grouped into calling categories (e.g. Lemckert and Grigg 2010). This presents challenges for analysing data, given the loss of precision. Survey information about female frogs is also very hard to obtain as they do not call and are secretive. Assumptions have to be made that estimates of numbers of males accurately reflect overall population trends, although this may or may not be true. However, as all individuals from the surrounding area move to a single breeding site, water bodies have the potential to be very useful for describing trends in frog populations, just as caves are for bats.

Perhaps because of these constraints, only limited trend modelling of frog populations has been undertaken in forested areas of eastern NSW. For example, a study of broad population responses of multiple species to the impacts of fire was completed for a series of ponds at Chaelundi in NSW (Lemckert *et al.* 2004) and indicated both that fire had not clearly impacted the populations at burnt sites and that population responses over time were broadly uniform in nature (Figure 42).

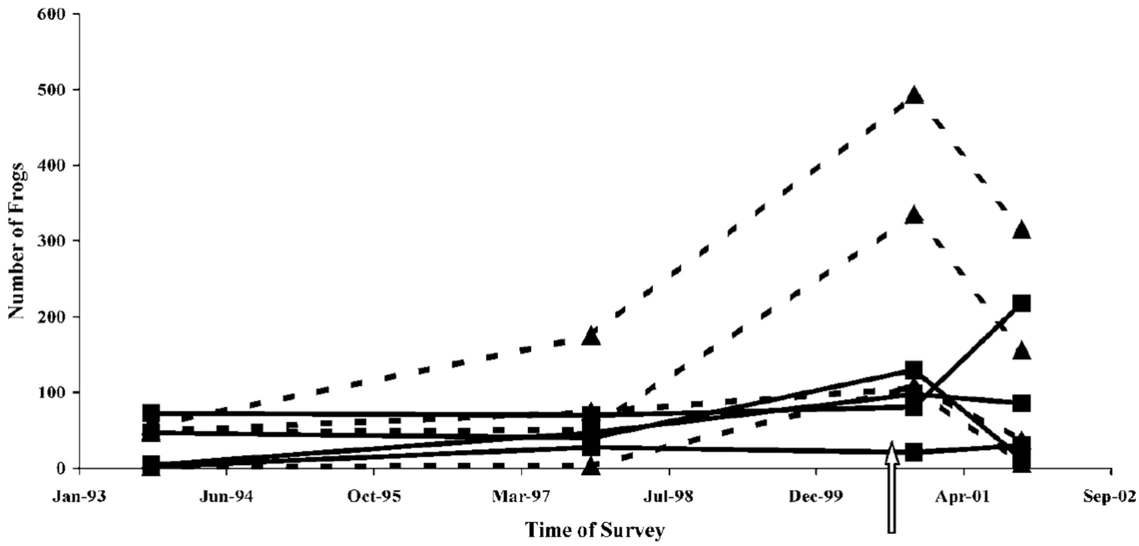


Figure 42. Plots illustrating temporal trends in Chaelundi frog occupancy

Occupancy measured at four burnt (solid lines) and four unburnt ponds (dotted lines) illustrating temporal trends in total frog populations present through time (for more details see Lemckert et al. *2004).*

This work was part of a broader study of habitat relationships of frogs that included multiple surveys of a range of ponds over more than 10 years. One part of the study assessed responses of species to timber harvesting disturbance (Lemckert 1999) and found that the Great Barred Frogs (*Mixophyes fasciolatus*) at these ponds may be sensitive to disturbance. Data from that study has been analysed in a dynamic occupancy modelling framework to assess trends in occupancy for the species. Occupancy increased rapidly from ~0.4 to ~0.85 between 1993 and 1994 and remained stable for the duration of the study (Figure 43). It is unclear why occupancy was so low at the start of the study.

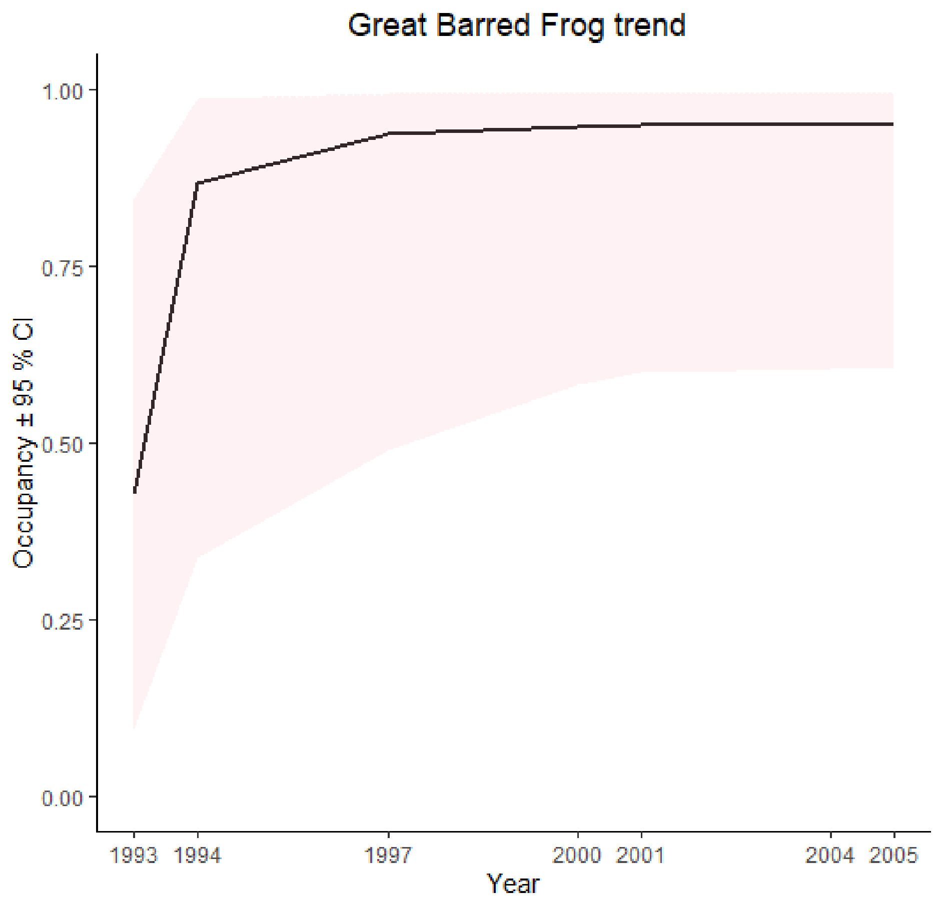


Figure 43. Plot illustrating the trend in occupancy for the Great Barred Frog between 1993 and 2005

Unlike occupancy, male calling activity revealed a different trend for the Great Barred Frog (Figure 44). Activity fluctuated over time but was fairly consistent among sites and the peaks and troughs in activity were associated with prevailing weather conditions during the surveys. The number of calling male frogs was greater during warm conditions after rainfall and reduced when conditions were cooler and drier.

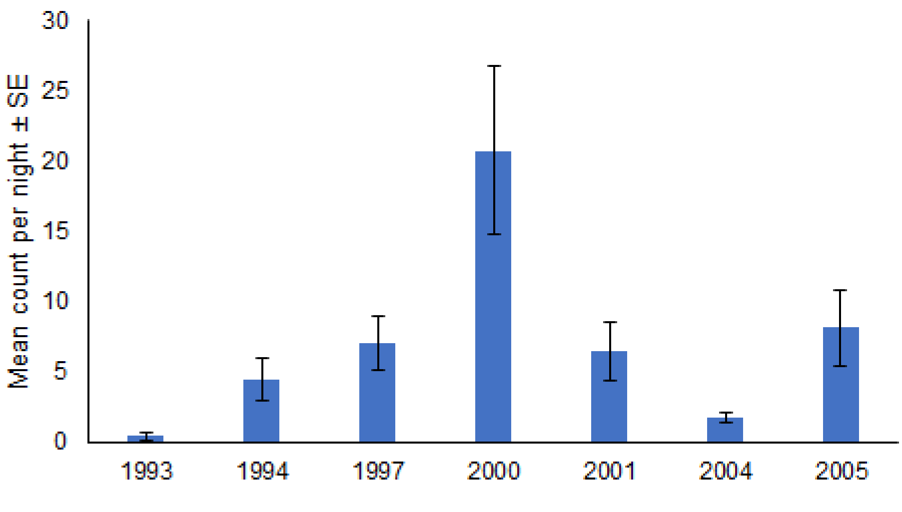


Figure 44. Mean number of calling male Great Barred Frogs counted at 21 ponds between 1993 and 2005

This variation in numbers could be large over even relatively short periods of time with an example being Pond AA where the number of calling male Great Barred Frogs recorded calling over time is presented in Figure 45. This represents the period from September 2000 to March 2001 when the pond was surveyed on nine separate occasions and shows that numbers rose and dropped markedly even between nights as conditions changed. Hence monitoring changes in population sizes using calling males, which is the standard means of conducting frog surveys, provides for a highly variable data set requiring very careful planning if frogs are to be monitored reliably.

Variation in calling due to ambient weather conditions should be accounted for when modelling both call activity and occupancy (including detectability). Either approach could be suitable for monitoring if imperfect detection is accounted for. The trend in occupancy shown in Figure 43 has wide confidence intervals because surveys were not originally designed with occupancy analysis in mind. Sufficient repeat visits and greater site replication will be required to increase the precision of frog trends in future monitoring programs (see Section 7.5 Power analysis). However, calling activity or counts of individuals have the potential to provide earlier indications of population change than species occupancy when species are abundant or present at most sites. This is because one calling male is treated the same as 100 calling males in occupancy modelling and large declines in total populations may still not become evident if a few males remain calling. Well-planned repeated counts of calling males are likely to provide the most sensitive measure of populations where such sampling can provide accurate estimates of the actual number of calling males present. This is especially the case for more localised species where large meta-populations are not available for occupancy surveys at many sites.

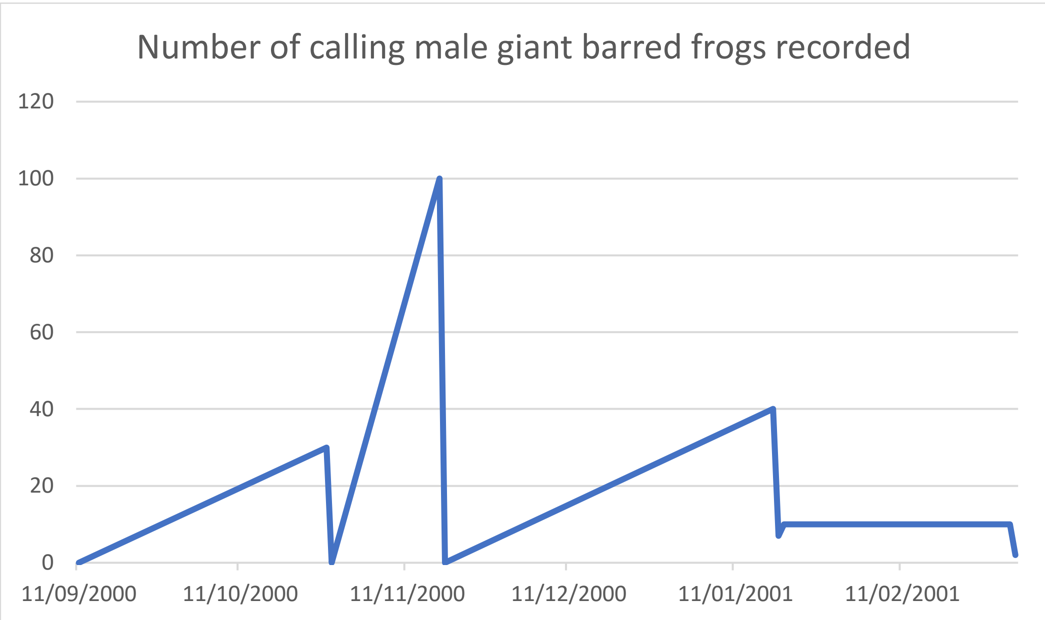


Figure 45. Plot of number of calling male Great Barred Frogs counted at Pond AA in 2000–2001

7.4.8 Trends using camera data – WildCount species monitoring program

The NSW National Parks and Wildlife Service established a fauna species monitoring program (WildCount) using remote cameras (four per site) located at each of about 200 sites throughout national parks and conservation reserves in eastern NSW. The cameras were each deployed for a minimum of 14 consecutive days, usually in autumn, for 5 consecutive years from 2012–2016. This resulted in the detection of 157 species, of which 39 of the most commonly recorded species were analysed using species occupancy modelling (Mills 2019). Most species (32 of 39) appeared to be stable over the 5 years of monitoring, but two species (Long-nosed Bandicoot *Perameles nasuta* and European Rabbit *Oryctolagus cuniculus*) declined in occupancy over the survey period and another five species (Mountain Brushtail Possum *Trichosurus caninus*, Satin Bowerbird *Ptilonorhynchus violaceus*, Spotted Quail-thrush *Cinclosoma punctatum*, Wonga Pigeon *Leucosarcia melanoleuca* and Feral Pig *Sus scrofa*) appeared to be increasing in occupancy (Mills 2019).

These data were reanalysed by Dr Doug Mills (NSW NPWS) for this project using a subset of 155 sites (i.e. sites with forest vegetation types, and those occurring within the four RFA regions, which were partitioned into two regions, northern and southern, for analysis). This reduced the number of species that could be effectively modelled using species occupancy modelling to 24 species (seven introduced species and 17 native species; Table 38, Appendix 9).

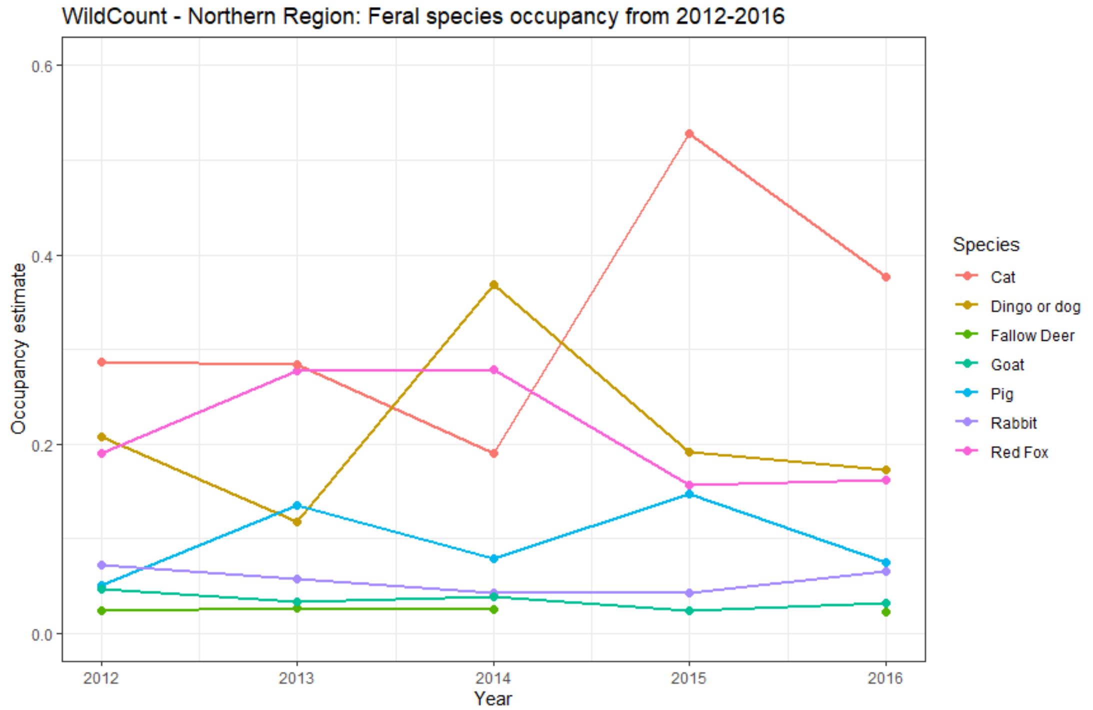
Table 38. Mean occupancy estimates for introduced species and native species using camera traps

Mean occupancy estimates for introduced species and native species using camera traps in northern NSW (UNE and LNE regions; n = 95 sites) and southern NSW (Southern and Eden regions; 60 sites) from 2012–2016 in the WildCount species monitoring program. NA = model unable to converge or species apparently absent.

Species	Mean Occ_Northern Region	Mean Occ_Southern Region
Introduced species		
Cat	0.33	0.49
Red Fox	0.21	0.54
Dingo or dog	0.21	0.11
Pig	0.10	NA
Rabbit	0.06	0.17
Goat	0.03	0.04
Fallow Deer	0.02	0.09
Native species		
Swamp Wallaby	0.75	0.91
Short-beaked Echidna	0.49	0.44
Common Brushtail Possum	0.43	0.65
Long-nosed Bandicoot	0.42	0.27
Superb Lyrebird	0.37	0.46
Northern Brown Bandicoot	0.30	NA
Short-eared Brushtail Possum	0.30	NA
Mountain Brushtail Possum	NA	0.21
Australian Brush-turkey	0.29	NA
Red-necked Wallaby	0.23	0.37
Spotted-tailed Quoll	0.22	NA
Lace Monitor	0.22	NA
Eastern Grey Kangaroo	0.18	0.41
Red-necked Pademelon	0.15	NA
Common Wombat	0.15	0.67
Long-nosed Potoroo	0.07	0.02
Red-legged Pademelon	0.07	NA

The overall trend in occupancy for most species in forested environments was ‘relatively stable’ over the 5 years from 2012–2016. There were no major fluctuations during this period (Figures 46 and 47; Appendix 9). A key point of interest, however, was the widespread occurrences of introduced species in both regions, in particular Feral Cats and Red Foxes, which were estimated to occur on every second site in southern NSW (Figure 46). Wild dogs were more frequent in northern NSW, while Rabbits and Fallow Deer occurred more in southern NSW. The introduced predators were more common and widespread than many native species, and are likely having a significant impact on them. The interactions between introduced predators versus native critical-weight-range species have not been investigated in the WildCount data. It is unclear whether the WildCount monitoring design had the power to conclude that increases in feral predator numbers were significant. Future work should target the presence and activity of feral species as covariates in occupancy models for native mammals within the critical weight range (35–5,500 g) as well as susceptible ground-dwelling and understorey birds and reptiles (see the example above of the trends in Southern Brown Bandicoots, although in this case, rainfall was the major driver in the declining trend; Section 7.4.3).

(a)



(b)

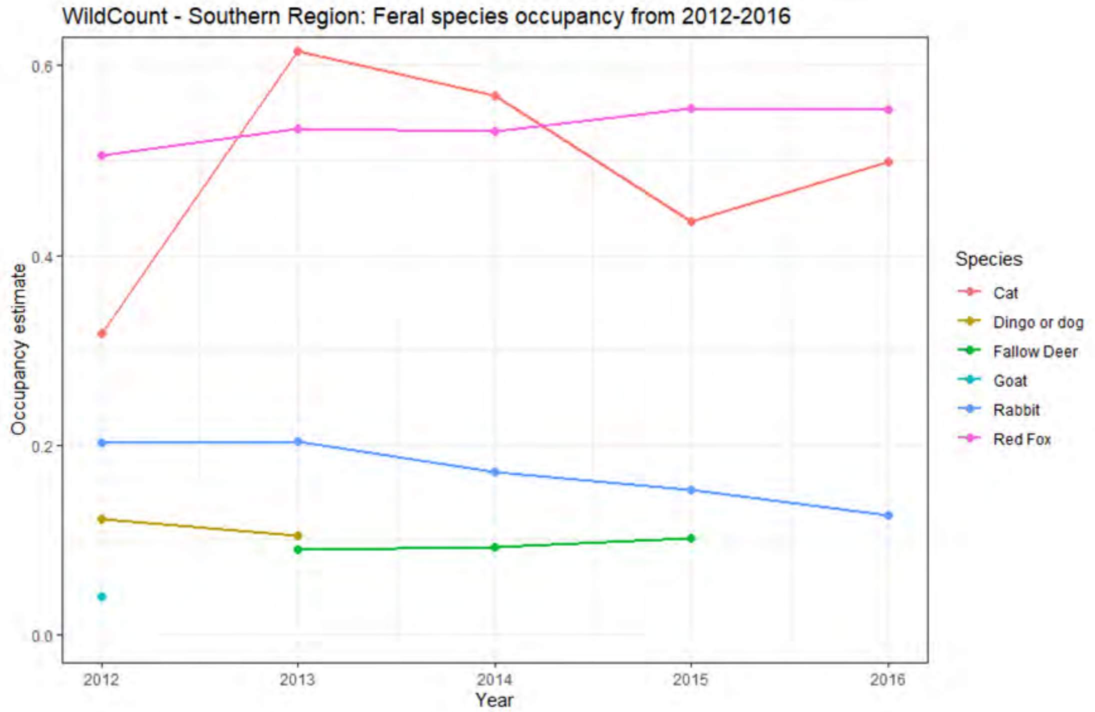
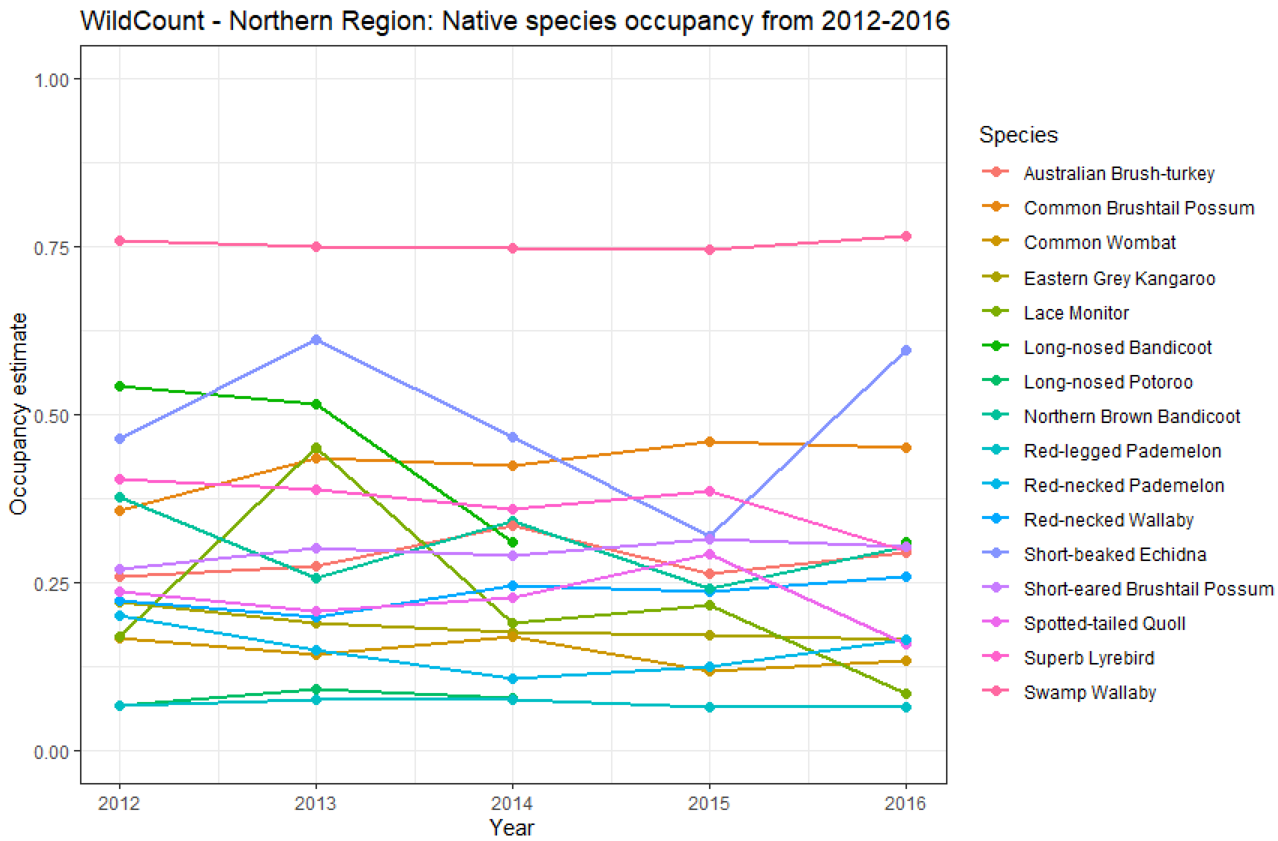


Figure 46: Trends in occupancy of feral fauna species in (a) northern and (b) southern NSW

(a)



(b)

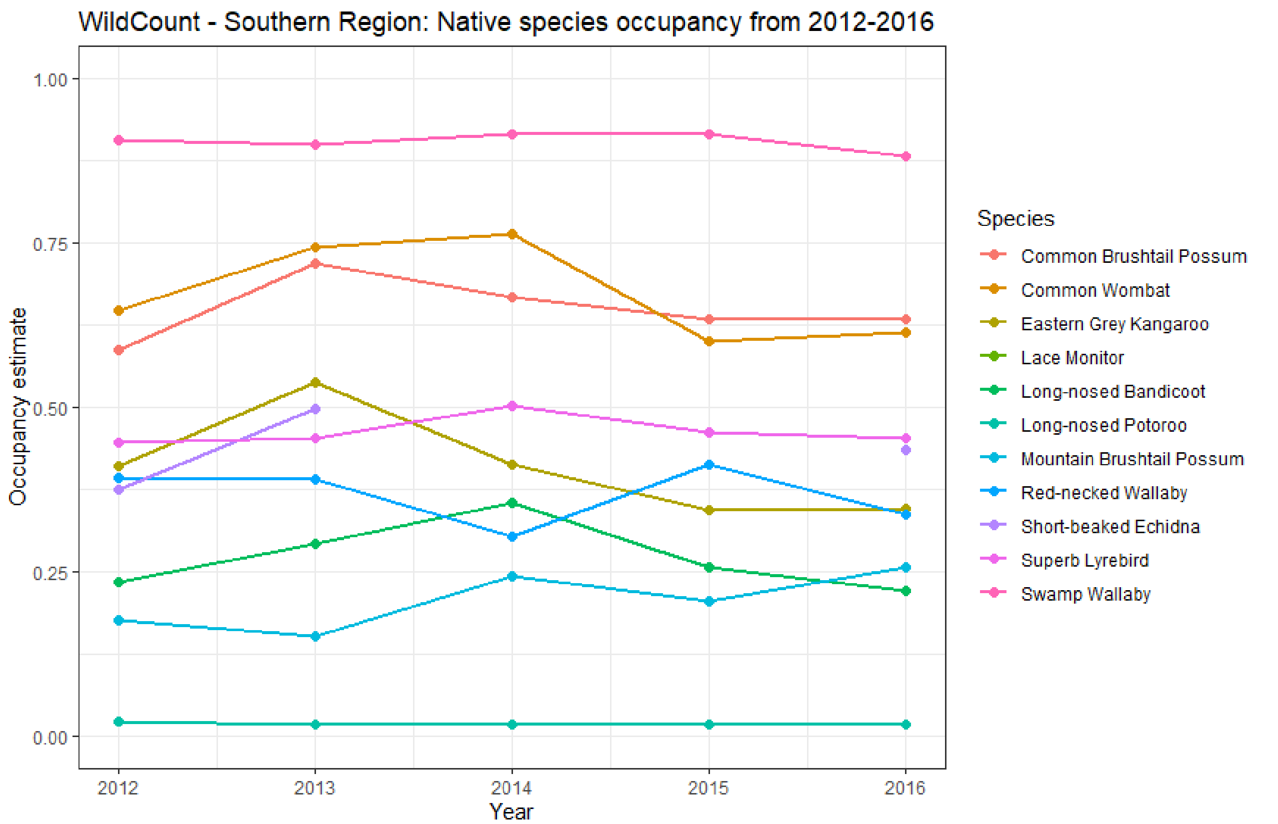


Figure 47: Trends in occupancy of native fauna species in (a) northern and (b) southern NSW

The most common native species detected using remote cameras was the Swamp Wallaby (*Wallabia bicolor*), a species that was estimated to occur on more than 90% of sites in southern NSW. Some large differences were observed between regions for several species. For example, species apparently more widespread and common in northern NSW included Long-nosed Bandicoot, whereas the Common Brushtail Possum (*Trichosurus vulpecula*), Red-necked Wallaby (*Macropus rufogriseus*), Eastern Grey Kangaroo *(Macropus giganteus*) and Common Wombat (*Vombatus ursinus*) were apparently more widespread and common in southern NSW. In this study, all Mountain Brushtail Possums were assigned to *Trichosurus caninus* if they were observed in northern NSW or *T. cunninghami* if they were observed in southern NSW (although there is some doubt that the genetic divergence is sufficient to support the case for two separate species).

It should be noted that remote cameras, as deployed in the WildCount species monitoring program, were only able to record data in sufficient quantities for analysis (by region) for five of the 31 species listed as priority for the FMIP and Coastal IFOA species monitoring programs (i.e. Common Wombat, Spotted-tailed Quoll *Dasyurus maculatus*, Long-nosed Bandicoot *Perameles nasuta*, Common Brushtail Possum and Long-nosed Potoroo *Potorous tridactylus*; Table 2). However, all but three species were listed in the more comprehensive list of 140 priority species (Table 1).

7.5 Power analysis

7.5.1 Power to detect species using different methods

Generic power curves were generated to demonstrate the sampling effort required to achieve a given power for detecting a trend in occupancy with 5 or 10 years of monitoring. These curves may be applied to any species for which occupancy and detection probability is known. This is useful as some methods used to establish 1990s baselines may not continue to be used in future monitoring programs.

Broadly, the power curves demonstrate that a significantly greater sampling effort is required to detect trends in five years of monitoring compared to a 10-year program. For example, a relatively widespread and detectable species (occupancy = 0.8, detection probability = 0.8) requires ~150 sites with three visits to be 80% confident of detecting a −30% trend in 5 years (Figure 48), whereas ~15 sites are required to detect the same trend over a 10-year period (Figure 49). At the other end of the spectrum, a rare species that is difficult to detect (occupancy = 0.2, detection probability = 0.2) requires ~3,200 sites with 14 visits to be 80% confident of detecting a −30% trend in 5 years (Figure 48), whereas ~650 sites are required to detect the same trend over a 10-year period (Figure 49). The desired power for detecting a trend also influences the sampling effort required to detect a −30% trend in occupancy. To illustrate this, a moderately widespread species with moderate detectability (occupancy = 0.6, detection probability = 0.6) requires ~85 sites with five visits to have 80% power for detecting this trend over 10 years, whereas ~110 sites are needed to achieve 90% power (Figure 50). The implications for future monitoring of fauna in eastern NSW forests is that rarer priority species will be difficult to monitor effectively at a landscape scale, and in these instances targeted monitoring or question-driven research will be more effective. An example is the Long-nosed Potoroo, with a baseline naïve occupancy of < 1% in the 1990s (Table 1) and estimated occupancies (from camera trapping) of only 0.02 and 0.07 in the southern and northern NSW national park estate, respectively, in 2012–16 (Table 38).

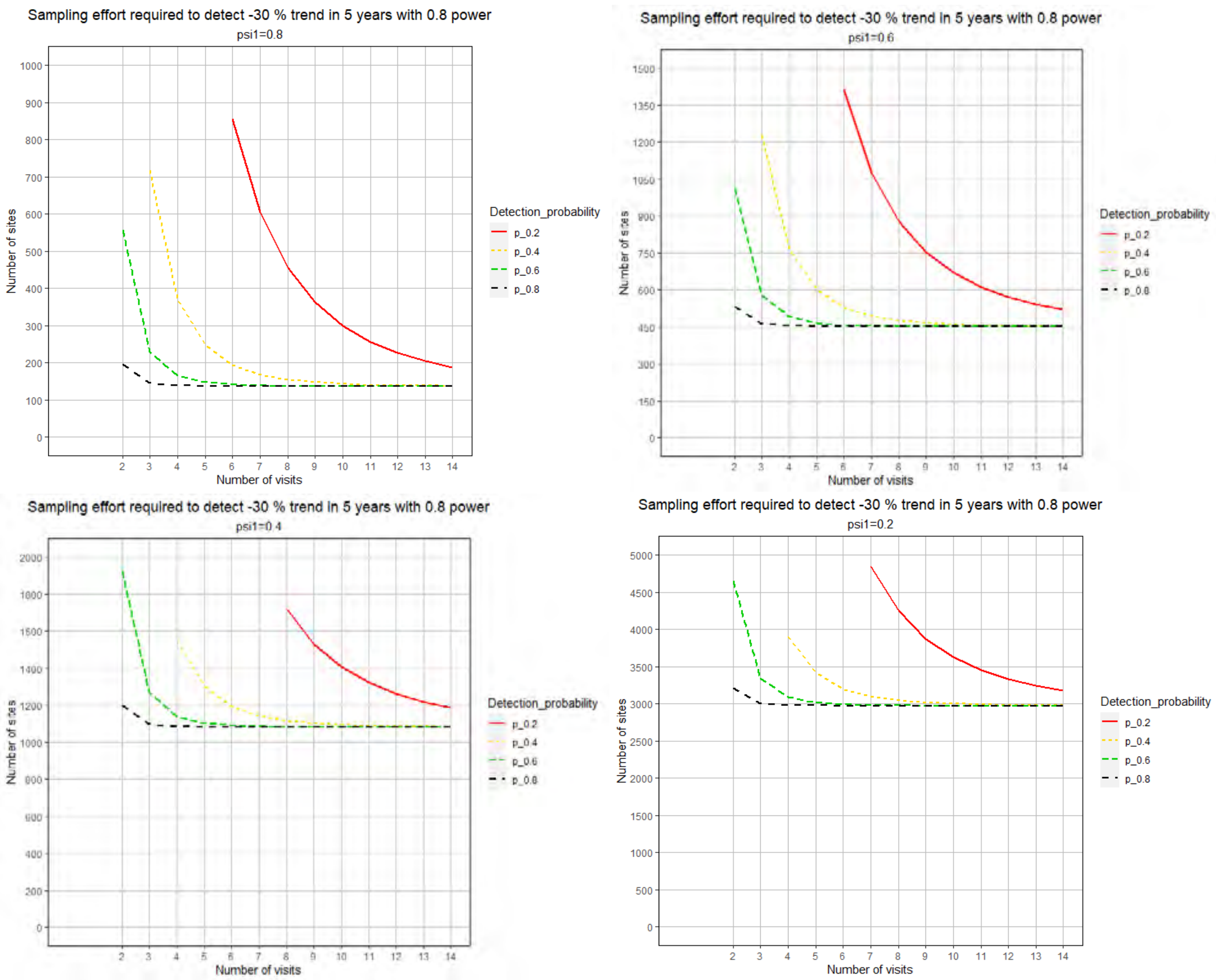


Figure 48. Sampling effort required to detect a −30% trend in occupancy after 5 years

Curves illustrate the sampling effort (number of sites on the y-axis vs number of visits on the x-axis) required to detect a −30% trend in occupancy in a 5-year monitoring program with 80% power and an alpha = 0.1 under different initial occupancy (psi1 = 0.2–0.8) and detection probability (p = 0.2–0.8) scenarios. Detection probability is per visit.

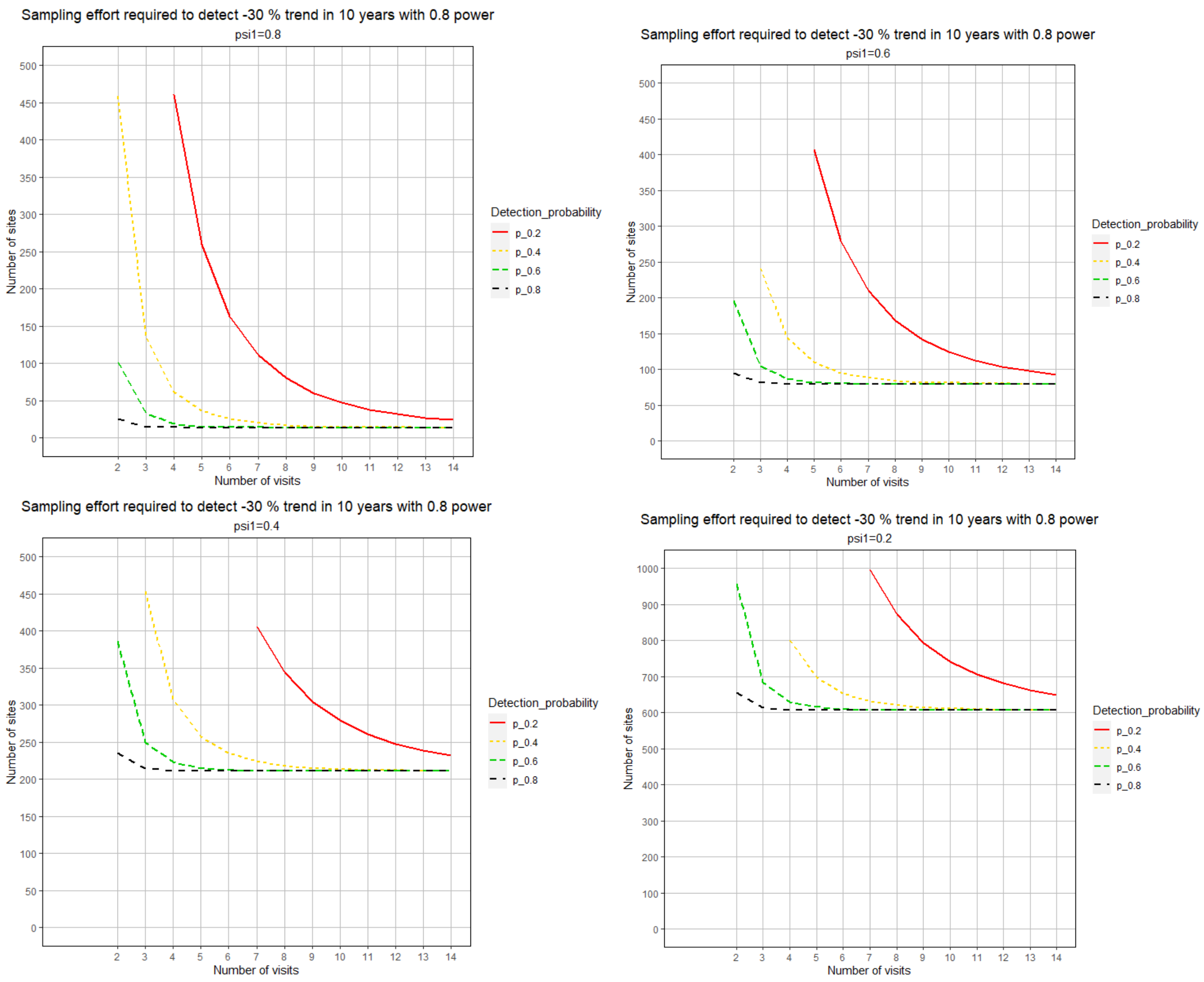


Figure 49. Sampling effort required to detect a −30% trend in occupancy after 10 years

Curves illustrate the sampling effort (number of sites vs number of visits) required to detect a −30% trend in occupancy in a 10-year monitoring program with 80% power and an alpha = 0.1 under different initial occupancy and detection probability scenarios. Detection probability is per visit.

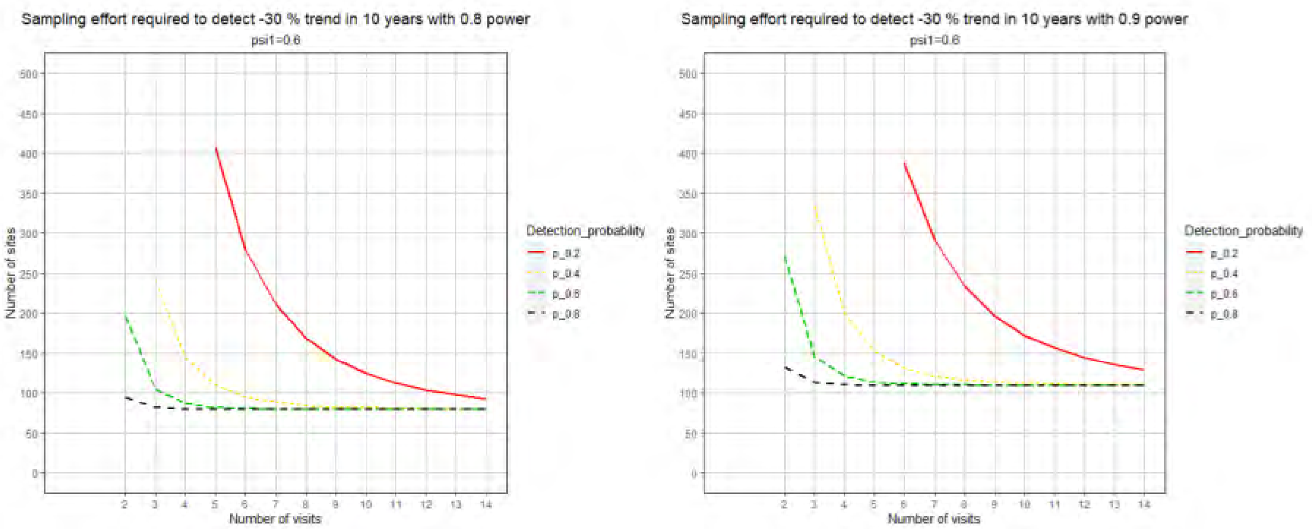


Figure 50. Sampling effort required to detect a −30% trend in occupancy after 10 years with 80% (left) and 90% (right) power

The curves illustrate the sampling effort (number of sites vs number of visits) required to detect a −30% trend in occupancy in a 10-year monitoring program with 80% and 90% power and an alpha = 0.1 for a moderately widespread species under different detection probability scenarios. Detection probability is per visit.

7.6 Case study: power to detect trends for Koala occupancy using acoustics

A key question for monitoring is how much survey effort is optimal to detect trends over time with sufficient power. A landscape assessment of Koala occupancy in the north-east of the state revealed that with 60 sites surveyed per year, standard errors were small, indicating good potential for detecting change (Law *et al.* 2018). We undertook power analyses to assess how many sites are needed to be sampled in order to detect a 30% reduction in Koala occupancy in 10 years (in line with IUCN criteria for listing a Vulnerable species) using acoustic surveys.

7.6.1 Methods

7.6.1.1 Power analyses to assess sampling effort

We assessed the sampling effort required to detect an annual −3.89% (equivalent to −30% in 10 years) decline in Koala occupancy with 80% power when using estimates for detection probability (0.449 per night) and occupancy (0.635 per site) derived for Koalas in modelled moderate-high suitability habitat in the northeast hinterland forests (Law *et al.* 2018). The following sampling designs were assessed:

1. four nights of acoustic sampling each year for 2–10 years;
2. seven nights of acoustic sampling each year for 2–10 years;
3. 14 nights of acoustic sampling each year for 2–10 years.

Since overall occupancy (0.335) is lower when sampling sites that span a range of modelled habitat suitability (i.e. low to high), an additional power analysis was carried for a single design (seven nights of acoustic sampling each year for 10 years) to assess how sampling sites without regard to Koala habitat quality influences the required sampling effort to detect a 30% reduction in Koala occupancy with 80% power.

Power analyses were undertaken in R following the approach of Guillera-Arroita and Lahoz-Monfort (2012) and with α = 0.05. Line graphs were used to illustrate the influence of sampling design on power to detect trends.

7.6.1.2 Power analyses to assess sampling effort for annual sites for multi-season occupancy modelling

Unlike a single-season framework, a multi-season approach used for trend analysis allows for the influence of potential covariates on dynamic population parameters (i.e. colonisation and extinction) to be modelled. To undertake multi-season occupancy modelling some subset of sites require annual monitoring. Power analyses were undertaken for sampling design number 2 described above to determine how many annual monitoring sites are required to achieve 80% power to detect an annual −3.89% (equivalent to −30% in 10 years) decline in Koala occupancy in a multi-season analysis framework. The simulation tool, GENPRES, was used to assess occupancy and detection probability when 10, 20, 30, 40 and 50% of all sites were included as annual sites. Occupancy and detection probability values derived from simulations were used to assess power following the approach of Guillera-Arroita and Lahoz-Monfort (2012). A line graph was used to illustrate how power to detect a trend varies with the percentage of all sites that are sampled annually.

7.6.2 Results

7.6.2.1 Power analyses to assess sampling effort

Power analyses revealed that there was a considerable increase (up to ~18% in power to detect a trend when acoustic sampling extended beyond four nights per year, whereas the increase (~3% in power gained when doubling the amount of nightly sampling from seven nights to 14 nights was relatively smaller (Figure 51). The cost of data processing (i.e. eliminating false positives) should be considered when deciding the amount of nightly sampling per year. Furthermore, a 30% reduction in Koala occupancy over 10 years could be detected with 80% power with monitoring at 57 (14 nights/year), 61 (seven nights/year) or 93 sites (four nights/year) (Figure 51).

When Koala habitat is not targeted for monitoring, 4.5-times (n = 61 sites vs n = 277 sites) more survey effort is required to detect a 30% reduction in occupancy in 10 years with 80% power (Figure 52).

7.6.2.2 Power analyses to assess sampling effort for annual sites for multi-season occupancy modelling

Power analyses revealed that there was little benefit in having > 30% of all sites sampled each year as annual sites (Figure 53). Furthermore, power increased with the number of years of monitoring by about 9% when number of years of monitoring increased from 1 to 5 years. If the duration of monitoring is 10 years, sampling 10% of all sites annually will achieve 90% power for detecting a −30% trend.

7.6.3 Conclusions and recommendations for monitoring Koalas with acoustic surveys

Our conlusions regarding sampling effort for Koala occupancy modelling are:

- Landscape monitoring of Koalas using passive acoustics should be undertaken for at least seven nights per year.

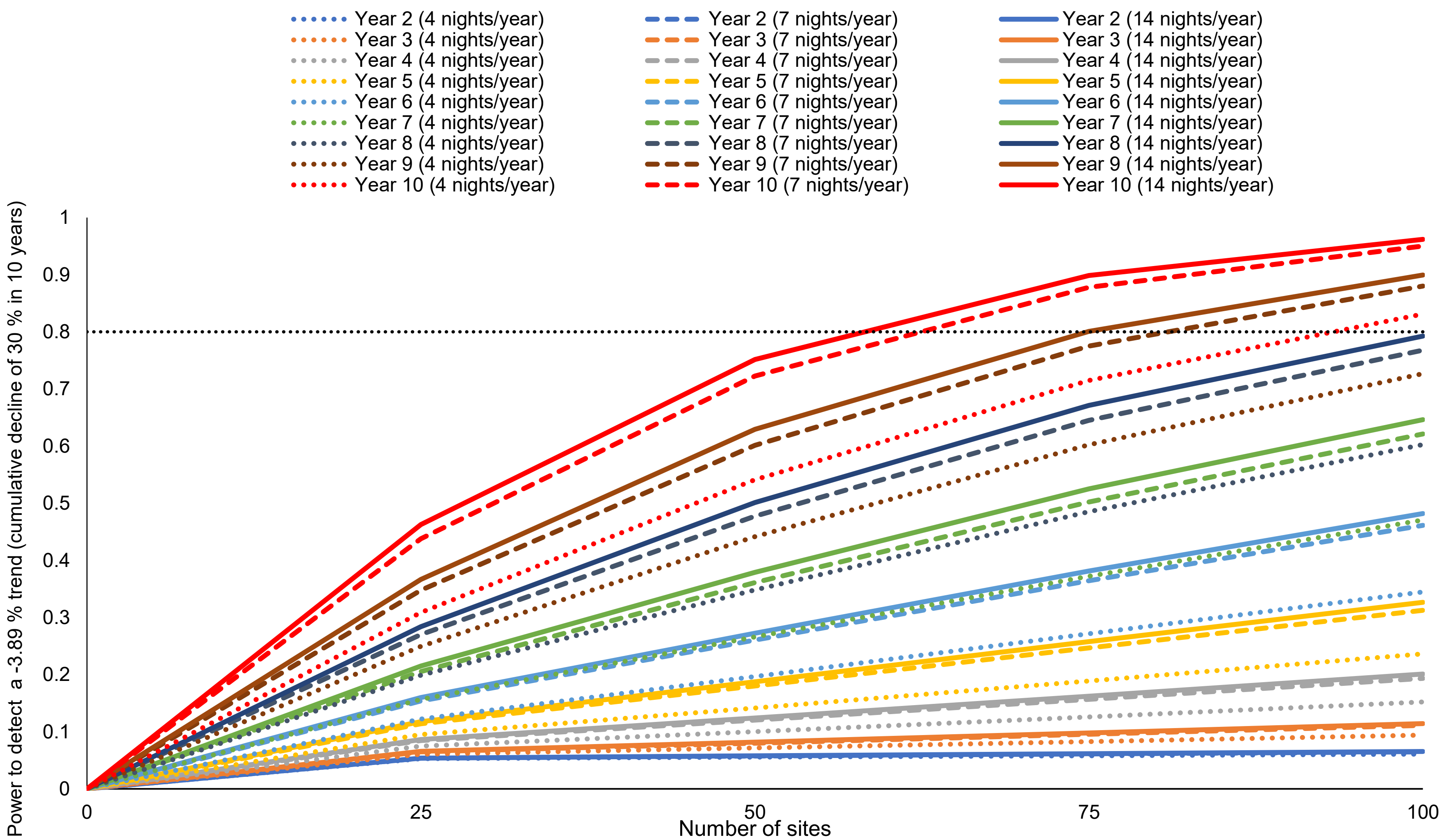


Figure 51. The number of sample sites required to detect a 30% reduction in Koala occupancy within 10 years with a power of 0.8 under three sampling designs

The designs were: four nights/year, dotted lines; seven nights/year, dashed lines, and 14 nights/year, solid lines. Colours represent different durations of monitoring

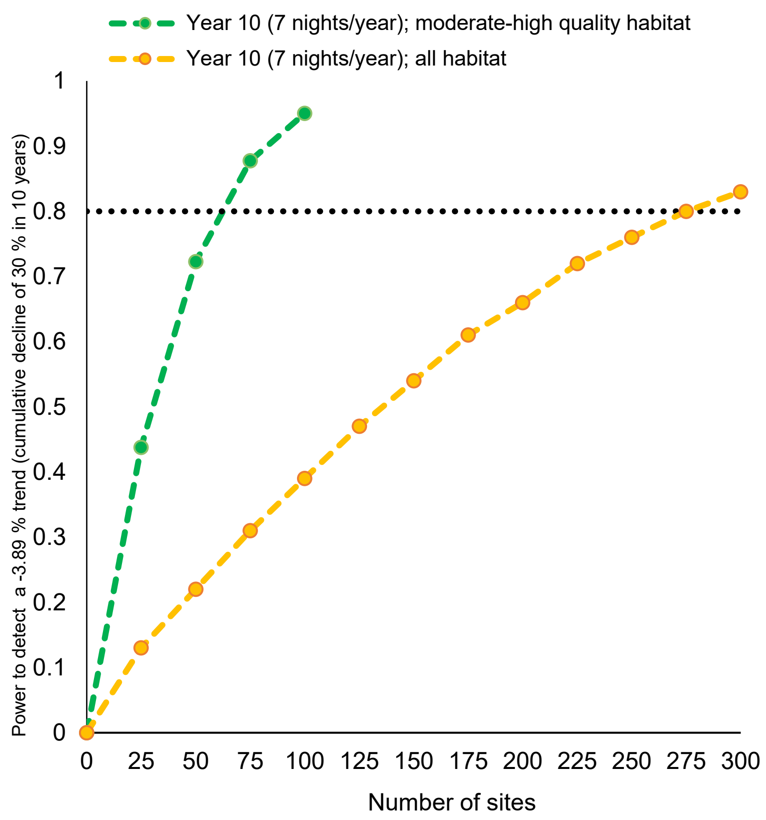


Figure 52. Power curves illustrating the number of sites needed to be sampled to detect a 30% reduction in Koala occupancy in 10 years with 80% power, when habitat quality is considered

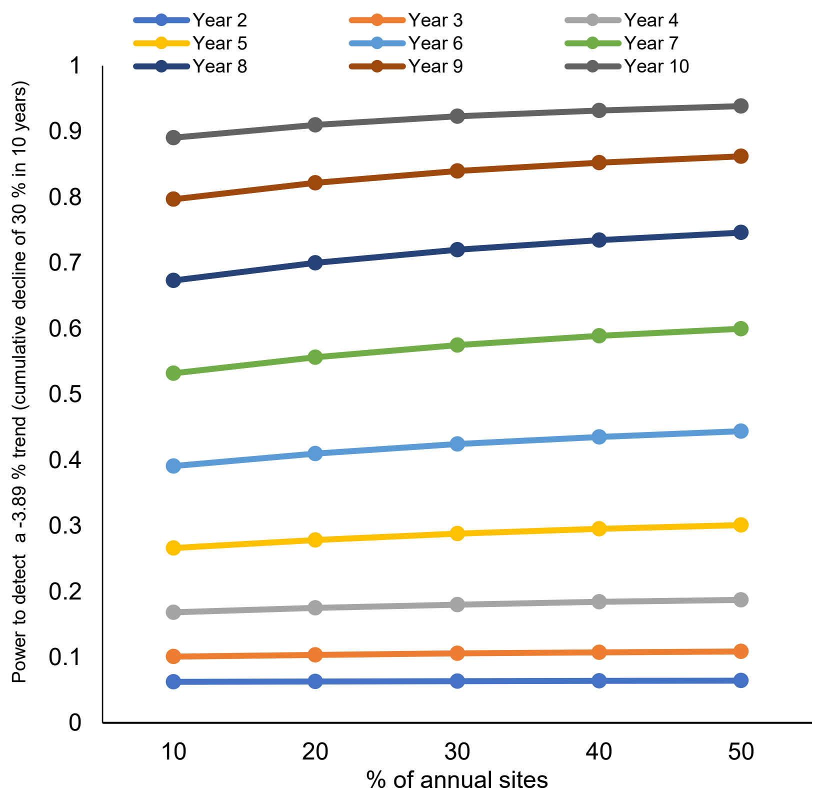


Figure 53. Influence of the percentage of annual monitoring sites on the power to detect a 30% reduction over 10 years in Koala occupancy with 12 different sampling designs

- Targeted sites that are modelled moderate-high suitability habitat should be prioritised to reduce survey effort – at least ~60 sites should be located in modelled Koala habitat. These sites are likely to have higher initial occupancy. As part of a broader program of acoustic monitoring for biodiversity, sites that are low-quality Koala habitat may also be sampled and a Koala habitat model can be used as a covariate in analyses.
- At least 10% of sampling sites modelled as moderate–high suitability should be surveyed annually to allow for multi-season occupancy modelling to detect a −30% trend in 10 years with 90% power.
- Koala occupancy at sites that form a broader program of acoustic monitoring for biodiversity should be located in both high and low habitat-quality areas to allow Koala occupancy to be modelled across the landscape using variables that influence occupancy (e.g. elevation, NDVI). Furthermore, maps of modelled occupancy can be produced to demonstrate snapshots of Koala occupancy over set periods of time when a sufficient level of sampling has been achieved (e.g. a 3-year window). Maps of change can be produced using these snapshots to identify areas where Koala occupancy has increased, decreased or has remained stable.

8. Outcomes

8.1 Priority species for monitoring, and estimated occupancy in the 1990s

8.1.1 Fauna

A total of 140 fauna species, consisting of 53 mammals, 37 birds, 32 reptiles and 18 frogs, were identified as a priority for baseline modelling. These species were identified *a priori* using a combination of expert opinion and published data. Important criteria by which species were listed in Table 1 (although not all criteria apply to each species) included: forest-dependent for all or part of its life-cycle; representative of a particular ecological functional group; sensitive to intensive logging; sensitive to introduced predators; sensitive to climate change; threatened status under the NSW *Biodiversity Conservation Act 2016*; listing as a priority under the NSW 'Saving Our Species' program; and, listing as a key threatening process under the NSW BC Act. No particular consideration was given to species abundance, although efforts were made to include widespread species and several that were of interest in particular RFA regions.

However, only 33 (23.6%) fauna priority species had naïve occupancy (NO) > 0.10, and 51 species were > 0.05 (which is adequate for species occupancy modelling purposes), but 56 (40%) species occurred on less than 1% sites (i.e. NO < 0.01; Table 1) and could not be modelled. Unless survey methods can be improved, which may include repeat visits using existing methods, only about half of the 140 priority fauna species will be recorded in sufficient numbers for analysis (i.e. species in Table 1 with NO > 0.01–0.05). A further consideration is that, where possible, species should be detectable using the survey methods proposed for use in FMIP and Coastal IFOA biodiversity monitoring programs (i.e. cameras, song meters and bat-call detectors). However, nearly one-third of all priority fauna species (n = 44; 31.4%) were considered unlikely to be reliably detected using any of the 'standard survey and monitoring methods' that are proposed for use in the proposed FMIP and Coastal IFOA biodiversity monitoring programs. This includes most of the reptiles on the list and several of the highest priority mammals and bird species. To address these deficiencies in the proposed survey methods, it will be important to include nocturnal site visits (e.g. spotlighting for the Greater Glider) and diurnal site visits (e.g. hand searches for reptiles) to reliably detect the presence of these important species.

Recent research has shown that several priority species are already showing significant recent declines in their distribution and abundance, and should be targeted for survey in monitoring programs. The now more frequent and extended periods of hotter, drier weather extremes associated with climate change in many environments have been implicated in the collapse of some regional fauna populations including the Koala (Lunney *et al.* 2017), Greater Glider (Smith and Smith 2020; Wagner *et al.* 2020) and a number of species of frogs (Geyle *et al.* 2021). Similarly, introduced predators (foxes and cats) have long played a significant role in the regional and national extinctions of many critical weight range mammals in Australia (Woinarski *et al.* 2015), regardless of ecosystem states and conditions, so the distribution and abundance of these and other introduced species need to be specially targeted for monitoring and control.

8.1.1.1 Species sensitivity to disturbance

The list of priority baseline fauna species was chosen to include 61 species known or likely to be sensitive to timber harvesting (including 39 species that are dependent on tree hollows for breeding or shelter), 15 species known or likely to be sensitive to climate change, and 21 species known or likely to be sensitive to introduced predators (Table 1). The results of species occupancy modelling for 28 priority fauna species (Section 7.2.1) showed that Candidate Old Growth was a significant variable associated with the distribution of seven species (Glossy Black Cockatoo, Koala, Leaden Flycatcher, Mountain Brushtail Possum, Powerful Owl, Varied Sittella, Yellow-bellied Glider), the first six of which were also listed in Table 2 (Section 4) as priority species for the FMIP. Years since Fire was a significant variable associated with the distribution of five species (Australian King Parrot, Common Brushtail Possum, Greater Glider, Southern Boobook, Varied Sittella), the first three of which were also listed in Table 2. The Number of Fires between 1962 and 1991 was a significant variable associated with the distribution of 10 species (Australian King Parrot, Bell Miner, Brown Treecreeper, Common Ringtail Possum Koala, Long-nosed Bandicoot, Masked Owl, Noisy Miner, Sugar Glider, Varied Sittella), the first seven of which were also listed in Table 2. Details about species directional responses to these disturbance history variables are provided in Appendices 7a and 7b.

The species modelling results from this project support the *a priori* assessments of species sensitivity to logging, in terms of the significance of the Candidate Old Growth Forest covariate used in the models (see Section 8.4). However, Candidate Old Growth, which was used in its absence as a surrogate for logging history and severity, did not feature as strongly as expected in most of the species occupancy models (Figure 54) or in the species habitat models (Figure 55). The fire history variables also did not feature as strongly as expected (Figure 54). These inconclusive results for many species are thought to be related to the quality and resolution of the covariates available for the analyses. A major deficiency in the modelling efforts was the inability to adequately characterise disturbance events in the landscape. The Candidate Old Growth Forest layer (used as a poor surrogate for logging impacts) and the fire history layers did not represent severity or fine-scale extent for either logging or fire, and this is an important area for improvement in future monitoring programs.

The species modelling results may also have under-estimated the number of species that are likely to be sensitive to climate change, given the significance of climatic variables in the models for so many species (see Section 8.6). However, correlations with a variable does not of itself imply that a species is sensitive to that variable per se, as both variables may be associated with a third causal factor. Sensitivity to other climate change-related disturbances, such as drought and extreme weather events, were not explicitly considered.

The results of this study were also unable to provide new information about the sensitivity of native species to introduced predators (or introduced herbivores) because information about the occurrences of these introduced species was inadequate for inclusion in the species models.

8.1.2 **Flora**

Among species which occur frequently and are widespread within at least one RFA region, we identified a subset of 127 of our 191 priority flora species (192 taxa) in Chapter 5 and Section 6.3 that we suggest should be a priority for monitoring based on observed patterns of distribution in respect of Candidate Old Growth (COG) Forest (and by inference, disturbance from forest harvesting), fire history or climate (Table 3). Our final choice of species was partly subjective and based on arbitrary thresholds. Thresholds are necessarily arbitrary because all species respond to disturbance, fire and climate to some extent and even if it were possible to make accurate predictions about likelihood of increase or decline, or extinction of species in the long term, the decision as to acceptable magnitude of change in any particular context is subjective. We have provided a consistent approach for ranking species for priority using survey results to characterise patterns of distribution in relation to COG, fire history or climate and applying thresholds to criteria of magnitude and confidence, of differences among categories of these factors. The list of priority species may be varied by changing the thresholds or varying the weight given to the criteria. An element of subjectivity will remain in the final choice, especially for choices in respect of COG and fire, because the data were not only imperfect but inadequate to fully account for interactions among these factors and for species-specific responses to other aspects of the physical environment for which spatial data are lacking.

For species with lower occupancy, the confidence that observed patterns represent real responses is greatly reduced. We found that just 24% of all species recorded in the baseline flora surveys had a (naïve) occupancy (NO) of 0.01 or greater (Section 7.1.2.3). That leaves 76% (2,128 species) with lower occupancy listed in Appendix 6 for which there is low to very low confidence that the observed differences represent actual responses. This group of species with low occupancy includes species for which large changes are most likely to be of significance for conservation or persistence of the species, because of their low frequency in the landscape. This group also includes species likely to require the most resources for effective monitoring, because of their low frequency of recording. Our results in Appendix 6 are useful for indicating which of these species may have the highest magnitude of response and may be given priority for monitoring, but the degree of confidence is much lower than for species with higher occupancy (NO > 0.01).

8.1.2.1 Species sensitivity to disturbance

By using Candidate Old Growth (COG) Forest mapping, native flora species that are potentially sensitive to disturbance from timber harvesting were identified at a broad scale and over the medium to longer term (one to several decades). These species are listed in Appendix 6 as positively responding to the COG covariate in at least one RFA region. Timber harvesting generally results in a mosaic of different types and intensities of disturbance. Our results are relevant to this context but may not be representative of responses in particular patches of this mosaic. Our results suggested that for the majority (75–85%) of species with occupancy > 5%, the effect of forest harvesting in the medium term (one to several decades) and at the regional scale was a change in occupancy of no more than approximately 30% between COG and non-COG mapped areas. This does not preclude greater changes at different time scales, in particular vegetation types or in the most heavily disturbed part of the harvesting mosaic. Note, however, that the imperfect nature of the COG mapping means that the impact of timber harvesting on flora species occupancy may have been underestimated.

Our results need to be interpreted in the context of the limitations of the data. The COG mapping is known to contain inaccuracies, with areas mapped as COG including some forest stands that were logged prior to the early 2000s. Without rigorous ground truthing of the mapped layers, it is impossible to say how imperfect the mapped COG layers are. Areas mapped as COG have also been disturbed by other factors, such as fire, severe storms and possibly Aboriginal land management in the distant past. Most importantly, environmental and other characteristics that determined historical patterns of timber harvesting and other forms of disturbance may have yielded spurious responses. In general, timber harvesting was most intense, repeated or of longer duration in areas of high timber value closer to settlements. As a result, undisturbed areas in these environments were of limited extent and may not have been representative of the more extensive disturbed areas. For example, they included areas that were reserved for particular values rather than representativeness or were avoided due to steep slopes or access difficulties. Modelling can account for some of the interactions (e.g. the tendency for disturbed areas to be at lower elevations in areas of lower relief near the coast) but no retrospective study can sample disturbance and environment combinations that no longer exist or are no longer representative of their class.

Relatively few of the more frequent species exhibited changes of more than 30% in occupancy between stands mapped as COG and non-COG, and for those for which confidence was lower (< 95%) the change was mostly < 50%. Species for which a difference of more than 30% was highly likely, with confidence > 95%, included those with higher occupancy in COG (species shown as having a positive response to COG in Appendix 6) and others with higher occupancy in disturbed areas (species with a negative response to COG). In some cases, this difference was confounded by interactions with environment and a difference did not necessarily mean a change due to disturbance alone. In particular, many of the species for which there was high confidence that the difference was > 30% occupancy in COG sites, were species that occur in environments that are rarely harvested due to low commercial timber volume, such as infertile rocky sites, and were indicated as having a false ('F') positive response to COG in Appendix 6. The environmental correlates that determine likelihood and intensity of harvesting (such as soil fertility and extent of rock) were not well described by the available remotely sensed or modelled physical data and therefore were not necessarily adequately accommodated in models of species occurrence relative to COG and, by inference, timber harvesting.

From GAM results, all regions had more species associated with disturbed sites (COG01 = 0) than with undisturbed sites. UNE region had the highest number (16) of species significantly and strongly (a difference ≥ 30%) associated with COG sites (i.e. higher occupancy in undisturbed areas), but most of these were species restricted to low fertility soils on rocky sites, often on Kangaroo Creek sandstone. These environments had a disproportionately high number of sites assessed as COG because they had low to negligible commercial timber value. Examples of species in this category were the canopy tree *Eucalyptus planchoniana*, shrubs *Banksia oblongifolia*, *Leptospermum trinervium*, *Melichrus procumbens* and *Petrophile canescens*, and herb *Patersonia sericea*. In the response summary (Appendix 6), these and other species that occurred in similar habitats were interpreted as false responders for this reason. However, there are likely to be other species for which interactions were subtler for which we have misinterpreted the response. For UNE region, among the few species with a higher occupancy in undisturbed forest and for which this was likely to be a true response was a small tree, *Alectryon subcinereus*, and a vine, *Embelia australiana*, both of which occur in wet sclerophyll forest but are more common in rainforest. There were many more species with a higher occupancy in disturbed forest, for which the difference was not readily attributable to interactions with environment. These included species with a wide range of life forms and habitats, such as the canopy tree *Eucalyptus pilularis*, vine *Stephania japonica*, scrambler *Rubus rosifolius* and herb *Lobelia trigonocaulis*.

LNE region had only two species with a strong and significant positive association with undisturbed sites. One of these (*Lomatia silaifolia*) is regarded as a false result. It occurred in several vegetation formations but more frequently in Shrubby Dry Sclerophyll Forest (SDSF). Its association with COG varied among formations and in Shrubby Wet Sclerophyll Forest it was more frequent in non-COG (i.e. harvested) sites. The positive association between *L. silaifolia* and COG in the generalised additive model (GAM) was strongly influenced by its high frequency in relatively undisturbed plots in SDSF on low-fertility, siliceous soils, which were undisturbed because they had low timber value. For this species, the inconsistent results suggest an inadequate GAM due to the lack of adequate environmental covariate layers (especially surface rock and soil properties) rather than an avoidance of logging per se (Appendix 6). For the other, *Solanum hapalum*, the GAM result was inconsistent with the raw occupancies, which could indicate a deficiency in the model or an actual greater occurrence in undisturbed sites.

Southern RFA region had eight species with significantly higher occupancy in undisturbed (COG) sites but four of these (e.g. *Lomatia ilicifolia*, *Monotoca scoparia*) occur on low fertility soils in areas rarely subject to timber harvesting and are regarded as false responses.

Across all regions, epiphytes as an ecological group may be expected to have a positive association with undisturbed sites due to their requirements for features (hosts and microclimates) that develop during relatively long stable periods without disturbance. To some extent this is reflected in the results, with more species of epiphytes having higher occupancy in undisturbed (i.e. COG) sites, but most species of epiphytes were insufficiently recorded to allow a high degree of confidence. There were also some species (e.g. *Papillilabium beckleri*) that grow as twig epiphytes and appear to be short-lived, which displayed a contrary response, having higher occupancy in disturbed (non-COG) sites. In any case, epiphytes as a group should have priority in monitoring.

Overall, among species with higher occupancy, there were very few species for which there was convincing evidence of a positive association with 'undisturbed' sites mapped as COG. Species with lower occupancy at a regional scale, because they have a relatively restricted distribution or because they have relatively low population size, are more likely to include species with adverse response to disturbance. They are also the species for which the consequences of an adverse response to disturbance are likely to have the most serious conservation implications. For these species, the confidence thresholds may need to be relaxed to obtain an indication of which species may respond in this manner and which may thus be good candidates for monitoring. The results using binomial confidence limits are also potentially useful in indicating species that may have an adverse response to disturbance, but spurious results are more likely.

8.1.2.2 Discussion of Maxent models with respect to COG, fire and climate

Just 18 species had importance values ≥ 5% for COG among the Maxent models of the 174 priority flora species (Section 8.4). They were almost all rainforest trees, shrubs, vines or epiphytes. There was reasonable alignment between these species and the 13 species positively associated with COG (i.e. undisturbed forest) in GAM analyses (Table 3; Appendix 6), with eight rainforest species in common: four trees or shrubs (*Alectryon subcinereus*, *Orites excelsus*, *Ceratopetalum apetalum* and *Acmena smithii*), two epiphytic orchids (*Sarcochilus falcatus* and *Dendrobium pugioniforme*), a vine (*Embelia australiana*) and an herbaceous perennial tussock (*Lomandra spicata*). Nine of the remaining 10 species were associated positively with COG (i.e. with forest largely undisturbed by recent timber harvesting) in Maxent modelling and were rainforest and wet sclerophyll denizens: six trees or shrubs (*Decaspermum humile*, *Rhodamnia argentea*, *Gossia acmenoides*, *Gossia hillii*, *Rhodomyrtus psidioides* and *Mallotus philippensis*), two epiphytic ferns (*Platycerium bifurcatum* and *Asplenium australasicum*) and a vine (*Parsonsia straminea*). The introduced shrub, Montpellier Broom (*Genista monspessulana*), on the other hand, was negatively associated with COG (i.e. this species was likely associated with disturbed forest). The five additional species associated with largely undisturbed forest mapped as COG in GAM analyses (Table 3, Appendix 6) were also rainforest or wet sclerophyll forest trees or shrubs (*Eucalyptus fastigata*, *Notelaea venosa* and *Solanum hapalum*), a fern (*Adiantum hispidulum*) and herb (*Solanum pungetium*).

The difference between the COG results of the two methods may have been due to several reasons: (1) the Maxent models used more data points, which likely allowed refinement of the relationships with climatic variables; (2) GAM analyses were done on a regional basis and the observed response of some species varied among RFA regions; (3) Maxent models took correlations among covariates into account in a different manner to that of the GAM models, so that the influence of COG relative to correlated climatic variables was likely expressed differently.

In summary, and considering both the results of the GAM and Maxent modelling, the species most likely to be sensitive to timber harvesting were six species of rainforest and wet sclerophyll forest: two trees or shrubs, *Acmena smithii* (Lilly Pilly) and *Alectryon subcinereus* (Native Quince); the scandent shrub or vine, *Embelia australiana* (Embelia), and three epiphytes – two orchids, *Sarcochilus falcatus* (Orange-blossom Orchid) and *Dendrobium pugioniforme* (Dagger Orchid) and a fern, *Asplenium australasicum* (Bird's Nest Fern). Two additional rainforest trees, *Ceratopetalum apetalum* (Coachwood) and *Orites excelsus* (Mountain Silky Oak), and a rainforest mat-rush or irongrass, *Lomandra spicata*, were identified with 'undisturbed' forest by both analyses, as well. Given that these species are primarily rainforest denizens, timber harvesting operations in eucalypt-dominated forest are unlikely to affect the survival of any of these species regionally. The remaining predominantly rainforest tree, shrub, vine, epiphyte, fern and herbaceous species listed above were associated with forest mapped as COG by just one analytical approach, but should also be prioritised for future monitoring of the impacts of harvesting operations.

There were no species for which binary fire (either ≤ 30 years or > 30 years since fire) contributed > 30% to the models. Those for which it contributed > 10% were almost all species of dry sclerophyll forest and many were species of low-nutrient environments, which are subject to relatively frequent fire. This contrasted with the GAM results, which included fairly even numbers of both dry sclerophyll and rainforest/wet sclerophyll species with significant responses (at $p \leq 0.05$) to the same binary fire variable. Some species with a highly significant GAM result (e.g. *Asplenium australasicum*) had a very low Maxent fire contribution. There is no simple explanation for this contrast, but it could perhaps be related to the lack of reliable fire history records for much of the private land from which additional records were derived for Maxent models.

Species for which rainfall and temperature variables made a high Maxent contribution were consistent with the selection of species as climate-sensitive, as described in Section 6.3.2. All of the species selected as temperature-sensitive had Maxent models in which at least one temperature variable contributed > 5% to the model outcome. For 58 of the 61 species, at least one temperature variable contributed > 10%. All but two of the rainfall-priority species had models for which a rainfall variable contributed > 5%, and for 44 of the 55 species, at least one rainfall variable contributed > 10%. There is a clear distinction between the broader-scale factors of temperature and rainfall being strong drivers, and local-scale topographic factors generally making very weak contributions. This is likely an artefact of scale and inadequate topographic data in respect of the features that influence plant species distribution in the study region.

8.1.3 Fauna and flora synthesis

Survey techniques for fauna priority species are more complex than those required for flora priority species. Multiple survey techniques, not just cameras, song meters and bat-call detectors, are required to monitor changes in species occupancy and distribution for all 140 fauna priority species, and these techniques need to be employed over several repeat 'visits' so that species detectability can be considered. Flora species, however, whether short-listed as priorities in species monitoring programs or not, can usually be adequately surveyed and monitored during single visits to relatively small plots in which all plant species present are recorded.

Synergies are possible when fauna and flora are monitored on the same sites, for example, plant species composition and structure are clearly important elements of animal habitat, and the presence of introduced herbivores are clearly important threats to many native plant species. While flora survey plots are typically small (20 m × 20 m), their contributions to a better understanding of fauna-vegetation (habitat) relationships can be greatly improved if these small plots form part of larger plots (e.g. 20 m × 50 m) where the additional area is devoted primarily to measuring aspects of forest structure that provide important habitat components for fauna. For example, larger plots are required to estimate the density of large hollow-bearing trees that provide important nesting and shelter resources for wildlife.

Temperature, Precipitation and NDVI were consistently important variables correlated with species occupancy and distribution for many fauna and flora species, and these relationships are more fully explored in Section 8.6. However, fire and logging history variables were relatively more important in flora species models than in fauna species models. It is likely that flora distributions are more easily predicted than fauna because animals are mobile, and animals can survive in marginal or sub-optimal habitat following recent disturbance that may degrade the quality of preferred habitat needed for successful reproduction.

The quality and availability of disturbance history mapping, in particular for fire and logging events, needs to improve if species occupancy and distribution models for both flora and fauna species are to become an operational component of the FMIP and Coastal IFOA species monitoring programs.

8.2 The role of SOM and ENM approaches in designing forest biodiversity approaches

Species occupancy estimates from this project can be used in two ways. First, median occupancy for each species provides an estimate of species occupancy across average conditions at sites surveyed in the 1990s. These data provide an important context for comparisons with future monitoring results, given the comprehensive 1990s database that has been compiled and analysed for this project, and which accounts for detection probability of different survey techniques. This means occupancy estimates from this study should be broadly comparable to future occupancy estimates, even if different survey methods are applied. Improved survey techniques, or improved implementation of existing survey techniques, would result in more accurate and precise estimates of occupancy.

Occupancy has been stratified or partitioned into expected median species occupancy estimates for each region and drivers of occupancy are also provided (e.g. climatic variables, region, tenure, etc.). The output from these models included a ranking of the most important variables used in the modelling and a map showing the predicted occupancy of each species throughout the project area during the 1990s. Variables not supported in models can generally be thought of as having a small or no influence on occupancy. If tenure was included as an influential covariate of occupancy, then this shows the importance of tenure in influencing overall occupancy of individual species in the 1990s. Significant changes in land tenure occurred post-1990s, so future modelling of monitoring data should include tenure to identify the extent of changes due to its influence.

A second use of occupancy is via spatial prediction of occupancy for each priority species that had sufficient data in the 1990s to provide an additional point of reference (map) for future monitoring. Future occupancy maps can be overlayed and subtracted from the 1990s surface to identify where decreases or increases in occupancy have occurred.

It is important to note that it is possible to have a reliable estimate of median/modal detection and reliable estimates of species occupancy, but not necessarily good relationships with spatial predictors. This is because the quality and resolution of the spatial data (covariate) layers that were available in the 1990s, especially records of the distribution and severity of logging and fire impacts, were not as accurate as they are today. So, mapping occupancy may be less reliable, although inclusion of standard error maps highlights areas of greater uncertainty.

The current project has identified baselines for future comparisons of species occupancy across a range of high priority species (including species which are likely to be sensitive to a range of disturbances and climate change). Future monitoring programs are likely to include fewer monitoring sites than the large number of survey sites that were available to us to develop 1990s baselines for species occupancy. This means that there is likely to be wider confidence intervals (i.e. less certainty) around future occupancy estimates, although better methods for survey are likely to result in improved probability of detection and overall precision. This demonstrates the importance of power analysis to guide future monitoring designs that are capable of detecting changes in species occupancy if it is occurring. Factors affecting the power of monitoring designs include the number of monitoring sites, the species targeted, the survey methods employed, the probability of occupancy, the number of 'site visits' that can be resourced and the duration of monitoring.

The current methods proposed for inclusion within the FMIP fauna species monitoring program (remote cameras, song meters and bat-detectors), while effective for a wide range of species, are not going to detect all, or even most, of our priority species (e.g. Greater Glider, and most species of reptiles). Results from pilot monitoring will help to inform the extent to which passive acoustic monitoring over longer periods will provide better survey results than traditional methods such as call-playback methods for large forest owls, etc. This means that additional survey techniques will be required or more targeted, localised monitoring will be needed. We recommend that a broad-based forest monitoring program using cameras, song meters and bat-detectors be complemented with targeted, and or localised, monitoring for priority species that will not be effectively monitored by a broad-based program.

Survey Gap Analysis has shown that more confidence can be placed in the species occupancy estimates for national parks and state forests in this project than those for private native forests and Crown forest lands, because far fewer survey sites were located in these last two land tenure categories. This also means that species occupancy baselines developed in this project may not necessarily be as reliable for comparisons with results derived from future monitoring programs on private forest lands.

As well as providing a 'static' baseline estimate of species occupancy in the 1990s we also provide examples of trend analyses using an occupancy modelling framework and other complementary approaches. The case studies presented show contrasting patterns among species and overall illustrate a general paucity of trend data for forest species. There is a clear need for a future forest monitoring program to contribute such data to assess the changing status of our biodiversity.

Species occupancy models were developed for only 28 fauna priority species in northern NSW and for 16 of these species in southern NSW, representing just 20% of the 140 fauna priority species, due to the unavailability of suitable data for analysis (i.e. species must be surveyed using repeat survey methods). Accordingly, an alternative approach was required to provide a spatial representation of potentially suitable habitat for all fauna species. Two statistical methods (ENMs) were considered, Maxent and Boosted Regression Trees, and for several reasons Maxent was selected as the most appropriate for use. Maxent is well suited for analysis of data in which only positive records of species presence are available and this enables all species records to be utilised, regardless of survey methodology (Elith *et al.* 2011).

ENMs using Maxent were developed for 446 fauna species and 174 of the 192 priority flora species (Table 7). The output from these models included a weighting (Importance Value) given to each of the covariates used in the modelling and a map showing the distribution of potentially suitable habitat for each species. Each of the three modelling approaches used different datasets, and so the results of each method are not directly comparable. The SOMs used only the systematic data (EIS, CRA, NEFBS) that were collected in such a way (i.e. where repeat visits were undertaken) that species detectability (i.e. false absences at survey sites) could to be accounted for, but this approach limited the number of species that could be modelled using SOM. The BRT method also used only the systematic data that were collected, but there was no requirement that only data be used where species detectability could be estimated. This enabled many more species to be modelled, but the quality of the data was necessarily reduced because false absences in surveys for each fauna species could not be accounted for. The Maxent method used only the positive records for each species (ignoring the absences from the systematic surveys, real or otherwise), but it also utilised any additional records that existed within the study region during the main 1990s survey period, regardless of any bias in data collection.

Comparisons between the results of species occupancy models and environmental niche models for the same species, even though different data sets were used, showed that more confidence and greater accuracy could be expected from the mapped results of the SOMs than the ENMs in the opinions of relevant species experts. This may partly be due to the capacity of the SOMs to estimate species detectability and to incorporate this into the occupancy modelling, as well as utilising the information about likely species absence at survey sites in the process, which ENMs are unable to do (Comte and Grenouillet 2013; Lahoz-Montfort *et al.* 2014). Also, the species occupancy models provide results that can be mapped as the distribution of currently occupied habitat for each species, rather than as the distribution of potentially suitable habitat for the same species. The approach undertaken to filter occurrence records for the ENMs truncated estimates of species environmental niches (Figure 20), thereby likely decreasing the accuracy of ENMs and their output.

Unlike SOMs, ENMs may be fitted using a wide range of methods and are able to utilise both systematically collected data (presence–absence data) or presence-only data (e.g. incidental observations including museum and herbarium records). The BRT method is highly flexible and may fitted using either presence–absence or presence-only data. MaxEnt can only be used with presence-only data but it is also possible to pool the presence records from systematic surveys with incidental presence records to enhance the spatial and environmental coverage. Improved maps of potentially suitable habitat for species were developed using data extracted from Atlas of Living Australia (ALA), which included records from anywhere within the study region during the 1990s. These maps can also be used in a similar manner to that described above where future habitat suitability maps (based on post-1990s records) can be overlayed and subtracted from the 1990s surface to identify where decreases or increases in habitat suitability are likely to occur. Caution needs to be applied in the interpretation of maps of species' potential habitat suitability, as some regions projected to be suitable may be uninhabited by the species due to connectivity or dispersal constraints. The application of the REMP procedure as used in this project is one way to improve confidence in the ENM mapped outputs.

ENMs are useful for defining and mapping the broad environmental space for species as a potential input to design of a monitoring program. ENMs could also be a useful addition to analysis of subsequent monitoring data. For example, the analysis could follow a model-based design, which would mean selecting the subset of monitoring sites occurring within a species' distribution when that species is analysed. The power analysis section explains how fewer sites are required to achieve power for occupancy analysis when sites are drawn from a species' habitat instead of the whole landscape. Another potential alternative is to include ENMs as covariates when modelling initial occupancy for species in trend analyses.

8.3 Regional differences in species distributions, including land tenure

Far fewer fauna data were available for analysis in the two southern RFA regions (Southern and Eden) than in the two northern RFA regions (UNE and LNE), and the data that were available were not as evenly sampled or representative of the regions as was the case in northern NSW. However, estimates of naïve occupancy have been provided for all fauna species in both the combined southern and combined northern regions.

Regional comparisons of fauna species occupancy showed that for 16 modelled species, occupancy was greater in the north for six species (Bell Miner, Common Brushtail Possum, Glossy Black Cockatoo, Masked Owl, Sooty Owl and Yellow-bellied Glider), whereas occupancy was greater for one species in the south (Satin Flycatcher). The Koala, Long-nosed Bandicoot, and many other species were recorded too infrequently in the south for occupancy modelling. Caution is needed when comparing these results because of sampling differences between the regions.

Regional differences in flora species distributions were more evident than with fauna species because of the high plant diversity of eastern NSW forests and because many flora species have much more geographically attenuated distributions than the mammals and birds which formed the focus of the species occupancy work in this project. Given that eastern NSW forests are located at the boundaries of several different biogeographical zones and gradients (southern Bassian vs northern Torresian, moist coastal vs dry inland, warm lowland vs cool upland, rainforest palaeo-refugia vs evolutionarily much more recent sclerophyll assemblages), our findings show a series of biogeographical patterns in the distribution of priority flora species. The most speciose groups were centred on the North Coast and South Coast, respectively, with several species spanning both of these zones. Additional groups of species were either centred in the northern ranges or southern ranges, with a few spanning both. A few species had inland distributions in the west of the study region, either spanning both north and south or confined to the Northern Region or South West Slopes. Small numbers of species spanned different combinations of these zones. It follows that there are marked regional differences in the flora of the different biogeographical zones across Northern Region and Southern/Eden Regions and that a flora survey program to monitor the health of NSW biodiversity will have to sample sufficiently intensively in each of these biogeographical zones to be able to assure the ongoing integrity of regional plant assemblages in different parts of the eastern NSW forests. It also suggests that if the fundamental climatic drivers (i.e. temperature, precipitation) of these floristic patterns are changing, then the boundaries of these zones will be where early changes will be likely detected as species distributions expand or contract in the face of changing climate.

Land tenure was also a significant factor influencing the distribution of fauna species in the study region. To an extent, this was not surprising because the overall survey design meant that forests occurring on two public land tenures, state forests and national parks, were surveyed more comprehensively than forests occurring on private lands. However, even with these constraints, the species occupancy models were able to take account of differential sampling effort. Land tenure was a significant covariate in the species occupancy models for 14 fauna species (Table 39). These data show that: (1) species with greater occupancy in state forests than other tenures included the Greater Glider and Yellow-bellied Glider; (2) species with greater occupancy in national parks than other tenures included the Common Ringtail Possum and Masked Owl, and that (3) species occupancy on private forest lands was sometimes similar to either state forests or national parks. Species occurring at similar occupancy across all three land tenures included Long-nosed Bandicoot, Powerful Owl, Eastern Falsistrelle and Southern Boobook (Table 39). The Maxent models for fauna and flora did not include land tenure among the covariates, but it would be a straightforward GIS process to calculate the mean or median habitat suitability by land tenure and RFA region for each fauna and flora species with a satisfactory ENM. Time has not allowed us to do this, to this point.

8.4 Synthesis of the main drivers of species occupancy and distributions

One of the main objectives of this project was to identify the key drivers of species occupancy and distributions. We have approached this in several ways during this project including primarily literature review and the contributions of covariates in 'explaining' the modelled distributions of fauna and flora species. Other approaches include an examination of the variables that were correlated with changes in species occupancy (or activity) over time, or changes in the extent of potential habitat suitability over time, as discussed in Section 7.4 (Species trend analyses) and Section 7.3 (Climate projections), respectively.

Table 39. Occupancy estimates by tenure for selected species for which tenure was a significant covariate in the list of supported models

Species	Region	State forest	National park	Private native forest
Common Ringtail Possum	Northern	0.12	0.23	0.12
Glossy-black Cockatoo	Northern	0.52	0.40	0.43
Greater Glider	Northern	0.52	0.34	0.34
Grey-crowned Babbler	Northern	0.003	0.001	0.003
Leaden Flycatcher	Northern	0.54	0.29	0.54
Long-nosed Bandicoot	Northern	0.62	0.67	0.64
Mountain Brushtail Possum	Northern	0.27	0.62	0.62
Noisy Miner	Northern	0.04	0.02	0.04
Powerful Owl	Northern	0.56	0.56	0.53
Varied Sittella	Northern	0.96	0.02	0.96
Yellow-bellied Glider	Northern	0.39	0.13	0.13
Eastern Falsistrelle	Southern	0.850	0.849	0.849
Masked Owl	Southern	0.07	0.56	0.07
Southern Boobook	Southern	0.795	0.795	0.80

In Section 3.1.1.2, we reported that many fauna species displayed strong associations with one or more key environmental or topographical gradients, including elevation and temperature (which were inversely related), rainfall and fire history (which represented a gradient from wetter to drier forest types), latitude, and solar radiation, the intensity of timber harvesting operations, elevation range (or roughness) and topographic position. The two main forest disturbances, timber harvesting and fire, also appeared to have different effects on forest fauna assemblages, with many species displaying positive or negative associations with these two factors. In addition, forest floristics (e.g. forest tree and understorey species composition) and forest structure (e.g. canopy and understorey height and density, and the abundance of old, hollow-bearing trees and coarse woody debris) have all been identified as having important effects on the distributions and abundance of many fauna species. Unfortunately, most of these important and direct floristic and structural variables cannot yet be differentiated adequately using automated techniques and subsequently mapped at fine scales across large forested areas using remote sensing, although work is progressing in this area (Owers *et al.* 2015).

While assessment of structural variables has typically relied on expert site assessment (e.g. DPIE 2020b: Biodiversity Assessment Method), a concurrent pilot program (FMIP Baseline Project 1) is investigating the use of LiDAR and image-based ground and low-level aerial data captures to assess plot-scale (~20 × 20 m) forest structure and extend the information across the landscape. If successful, these methods will greatly enhance the capability to extend fine-scale forest structure mapping at local and regional scales. The significance of these metrics to fauna and flora modelling is discussed further in Section 9.1.4.

Instead, most of the covariates available for analysis in this study (i.e. those with state-wide coverage, usually by interpolation or other derivations) include a range of climatic, topographic, soil, and productivity-related indices that are, at best, surrogates for other forest floristic and structural variables that are known to have a direct relationship with important aspects (food and shelter) of animal and plant habitats. Other potentially important variables (i.e. those documenting the frequency, extent and severity of disturbances such as fire and logging, and those documenting the local abundance of introduced predators, introduced herbivores, and other pests and diseases) were either inadequately recorded and mapped, or not at all. This is significant because about 30% of mammals and birds are dependent on hollows in old trees for breeding or shelter and about 15% of terrestrial vertebrates are threatened by predation from introduced cats and foxes in eastern NSW forests.

The species occupancy models and the environmental niche models resulted in the identification of a range of significant or important covariates useful in predicting either species occupancy or the distribution of potentially suitable habitat for each species. One way of identifying 'candidate' drivers for species occupancy and distribution is to summarise the frequency with which each covariate is used in the 'best' SOMs for each species, or to average the importance values for each covariate in the 'best' ENMs across all species. These two approaches are used in the following Figures. However, it is important to recognise that all of the significant covariates used in the SOMs and ENMs are likely to be correlations with other unmeasured variables that may have a more direct impact on species responses.

In the first example, we have summed the frequency with which each covariate was used in the best ($\Delta AIC \leq 2$) species occupancy models. The first five covariates in the best SOMs were given a weighting of 2, on the basis that these variables accounted for most of the variation, while the remaining variables in these models were given a weighting of 1. A summary of this information is presented below for 28 fauna species in northern NSW and for a subset of 16 of these species in southern NSW (Figure 54). Mean Annual Temperature and the Normalised Difference Vegetation Index (NDVI) were the two most frequently used covariates in the best species occupancy models. Other climate-related variables were also frequently used, including Mean Annual Precipitation, as were broad forest vegetation types (Keith formations). Landscape Roughness was the most frequently used of the topographical variables. The disturbance history variables, Candidate Old Growth Forest, Years since Fire and Number of Fires, while important for some species, did not appear to be major 'drivers' for most species (Figure 54). COG, Years since Fire, and Number of Fires were considered primary 'drivers' for 11%, 7% and 18% of all modelled species, respectively. These disturbance covariates were associated as secondary 'drivers' in SOMs for < 7% of species, indicating a minor association with occupancy. Species responses to disturbances such as logging or fire, or indeed any covariate, can be positive or negative. It has already been noted that the frequency, extent and severity of all disturbance history variables require substantial improvement in measurement and mapping before they can be reliably used for analysis in species monitoring programs.

In the second example, we have averaged the Importance Value (i.e. permutation importance) attributed to each covariate in the best Maxent models for each fauna species. Only those covariates with an Importance Value greater than 5% were included in the analysis (i.e. those covariates contributing the most to each model). A summary of this information is presented below for 446 fauna species in the combined northern and southern RFA regions in NSW (Figure 55).

Normalised Difference Vegetation Index, Landscape Roughness, and a range of climatic variables including Minimum Temperature in the Coldest Period, Temperature Seasonality, Mean Annual Temperature and Precipitation Seasonality, were the greatest contributors to Maxent species distribution models for most species (Figure 55). Candidate Old Growth Forest also frequently appeared as a significant covariate in the Maxent fauna models, but this can represent a positive or negative response (e.g. Koalas show a negative relationship with old growth).

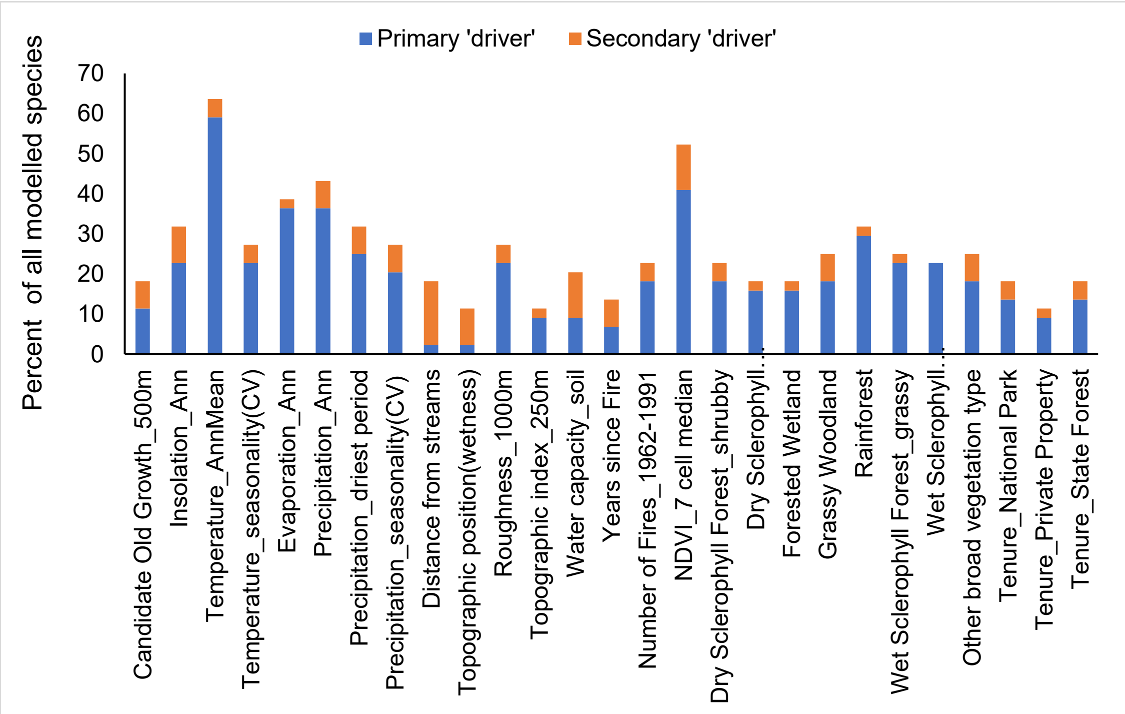


Figure 54. Contribution of covariates to 44 fauna SOMs for 28 species in northern and southern RFA regions

Although the project started with a common set of covariates, some covariates differed between fauna SOM and ENM, and fauna and flora ENM, at the discretion of the analysts, due to: differences in software and the ability of the software to manage different numbers and types of covariates and autocorrelated variables; the modeller's experience with these covariates in previous similar work; fundamental differences between fauna and flora and environmental correlates; the result of trialling various covariates in preliminary modelling of species before finalising the covariate set, and the fauna modelling being completed first and informing the flora modelling

Inferences about causality from importance values for covariates in correlative models like Maxent should be made with caution. As noted earlier, covariates used in Maxent models are surrogates for directly relevant aspects of a species' environment. This makes it very difficult to draw direct cause–effect relationships based on coefficient values or variable importance measures (Mac Nally 2000). At best, variable importance values can be interpreted as landscape-wide overall causal factors that influence the distribution and abundance of modelled species through complex mechanisms. This tenuous relationship is reflected in the difficulty in linking habitat suitability and variable importance from ENMs to critical population parameters such as density and abundance (the abundance-suitability hypothesis; for a review see Jiménez-Valverde *et al.* 2021). Therefore, ENMs should be regarded as working hypotheses of environmental influences (Wilson 2006; Jarnevich *et al.* 2015) indicating regions of change or stability (e.g. refugia).

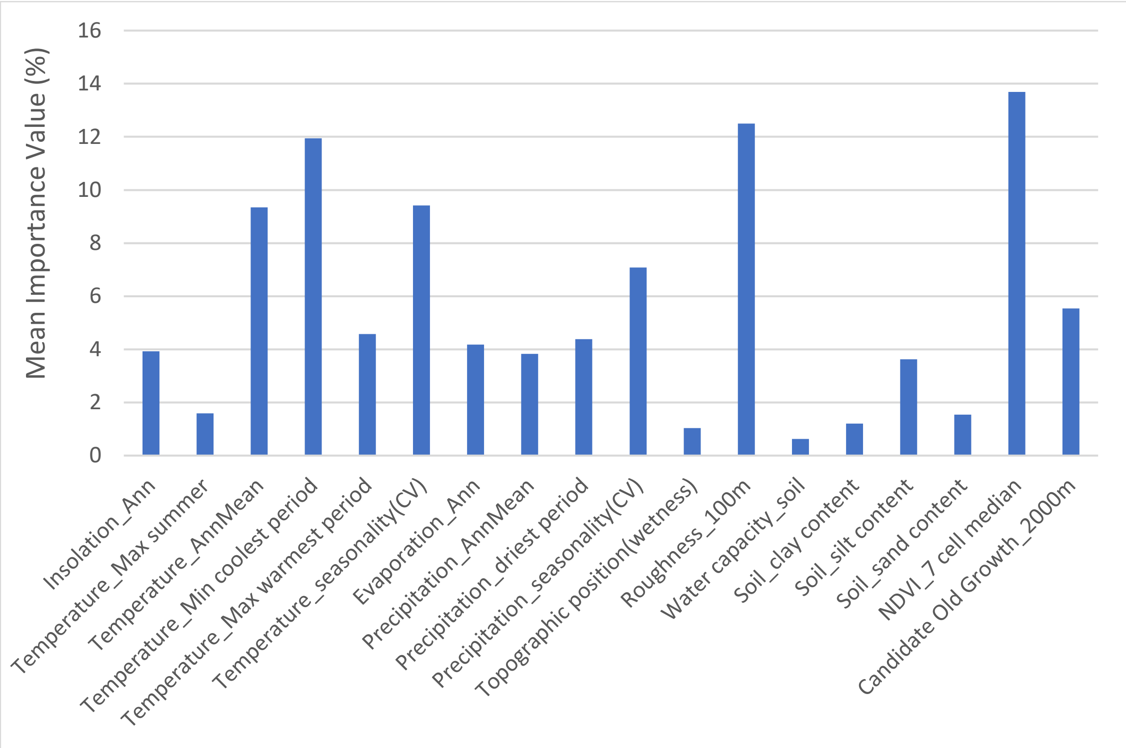


Figure 55. Contribution of covariates to Maxent models for 446 fauna species in the combined northern and southern RFA regions.

In the third example, we averaged the permutation Importance Value attributed to each covariate in the Maxent models for all 174 flora species (Figure 56A). To focus on the most important covariates in each flora species model, only those covariates with an Importance Value greater than 5% were included in Figure 56B. Climatic variables, particularly Mean Annual Temperature, Mean Annual Radiation, Precipitation Seasonality, Temperature Seasonality, Mean Annual Preciptation and NDVI were the greatest contributors to Maxent species distribution models for 50–80% of priority flora species. In contrast to the fauna models, Landscape Roughness and other topographic variables were relatively unimportant in accounting for the distribution of most plant species. Covariates describing soil characteristics were also relatively unimportant. However, it is likely that the measurement and mapping of topographical and soil covariates needs to be at greater resolution and accuracy to be useful in flora species distribution modelling. The two disturbance history covariates, Candidate Old Growth (COG) Forest and Fire Present/Absent in Period 1962–1991, were similarly unimportant for most priority flora species, but for a select 18 species, COG was moderately important and of comparable importance to other topographic and soil covariates for species where permutation importance > 5% (Figure 56B). The one Boolean fire covariate was too coarse and inaccurate to be useful. The utility of other fire variables (e.g. Number of Fires in the past 30 Years and Years Since Last Fire) should be investigated further.

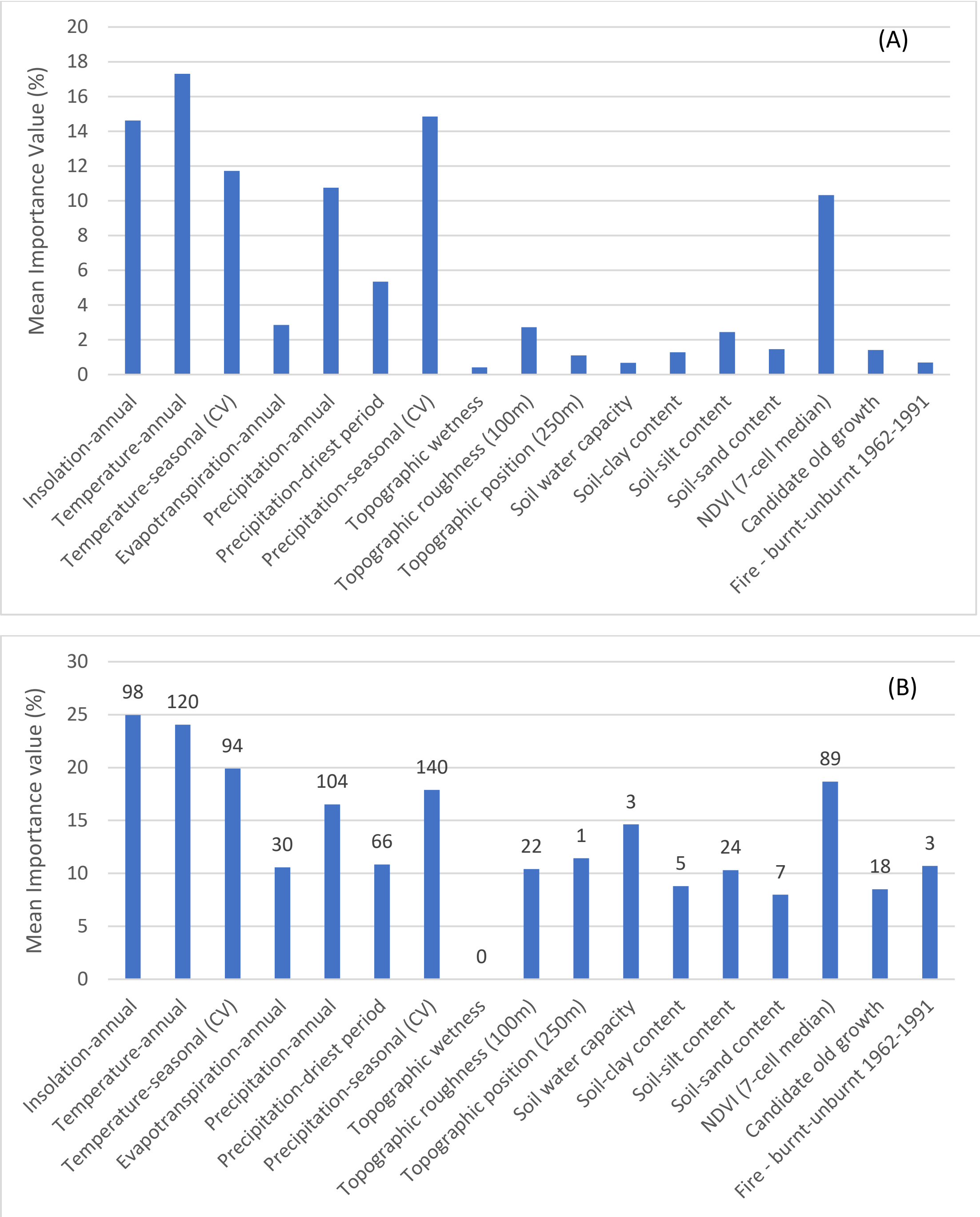


Figure 56. Contribution of covariates to Maxent models for 174 flora species in the combined northern and southern RFA regions

(A) Mean permutation importance value across all 174 species models; (B) mean permutation importance value (IV) for each covariate from just those models where IV > 5% (sample sizes shown above histogram bars)

8.5 Climate projections

The climate trajectory analysis for fauna was conducted using preliminary results from the Persistence in the Landscape Project (PLP), masked to forested parts of the four RFA regions. The PLP models are currently being reviewed and refined.

The preliminary results for the seven focus fauna species in the current project indicated generally deteriorating habitat conditions at least up to 2070 (but likely ongoing) for the seven forest species examined, as well as for the majority of the 78 species modelled for the PLP. The outlook for many species appears to be dramatically worse, including for the Rufous Bettong, with projected losses of 80% of landscape capacity between 2000 and 2070. Other additional factors not considered in landscape capacity, such as extreme fire, can dramatically reduce prey and destroy nesting opportunities.

In accordance with community-level studies using the same climate projections (OEH 2016; Drielsma *et al.* 2017; Love *et al.* 2020b), fauna species are expected to generally contract from the hottest and driest parts of the study region, but remain relatively stable or in some cases expand their ranges (but, often at reduced levels of landscape capacity) at higher altitudes and in sheltered topographies where conditions remain cooler and wetter and where the velocity of climate change is less (Love *et al.* 2020b). Cool mountainous regions, notably the Gondwana World Heritage Area, provide climate refugia to differing degrees to all of the seven focus species.

The preliminary results indicate declines due to climate change can represent a continuing downward trajectory for fauna comparable to historical rates of loss from other causes (mainly clearing and land use). Within the small sample of (seven) focus forest species the results varied, with Rufous Bettong projected to clearly outstrip past rates of loss (0.20% per annum of landscape capacity), with projected losses of 0.73% per annum between 2000 and 2070. For the full set of 78 PLP species there are 29 species for which this is also the case. The ultimate fate for all species will depend on the drivers from traditional disturbances in combination with additional climate change drivers. The best case is that with all conservation and best-practice management in place, the average projected rate of loss for the seven forest species (0.50% of landscape capacity per annum) is projected to exceed the historical rate of loss (0.15% of landscape capacity p.a.) since European settlement; the worst outlook is that climate change will add significantly to the historic decline from other sources.

The preliminary climate projections undertaken for the 81 climate-sensitive flora species in this project identified species that will seemingly be little affected by climate change, as well as winners and losers, and that as climate change proceeds, the number of unaffected species will decline and the numbers of losers will surpass the numbers of winners. However, these findings must be tempered by the uncertainty surrounding the precise changes in climate that will unfold. For the flora analysis, we used the MIROC global climate model (GCM), but different GCMs predict different climatic futures. Of the four leading GCMs used in local climate change research currently (AdaptNSW), CCCMA predicts, in crude terms, a hot, wet future, ECHAM projects a hot future with little overall change in precipitation, MIROC indicates a warm, wet future and CSIRO foreshadows warm and dry conditions. Thus, it is not surprising that our modelling suggested that by 2070, the flora species centred on the North Coast or extending to the South Coast will enjoy increased habitat suitability at the expense of all other groups of species centred in cooler or drier parts of the eastern NSW forests. However, if 2070 turns out to be hot with little change in precipitation (but effectively drier due to the impact on evapotranspiration), as predicted by ECHAM, the North Coast and North and South Coast group of species will likely be the losers and experience reduced habitat suitability, with the groups of species in the cooler southern ranges and on the South Coast more likely to be the winners. In short, a future forest biodiversity monitoring program should be informed by the most likely scenarios around climate change. Where multiple plausible climate scenarios diverge in predictions, as with those used for AdaptNSW, all should be used as this allows for identification of regions of the species' range where a consistent response to climate change is predicted. From here, a monitoring program can focus on the zones and zone edges where susceptible flora species are most likely to show early responses in the form of dieback, plant deaths, range contractions upslope or on to south-western aspects, and their replacement by lowland and drier-adapted species.

8.6 Trends in species occupancy post-1990

Example trends were presented to illustrate different approaches for monitoring trends over time and the dynamic nature of trends as populations recover from major disturbance events such as fire. Each of the trends presented captures a different time period and a key point to be derived from these examples is that baselines need to be used with great care depending on where along the recovery or climatic trajectory a baseline is set. Clearly use of a single year as a baseline is fraught; rather averaging over a number of years is likely to better represent a range of conditions. Occupancy estimates presented in this report combine multiple datasets from forest surveys in the 1990s and so satisfies these criteria and could be used for a number of species as a broad baseline to provide context for future monitoring.

A clear benefit of occupancy modelling of trend data is that it accounts for imperfect detection, which is a common problem for fauna survey data. Occupancy monitoring typically relies on sampling many sites (50–100 per region) to capture changes at a meta-population or regional scale. This approach is well suited to methods that include repeat visits to sites over a short period of time, such as camera trapping, passive acoustics and ultrasonic monitoring. Other approaches can also account for imperfect detection such as modelling of mark-recapture data. Although this method provides detailed data on population dynamics, including survival, the expense of regular marking and recapture means that such programs are only ever feasible at local scales. They do, however, provide an important supplement to occupancy monitoring at larger spatial scales. Abundance monitoring can also be achieved for some species and this is likely to be more sensitive than occupancy monitoring. An example is the use of systematic spotlighting transects for the Greater Glider, which can account for detectability using methods such as distance sampling to yield an adjusted estimate of density. For highly mobile groups like bats, occupancy monitoring is not a sensitive measure of change. Instead, trends in activity levels provide a more sensitive measure to describe change over time (Law *et al.* 2021). Frog monitoring clearly presents a challenge due to the great variability in calling behaviour of populations and the effects of temperature and rainfall. Acoustic monitoring needs to account for the effect of rainfall and temperature on calling and therefore detection, which in theory should be possible with occupancy modelling. Overall, the great variety in trends of different species illustrates the importance of capturing data on individual species and the inadequacy of using simpler surrogates to describe such varied trends.

8.6.1 Reptiles

Trend modelling for reptiles is not available for studies known to us. Reptiles have generally been poorly represented in most forest and forestry studies, possibly because they are perceived to not be sensitive to habitat disturbance, and indeed may be thought to be favoured by it. There are also relatively few reptile species present in forested areas that are listed as threatened species and so they are not a strong target for research or monitoring.

However, reptiles represent potentially an important and useful vertebrate group for forest monitoring as there are species that are likely sensitive to disturbance in both positive and negative terms. Reptiles are ectotherms and so use heat from the surrounding environment to regulate their body temperature and activities. Thus, most species are reliant strongly on available sunlight to regulate activity and require some open canopy areas to use an area of habitat. Many species may be advantaged by the opening of habitat following disturbance and increases in their numbers indicate more open forests. However, there are also a suite of species that rely on closed forest environments including deep leaf litter and large logs and avoid open areas with sunlight. Such species provide the opposite indicator of relatively undisturbed and shaded environments and provide a contrast in community structures. Recent advances in habitat assessment methods such as the use of LiDAR are able to provide much finer scale measurements of features important to some species of reptiles such as canopy density, rock outcrops and log density. Being able to include these measurements at the scales of tens of metres should allow for a much more accurate characterisation of habitats and fine-scale correlations of reptile incidence with habitat features. This in turn could provide very accurate trend modelling of species over time and a clear understanding of the extent and severity of habitat changes through a group responsive to such changes.

Reptiles are generally smaller and less mobile than birds and mammals and many have relatively small home ranges. Hence, they can be expected to respond to habitat features and disturbances of critical features at much smaller 'local' scales measuring in the hundreds or only tens of metres. Rock outcrops are a good example in that a number of species are located exclusively in and around rock outcrops (e.g. many species of *Egernia* and geckoes). Presence of the rock outcrop is critical whereas the forest is less so and it is disturbance of the rock outcrop that is critical to the survival of the population. That allows for likely stronger correlations with habitat measurements in any given area as they will use that area of habitat as all or the major part of their home range and cannot move to find alternative resources.

An important consideration for the proposed FMIP and Coastal IFOA monitoring programs is that the survey methods are not known to be effective for detecting reptiles. Most reptiles are diurnal and are only effectively sampled using the labour-intensive methods of visual hand searches of habitats and pitfall trapping in forested habitats. Reptiles do not call and so cannot be detected using remote recording devices and they are ectothermic and generally thermo-conformers to the surrounding environmental temperatures. This means that they are rarely detected on camera traps deployed to survey vertebrate fauna, which rely on thermal differences between the animal and environment to trigger the camera. A significant proportion of reptiles in forests are fossorial species dependent on deep leaf litter and fallen logs and rarely appear above the surface. These species will never be detected by camera traps except for very rare random events. Large reptiles such as lace monitors and bearded dragons are detected occasionally, but there appears to be little consistency or certainty in their detection and few studies on camera trap success to indicate if detection rates of such species have any potential to be used in comprehensive species monitoring programs (e.g. Dixon *et al.* 2018).

Recent work has been completed where reptile-specific (i.e. downward-facing) camera traps have been deployed using cork tiles or another such background to create a more specific thermal background that reptiles' contrast with to increase detection rates (Richardson *et al.* 2018). Combining these with drift-fences to funnel reptiles into the field of the camera trap does appear to increase detections, but the success appears to be variable across species and usually no better than pitfall trapping at the same sites. It remains unclear whether reptile species detection rates using cameras will be sufficient to make occupancy modelling and trend analysis viable. The deployment of cameras in these more specialised roles may reduce their effectiveness in detecting other species and increase the time and labour costs of their installation.

Of further note is that the methods used to obtain the baseline data used in this project came from surveys conducted in the 1990s using human surveyors. Camera traps were not available at that time and so were not employed in any form to allow for direct comparisons with data collected with the surveys proposed for the FMIP and Coastal IFOA monitoring programs. There is simply no information available to indicate how the detection rates of remote cameras, even if they do detect a number of reptiles, compare to the baseline data previously collected. Therefore, it is not reasonable to provide guidance on the number of cameras that would be required to be deployed or the time they should be set out for in order to provide similar or corrected detection rates to those obtained in the 1990s studies and so make direct comparisons of species distribution changes over the last 20–25 years.

8.6.2 Frogs

Several species of frogs are listed as important species for the proposed forest monitoring programs. Outwardly, monitoring frogs should be simple to incorporate as frogs are relatively easily sampled by remote call recorders and these are to be used on each of the transects in the field. Frogs are a major concern and a high priority for forest monitoring due to recent world-wide and local declines as a result of the chytrid fungus, which has led to much reduced and likely much more vulnerable populations. Frogs are also considered to be sensitive to environmental changes because their life-cycle has both terrestrial and aquatic phases.

However, as previously noted, frogs represent a significant problem for monitoring due to several factors. The current monitoring program design does not easily lend itself to frog monitoring, firstly because it allows for the deploying of a single detector on a stream at only one of the three sub-plot locations at an established grid monitoring point. Frogs are surveyed by recording the calls of males during the breeding season and, in all but a very few cases, males call only around water bodies, and so the design is only likely to be able to sample frogs at the single stream transect. Frogs simply will not be heard at the other transects where there is no water present. This reduces the opportunity to detect frogs by 67%, but is better than nothing.

The current program also places the detector randomly on streams. Male frogs usually cluster in calling groups that are not uniformly distributed along each stream – some species call around riffles, some large pools, some smaller pools. Randomly placing a single detector on a stream will further dilute detection rates of stream-breeding species as they will likely be placed in a suitable 'calling zone' on any sampled stream for a given species less than half the time. If the detector is not placed in a suitable calling zone, it will not detect species of frogs using that type of calling habitat, no matter how long the detector is deployed for.

As a final obstacle to detecting frogs using call recorders, these devices have a low detection range in noisy environments or for frogs with soft calls (that can only be detected within 10 m) and so a recorder has to be placed in close proximity to a calling frog to be certain to detect the species. The recently written NSW survey guidelines for threatened frogs in the Biodiversity Assessment Method (DPIE 2020b) require a detector to be set in place every 50 m of breeding habitat being sampled in order to provide reasonable certainty of detecting a species if it occurs along a stream, which is clearly a substantially greater effort than has currently been proposed.

A further consideration is the analysis of data collected with remote recording devices. Call recognition software is being used to automate call analysis and greatly reduce analysis times for the large volumes of data collected with such devices when they are deployed over multiples sites for days or weeks at a time. However, call recognition programs continue to work poorly for frogs given the complex choruses that occur at breeding sites. Often numerous individuals from multiple species mix together to form a cacophony of sounds that call identifiers cannot separate into individual species with any regularity. Setting more sensitive recognisers usually results in very few or no calls being recognised for a target species, whereas reducing the sensitivity results in numerous false detections of calls that come from a range of other sources. This means that any monitoring requiring the use of remote recorders, at least for the moment, is going to require manual analysis of the collected calls for many species. Streams at least tend to have relatively fewer species and individuals calling along any part of their length at any given time, and so the sound profiles recorded have less noise and some species may be relatively consistently detected with identifiers where they are deployed for long enough periods to get a good window of recording. But that remains to be confirmed and, currently, no species of forest frog in NSW is being consistently and successfully monitored and analysed using call recorders and call identifiers.

The current program design does not cover isolated ponds (e.g. fire and stock dams), which are the preferred calling and breeding habitat for a range of forest frog species. This represents a potential problem in not sampling at least a third of all frog species present in any part of NSW. However, the need to include pond-breeding frogs in forest monitoring as a high priority is debatable, because such species appear to be mostly generalists and relatively robust to environmental perturbations. They also call in often large and complex choruses that provide a chaotic sound environment. This creates a difficult situation for the use of automated calling devices as it is hard to use call recognisers and so, again, and with the current technological limitations, calling activity has to be analysed manually, which is time and cost-intensive.

The baseline data obtained from the various surveys conducted in the 1990s were collected using human surveyors and none using the automated call recorders being proposed for future forest monitoring in NSW. There is no information available to indicate how the detection rates of call recorders compare to the baseline data previously collected. Therefore, it is not reasonable to provide guidance on the number of recorders and time that they should be set out for in order to provide similar or corrected detection rates to compare with those obtained in the 1990s studies and so determine species distribution changes over the last 20–25 years.

The advantage that call recorders do have is that they are able to be deployed for multiple days in a row in a cost-effective manner that will provide repeat survey data suitable for occupancy modelling. The calling seasons of NSW frogs are well documented (e.g. in Lemckert and Mahony 2008 and in the BAM survey guidelines for threatened frogs; DPIE 2020b) and so monitoring can be well targeted to individual species at the correct times of the year, as required. It is likely that a targeted species monitoring program (using experts) will be required for particular threatened frog species.

9. Recommendations for the FMIP/Coastal IFOA monitoring programs

9.1 Recommendations for immediate consideration

9.1.1 Monitoring program design

The distinction between the FMIP and Coastal IFOA species monitoring programs is unclear. Both are ostensibly designed for surveillance and detection of any significant trends in fauna species relative to abundance and distribution (evaluated for most species as the changing levels of occupancy) in NSW forests. However, the Coastal IFOA species monitoring program provides an opportunity to go beyond surveillance monitoring by incorporating management questions into the design. A paired compartment design in which species monitoring sites are located within a range of management treatment areas within compartments planned for harvesting (e.g. within proposed riparian reserves, habitat tree clumps, and areas distant from retained habitat after logging), could be contrasted with fauna and flora species monitoring sites located in similar locations within compartments that are not proposed for logging (e.g. in adjacent national parks). Alternatively, a series of small grids (say, 20 × 20 km) that straddle both harvested areas within state forest and unharvested areas in adjacent national park could be monitored.

The Coastal IFOA species monitoring program also provides an opportunity to include survey methods that are more appropriate for priority species of forestry interest that are not well surveyed using the standard methods that are likely to be applied in the FMIP species monitoring program.

9.1.2 Vegetation and flora species monitoring

Adopting distinct approaches to the FMIP and Coastal IFOA species monitoring programs, as suggested in the preceding section, would benefit and complement vascular plant species monitoring in eastern NSW forests going forward.

Many aspects of vegetation monitoring in eastern NSW forests are already accomplished remotely using aerial photography or satellite imagery, such as the mapping of forest types (Baur 1965) or plant community types (https://www.environment.nsw.gov.au/topics/animals-and-plants/biodiversity/nsw-bionet/about-bionet-vegetation-classification/vegetation-maps/state-vegetation-type-map), forest extent, fragmentation (FMIP Baseline Project 1) and the incidence of Bell Miner Assisted Dieback (A. Carnegie, pers. comm.). Technological advances will increase our ability to monitor forest health, structure and composition at increasingly finer scales in the future at ever-diminishing cost (Section 9.1.5.2). However, new remotely sensed datasets will continue to require ground truthing for validation, and it is unlikely that the remote or molecular identification of most plant species will be possible logistically for at least the next decade or two. This means that on-ground survey of vascular plant species and of vegetation structure and composition in eastern NSW forests will be required for the foreseeable future, both for validation purposes and the sole means of collecting important primary data.

As has been noted, perennial vascular plant survey is not plagued by the issue of low species detectability that besets fauna survey, with a tiny percentage of well-known exceptions (e.g. geophytes that only emerge above-ground to flower in spring). A single survey of a plot is all that is required to accurately record almost all perennial species in forests. Moreover, in the absence of severe disturbance (e.g. timber harvesting, fire, Myrtle Rust infection), forest succession proceeds over a timeframe of decades to centuries rather than years, meaning that a comprehensive, surveillance-style, forest monitoring program (as suggested for the FMIP) based on permanent plots could be built up over a 10–20-year period, while still responding to questions about short-term change on a 5–10-year basis, at modest cost. One aim of such a surveillance-style program should be to detect longer term change in flora species occupancy or abundance, say due to the selective grazing and browsing by feral herbivores or domestic livestock (e.g. cattle, goats, deer, horses, pigs), or the regional or global loss of faunal ecosystem service providers such as pollinators and seed dispersers, or climate change. Given this, the survey design should target forest protected from severe anthropogenic disturbance (to the extent possible). That is, the FMIP should focus on forest stands exempt from disturbances such as timber harvesting, future urban development, and frequent hazard reduction burning in asset protection zones, and be broadly stratified according to the key environmental drivers of precipitation, temperature and site quality (incorporating topographic position in the landscape, aspect and parent material), across all tenures. Moreover, the design should ensure good coverage of each of the main plant biogeographical zones in eastern NSW forests, noted earlier (Section 8.3), and the boundaries between these zones, to pick up early changes in species occurrence or abundance in the face of continuing climate change. Another aim of a surveillance-style FMIP should be to confirm or identify, characterise and monitor the locations where plants and animals persist and biotic communities remain resilient in drought and fire refuges to the changing conditions elsewhere across the forest estate.

A final design element for flora species monitoring in the FMIP should be a conscious periodic focus on infrequent vascular plant species to counteract the inability of unbiased designs to detect trends in the vast majority of vascular plant species for lack of records. The frequency distribution of plant species in eastern NSW forests is highly skewed in favour of rare and infrequent species (Section 7.1.2.3), as is typical of plant and animal communities. This means that most species will be recorded too infrequently for a monitoring program with a modest number of sites (2,000–4,000) surveyed in rotation in panels of 100–200 sites p.a. to yield meaningful data about changes in occupancy or abundance for the large majority of species, even over a cumulative 5-year period. For this reason, our selection of priority flora species was biased, in part, towards more frequent species. As already mentioned (Section 5), rare and threatened flora species including those restricted to one or a very small number of populations deserve their own bespoke monitoring programs, as has been instituted by the Saving Our Species program in NSW. However, here we refer to infrequent species that are not so rare or threatened to be listed under state legislation, but are too infrequent for an unbiased species monitoring program to yield sufficient data to detect meaningful change (i.e. the majority of the flora of the eastern NSW forests). For these species, if every 5 years, one or two annual surveys are biased towards sites where disproportionate numbers of infrequent species occur, the ability to detect change in a greater number of flora species will be improved.

As noted in the preceding section, the Coastal IFOA species monitoring program has the opportunity to target the impact of timber harvesting operations and associated regeneration burns, as well as other intensive forest management (e.g. frequent hazard reduction burning in asset protection zones) using a controlled experimental design. The importance of control sites, matched environmentally with nearby treatment sites, is clear, given the conclusions of many forest vegetation surveys conducted in the 1980s and 1990s. Reports of these snapshot surveys repeatedly noted that ‘Although both logged and unlogged stands were sampled, it is difficult to assess logging impact, mainly because there are no detailed pre-logging data available, and substantial differences may exist between previously logged and unlogged areas, independent of logging history. Present differences in vegetation may be related more to site factors other than logging history’ (Binns 1995b). In some management areas, timber harvesting was so pervasive that sufficient comparable unlogged stands could not be located in the state forests surveyed (e.g. Tweedie *et al.* 1995), and the recommendation for future studies was to source suitable matched stands in nearby national parks (Hatich 1997). A well-designed focus on timber harvesting impacts will improve understanding of forest biodiversity, and facilitate conservation planning for poorly known, early and mid successional species such as dunnarts (*Sminthopsis* spp.; e.g. Monamy and Fox 2005) and Hastings River Mouse (*Pseudomys oralis*; Law *et al.* 2016).

If our recommendations for the FMIP to target largely undisturbed forest are adopted, and the FMIP and Coastal IFOA monitoring programs are designed in such a way that they share a common approach to flora survey, at least in part, then there is potential for synergy between the FMIP and Coastal IFOA program, with FMIP sites potentially doubling as control sites for appropriately matched Coastal IFOA treatment sites. However, because of the landscape-scale focus of the Coastal IFOA monitoring program and the regional focus of the FMIP, there may be few or no relevant FMIP sites in a particular Coastal IFOA district, in which case the Coastal IFOA program will need to ensure sufficient matched control sites are surveyed.

Finally, because of the interdependence of fauna and flora assemblages, it will be important to co-locate flora and fauna monitoring sites, to the extent possible, in both the FMIP and Coastal IFOA monitoring program. Plant species monitoring will benefit from the cameras and song meters located at fauna monitoring sites (e.g. to monitor large herbivore impacts, mycophagous mammal activity, Bell Miner abundance, lyrebird diggings, etc.), while animal species monitoring will benefit from the information about plant species composition and forest structure at fauna sites.

9.1.3 Species occupancy

Appropriate expertise is required to model occupancy, spatial predictions of occupancy and its trends. This project has also highlighted the value of expertise in forest ecology and fauna species when undertaking and interpreting such modelling.

Occupancy estimates for fauna species from this project can be used in two ways:

1. First, a mean occupancy estimate provides an overview of species occupancy probabilities for average conditions at sites surveyed in the 1990s. These data provide an important context for comparisons with future monitoring results, given the comprehensive 1990s database that has been compiled and analysed for this project, and which accounts for detection probability of different survey techniques. This means occupancy estimates from this study should be broadly comparable to future occupancy estimates, even if different survey methods are applied. Improved survey techniques or the improved use of survey techniques would result in more accurate and precise estimates of occupancy.

   Occupancy has been stratified or partitioned into expected mean species occupancy estimates for each region, and drivers of occupancy are also provided (e.g. climatic variables, region, tenure, etc.). Variables not supported in models can generally be thought of as having a small or no influence on occupancy. If tenure was included as an influential covariate of occupancy, then this shows the importance of tenure in influencing overall occupancy of individual species in the 1990s. Significant changes in land tenure occurred post-1990s, so future modelling of monitoring data should include tenure to identify the extent of changes due to its influence. Baseline occupancy should be interpreted with its associated level of precision or confidence. It is also important to acknowledge that the median estimate provided for each species is representative of the sites surveyed in the 1990s, which are strongly biased to the public estate.

2. Second, a spatial surface of occupancy for each priority species with sufficient data in the 1990s provides an additional point of reference for future monitoring. Future occupancy surfaces can be subtracted from the 1990 surface to identify where decreases or increases in occupancy have occurred.

It is important to note that it is possible to have a reliable estimate of median/modal detection and occupancy, but not necessarily good relationships with spatial predictors. So mapping occupancy may be less reliable, though inclusion of standard errors highlights areas of greater uncertainty.

9.1.4 Environmental niche modelling and climate projections

For those species in which the 1990s surveys lacked repeat visits, we used ENMs to provide spatial representations of potentially suitable habitat based on records collated from the 1990s. However, examination of the filtered data for both fauna and flora indicated that these models did not do justice to our full knowledge of the occurrence for some species, and hence were suboptimal. We recommend that these models be rerun to utilise all the current occurrence information available. These models would be enhanced with an updated array of new explanatory covariates (below). We expect that the resulting models will be considerably improved, particularly in the west and coastal areas of the study region, because of the state forest and national park bias in the northern and southern ranges in the 1990s corporate surveys, as well as highlighting new environmental relationships.

There is considerable scope to extend our use of ENMs and REMP to facilitate a forest monitoring program. We recommend ENMs be used to identify areas of refugia for harvest-sensitive species, and highlight that this would be particularly valuable to the Coastal IFOA species monitoring program. It requires incorporating the output of high-quality ENMs into REMP, along with forest connectivity data produced through the Forest Extent Condition and Health – Monitoring Program, to estimate the amount and connectivity of habitat, given a species' needs and movement ability. Combining estimates for multiple harvest-sensitive species (e.g. by stacking maps, similar to Figure 22) will allow multi-species refugia to be identified, as well as key corridors that facilitate dispersal. Projecting ENMs onto future climate scenarios will enable forested areas likely to be critical to the long-term persistence of species to be identified. Indeed, this approach can be used to locate both refugia and areas where populations are likely to be exposed to stress from a broad range of natural and anthropogenic disturbance (e.g. fire and invasive species).

We have previously highlighted that there can be considerable variation in predictions of future climate scenarios. The uncertainty arising from this can prevent management decisions from being made. However, this need not happen, as decisions can be based on agreement in predictions of habitat suitability from ENMs projected on to multiple, plausible climate scenarios (e.g. see Baumgartner *et al.* 2018; Beaumont *et al.* 2019). Hence, when assessing the threat from climate change, we strongly advocate for ENMs to be projected onto a range of plausible climate scenarios. For NSW, these are typically scenarios derived from the NARCliM project (Evans *et al.* 2014). However, NARCliM was based on climate models developed for CMIP3 (Climate Model Intercomparison Project 3, released in 2010 and used in the Intergovernmental Panel on Climate Change's Fourth Assessment Report, AR4 and the emissions scenarios described in the Special Report on Emissions Scenarios (SRES, Nakicenovic *et al.* 2000). These are now dated, with the upcoming IPCC report (AR6) featuring CMIP6 models. The CMIP6 generation of models project slightly higher warming than the prior generation (Meehl *et al.* 2020), hence as downscaled data from these become available for impacts assessments, it will be important to incorporate them into ENMs.

In sum, climate projections reveal the potential of climate change to drastically reduce the capacity of NSW forests to support valued fauna and flora. It is strongly recommended that any future monitoring includes a significant climate projection component. This project begins the process of going beyond mere *post hoc* reporting, towards grappling with 'the long now' (Carpenter 2002), which spans the past, present and future. Clearly, the nature of the data, the uncertainty with it, and how it can be used varies across this time-span. These issues need to be addressed through research.

Finally, in the longer term, we recommend the development of a decision support tool to explore and visualise the potential consequences of different harvesting scenarios on fauna species. This tool would contain ENM maps and habitat condition or forest connectivity raster data. Adjustment of the raster data to mask putative harvest areas and re-running of REMP would allow for a rapid assessment of disruption to refugia and species corridors.

9.1.5 Survey gap analysis

Survey gap analysis shows that more confidence can be placed in the species occupancy estimates for national parks and state forests in this project than those for private native forests and Crown forest lands, because far fewer survey sites were located in these last two land-tenure categories. This also means that species occupancy baselines developed in this project may not necessarily be as reliable for comparisons with results derived from future monitoring programs on private forest land.

9.1.6 Covariates

There is a need for the ongoing analysis of flora and fauna species information with a broader historic–contemporary spatio-temporal filter combined with an expanded set of explanatory and 'driver' covariates. The accuracy and resolution of the existing suite of covariates can be improved using conventional approaches as well as new remote-sensing equipment, including airborne and satellite-derived information. There is also a need to continually improve the statistical basis for spatial modelling. Ultimately, most species models assume that various environmental variables provide a useful surrogate for the distribution of the habitat of modelled species, yet there are many reasons why the models can be wrong and the species absent – so a continual process of model validation, including ground-truthing, is required.

The potential to enhance current and related environmental covariates is large: one way to address the concept is to split the work into two parts: activities that can be reasonably done with current or modest additional resources, and those that can be envisioned in the relatively near future (i.e. over the next 5 years).

9.1.6.1 Covariate recommendations to follow the current programme

It is likely that a range of environmental explanatory variables incorporating historic and contemporary information will enhance our understanding of species occupancy and distribution in eastern NSW forests. Early development of these covariate datasets is important to improve detectability, occupancy and habitat suitability predictions in the short term.

- The lack of spatial information describing timber harvesting operations in eastern NSW forests at sub-compartment scale in terms of the impacts on post-harvest flora and fauna habitat has been noted previously. Covariate layers describing past and present harvesting operations in terms of the structure and composition of the habitat before and after timber extraction, are required. Periodic monitoring of the subsequent successional vegetation states and habitats is also needed to identify the impact of forest disturbance on flora and fauna, both the species that are sensitive to and those that benefit from timber harvesting.

- Cats and foxes as feral mesopredators have had a catastrophic impact on susceptible Australian fauna. Covariate datasets describing changing cat and fox abundance are required to help identify the susceptible fauna most likely at risk from these introduced predators, as well as the role of wild dogs, quolls, varanids and other native predators in mediating or exacerbating impacts. Extensive DPI camera trap arrays in northern and southern NSW forests established in the past decade, supplemented with WildCount records and the other targeted monitoring programs referred to in this report, are likely to provide an excellent basis for the development of predator covariate layers.

- Aggressive weed species have the capacity to divert or arrest forest succession and threaten sensitive flora and fauna. Two such species widespread in eastern NSW forests are Lantana and Blackberry. Spatial information about these two species, at least, should be compiled in order to screen for susceptible native flora species using covariate information about these species' historic and contemporary distribution and abundance.

- Covariates to better describe fine-scale temporary and permanent waterbodies, wetlands, riparian zones and the mesic micro-refugia with sustained access to soil moisture in NSW forests, should be immediately developed. This will enable an improved focus on aquatic and mesic-dependent fauna and flora species, such as frogs. It will also enhance our understanding of fauna and flora at risk from environmental change and the increasing incidence and severity of drought, especially as riparian zones function as refugia during fire and dry times.

- Temporal resolution. This and related projects have shown that it is possible to build effective models with current data. Improvements in data capture (satellite-to-ground remote sensing, camera trapping, and acoustic monitoring) will allow for similarly effective modelling to be repeated at close intervals, such as a 5-yearly or 10-yearly panel rotation, with additional provision for rapid-response assessments of transient events such as fire or extreme weather.

9.1.6.2 Covariate recommendations for implementation in the mid term

The following work should be undertaken as opportunities arise.

- Increased spatial resolution of covariate layers. The base for many critical covariates is the digital elevation model (DEM). Currently a DEM of ~90 m was used, based on sensible data resolution and computing power. The availability of 0.5–5.0-m LiDAR data over eastern NSW and rapid improvement to computational power both mean that comparatively fine-scale modelling is within reach, and includes critical factors such as mapping boulders and rock outcrops (important for many reptiles and endemic granite-outcrop flora species), pool–riffle reaches (frogs, meiofauna), and forest structure at the tree-crown level.
  - Key vegetation covariates from LiDAR data include Tree Canopy Density Metrics (Fisher *et al.* 2020), including Canopy Height Models, Crown Projection Cover and Foliage Projective Cover.

- Data fusion: LiDAR-based metrics can be considerably enhanced by data fusion with high-resolution imaging, opening up the potential for 'second-level' derivatives such as canopy vigour (and crown dieback), old growth occurrence, enhanced mapping of vegetation succession, riparian canopy cover, and modelling and mapping of fire extent and severity.

- Variation in soil properties is a fundamental driver of plant and animal occurrence and abundance, yet current modelling captured very little evidence of soil-based determinants of species occurrence. We believe this to be a result of the relatively poor quality of the available substrate layers information. Better substrate covariates would likely yield a marked improvement in occupancy and habitat suitability prediction.
- Spatial layers describing the occurrence and impact of the serious plant pathogens, Myrtle Rust and Phytophthora, may have considerable utility in predicting the decline of sensitive flora and the potential resulting trophic cascades, now and under a changing climate. The development of these layers and the associated modelling and projections, are a high priority.
- Similarly, the forest-wide biodiversity impacts of despotic fauna species such as Bell Miners (and the link with Bell Miner Associated Dieback) and hyper-aggressive Noisy Miners at forest edges are likely to be important, either now or are under a changing climate.
- Large-scale species monitoring programs generate huge quantities of data which need to be carefully curated and stored securely. With the exponential increase in cost-effective data capture, a significant issue is the accurate and timely processing, collation, storage, use, analysis and dissemination of data, especially as capture comes from an increasing range of sources and programs. Scoping, and trialling data infrastructure, workflow and operators ('big data') are essential requirements for modern science with high granularity at the landscape scale.

9.1.7 Survey methods

The current survey methods proposed for inclusion in the FMIP fauna species monitoring program (remote cameras, song meters and bat-detectors), while effective for a wide range of species, are not going to detect all, or even most, of our priority species (e.g. most reptiles, at least 13 species of mammal including the Greater Glider, and at least two diurnal raptors; Table 1). These methods need to be tested so that we can determine the species for which they are likely to be 'fit-for-purpose', because the 1990s fauna datasets were not collected using any of these methods. Hence, the utility of the current pilot monitoring field trials. These new methods need to be calibrated against the old (more labour-intensive) survey methods to see if they can work as well as expected. For example, can passive acoustic monitoring using songmeters provide better survey results than traditional methods, including listening and call-playback to detect large forest owls?

In addition to these new survey methods, it is likely that improved implementation of some existing survey methods will also be required. For example, the inclusion of repeat visits as part of the survey method will enable species detectability to be estimated, thus improving their effectiveness and utility for data analysis. Spotlighting is the only way of effectively surveying priority species such as the Greater Glider – a species which is highly vulnerable to intensive logging and climate change – and so it is likely that spotlighting will need to be incorporated into the Coastal IFOA species monitoring program, if not within the broader FMIP program. Other priority species with restricted distributions may require the development of more targeted methods and localised monitoring. More broadly, in terms of survey design, it is important that adequate treatment controls are available, particularly within the Coastal IFOA species monitoring program, and this may require some control areas to be established in adjacent national parks or that the program dovetails with the broader FMIP cross-tenure program.

The estimates provided for probability of detection in this report provide a means of assessing the effectiveness of the survey methods used in the 1990s. Use of both detection and occupancy estimates have been formalised in power analyses, and the results of these analyses should be used as a guide when assessing the number of sites required for different species in a monitoring program.

9.1.8 Landscape metrics

We recommend species occupancy as the most informative metric for cost-effective monitoring as representatives of broader faunal biodiversity, at least for species that have moderate levels of detectability and occupancy (e.g. range in occupancy from approximately 0.1–0.8). Where species occur at almost every site, species calling activity or counts of individuals are likely to provide better estimates of population trends. Composite indices should not be used instead of species-level indices, especially in the context of high risk and valued species. Given the idiosyncratic responses of individual species, it is difficult for composite indices to capture trends that will be meaningful for effective management. For example, an index of mammal species could easily incorporate contrasting trends for ground-dwelling and arboreal species due to different threats operating on each group.

There may be some value in combining data for guilds or functional groups, but intra-guild responses often vary markedly, for example for Sugar and Squirrel Gliders, due to different habitat requirements. Similarly, considerable literature has tested the value of various biodiversity surrogates, but a common theme is that they fall short of describing the components that they are meant to indicate, and so care must be taken in their derivation and application. We suggest that higher-order metrics are often short-cuts that can be misleading for species management. As such, we do not recommend them as an unqualified basis for a rigorous species monitoring program. As discussed elsewhere, in cases where occupancy and detectability are very high, more sensitive metrics may be more suitable than occupancy, for example, the calling activity of bats or frogs or counts of species abundance. For those species with restricted ranges or low occupancy or detectability, the best approach to monitoring is likely to be very specific, targeted monitoring. In many cases this won’t be feasible, and an alternative that focuses on a research experiment or hypothesis-testing project in relation to perceived threats or declines may yield better value for money than ongoing monitoring based on poor quality data.

The role of composite indices is to provide higher-level metrics of the status and trends of biodiversity at regional scales and at the ecosystem level of biological organisation, and therefore they are a useful complement but not an alternative to species-level information. The complex nature of biological systems precludes comprehensive understanding through a single lens. Monitoring needs to span spatial and temporal scales, and different levels of biological organisation. The BIP has taken a multi-faceted approach, but to this point individual species-level indices are lacking in that program. The PLP is one possible source for filling this gap. We recommend that the BIP consider how it can incorporate species occupancy, and the methods more generally developed for this baseline assessment.

The current project has resurrected historical fauna datasets and identified baselines for future comparisons of species occupancy for a range of high priority species (including species which are likely to be sensitive to a range of disturbances and climate change). Future monitoring programs are likely to include fewer monitoring sites than the large number of survey sites that were available to us to develop 1990s baselines for species occupancy. This means that there is likely to be wider confidence intervals (i.e. less certainty) around future occupancy estimates, although better methods for survey are likely to result in improved probability of detection. This demonstrates the importance of power analysis to guide future monitoring designs capable of detecting changes in species occupancy should it occur. Factors affecting the power of monitoring designs include the number of monitoring sites, the species targeted, the survey methods employed, and the number of 'site visits' that can be resourced and the duration of monitoring.

9.1.9 Priority species for monitoring

In Section 8.1, we discussed the outcomes of several processes and analyses that enabled us to identify 140 priority fauna species (Table 1) and 191 priority flora species (Table 3) that were appropriate for inclusion in the FMIP and Coastal IFOA species monitoring programs. All of these species have ecological characteristics, known or likely responses to disturbances including timber harvesting, fire, climate change or other biological threats, and often legal status, that justify their inclusion within the FMIP and Coastal IFOA species monitoring programs. However, not all of these species may be sufficiently widespread or abundant, or detectable using the range of survey methods that are proposed, to enable statistically significant conclusions to be drawn about future trends in their occupancy or abundance (see also Section 7.5 Power analysis).

In the case of flora priority species (Table 3), an effort was made to select species that are widespread in at least one RFA region. For vascular plants, there is only one survey method required to detect all species that are present (0.04-ha plots, preferably nested within 0.1-ha plots) and one survey visit is usually robust to factors that may affect plant species detectability. Accordingly, there are no major concerns about which plant species to monitor (i.e. all species are surveyed at each site); the main issue is whether enough monitoring sites will be established to ensure sufficient power to detect changes in occupancy for priority species.

In the case of fauna priority species (Table 1), multiple survey methods are required to detect all listed species. As indicated earlier, remote cameras, song meters and bat-call detectors, while likely to be effective for a wide range of species, are not going to detect all, or even most, of our priority species (e.g. most reptiles, at least 13 species of mammals including the Greater Glider, and at least two diurnal raptors; Table 1). Also, uncertainties exist about how well these new survey methods will perform in quantifying changes in species occupancy for a wide range of species, and the 1990s data tell us nothing about this. However, we do know that significant technological developments are required to automate species recognition using these survey methods, and ideally field comparisons with traditional techniques, to provide reliable data for analysis. A range of improved, but traditional, survey methods will be required to detect all fauna priority species, with the final number of species depending on the resources available for the monitoring programs.

No filtering of the list of fauna priority species has been undertaken in terms of their naïve or expected occupancy rates, because this will depend on the survey methods used and the number and distribution of monitoring sites, noting that species detectability and occupancy are the two factors affecting the power of the monitoring programs to detect change.

Broadly, trend analysis did not help us to identify (additional) fauna priority species for monitoring, nor did the results of species distribution modelling in relation to available covariates; the best candidate species for monitoring were already identified in Table 1, which was based on a comprehensive review of existing knowledge.

The special case for including reptiles and amphibians in species monitoring programs is outlined in the next two sections.

9.1.9.1 Reptiles

The following recommendations are made in regard to including reptiles in the FMIP and Coastal IFOA fauna monitoring going forward:

- The period from October to December should be targeted for reptile monitoring as this is the period when temperatures are warm, courtship and mating occurs, and reptiles are most active, making them their most detectable. This applies to essentially all reptile species.
- If individual species are to be targeted for monitoring, this should include both sun-loving and sun-avoiding species that will provide a contrast in responses to forest disturbance.
- Each of the four transects at each monitoring point could include an additional reptile-specific camera trap set with a cork tile (or similar) and drift fence in order to specifically target reptiles as part of the monitoring program. However, the merits of this approach need to be assessed more fully before rolling out into a monitoring program (see below).
- Targeted research should be undertaken to determine if modelling of reptile presence can be improved by including finer scale habitat measurements of variables impacted by forest disturbance in the modelling of reptile species occurrences.
- It is highly recommended that a study be completed that provides quantitative data on the actual detection rates of reptiles using camera traps. This includes the mean number of days required to detect any reptiles and the increase in detection that occurs at specialised reptile camera traps compared to standard camera traps. The former should include parallel surveys using the same hand searching techniques of the 1990s studies to allow direct comparisons of detection rates using both methods and so allow for accurate comparisons of species distributions between the 1990s and future monitoring programs.

It is recognised that the limitations imposed by camera traps may not allow for a satisfactory monitoring program for reptiles. Reptiles may ultimately need their own targeted monitoring program, either separate to the grid monitoring program proposed for birds and mammals, or by including an additional targeted reptile hand search at each site, following the example of additional spotlighting surveys for the Greater Glider. Repeating such surveys in quick succession can allow for the development of occupancy modelling if reptiles are to be included in the program.

9.1.9.2 Frogs

The following recommendations are made for the development of forest monitoring programs for frogs:

- As a rule, the period from mid October to the end of December provides a window where more than 80% of frog species present can be expected to call and so is a target period for frog surveys using remote recording devices.
- Recorders could be set in place for 14 days to allow for adequate coverage of weather conditions and ensure that a period of time will cover optimal or near optimal calling conditions, though the survey effort should be optimised based on pilot data.

- *Mixophyes balbus* and *M. iteratus* are the species that appear the most suitable for specific targeting during monitoring as they are known to be sensitive to forestry-related disturbance, and they call in streams during an extended calling period.
- Should the current proposed monitoring design of one stream transect in four be used, it is advised that three detectors be deployed on that stream transect in order to increase the detection of frog species along that stream and increase the potential to have detectors record different calling environments on the stream, but again this level of sampling needs to be validated first.
- It is highly recommended that a study be completed that provides quantitative data on the actual detection rates of frogs using remote recording devices. This includes the mean number of nights required to detect species at known sites and the distance at which detectors can be expected to record a species of frog. It should also include a series of parallel surveys using the methods and efforts in the 1990s baseline surveys in order to calibrate the effective detection rates of those surveys with call recorders, and so allow for accurate comparisons of species distribution changes between then and any future frog monitoring program.

Again, the limitations imposed by using call recorders in the proposed grid monitoring system may not allow for a satisfactory program of monitoring of frogs. Frogs may need their own targeted monitoring program, such as is the case for the Greater Glider. It is certainly our contention that frogs are of sufficient importance to warrant monitoring trends in populations of selected species in NSW forests in future.

In summary, we strongly urge the establishment of a species monitoring program that forms part of both the Coastal IFOA monitoring program and cross-tenure FMIP. Although there are substantial hurdles for some taxa, we believe occupancy monitoring that includes a range of representative taxa is generally feasible and will be critical to the effective management of NSW forest biodiversity in the future.

9.2 Suggestions for future work

Here we propose a range of future research suggestions that, we believe, would facilitate the ongoing development, implementation and ultimate success of the FMIP and Coastal IFOA forest monitoring programs, with a particular focus on flora and fauna species monitoring and species occupancy and distribution modelling and projections. Some projects should be funded immediately as important follow-on work from the current project and inputs to the ongoing design work being undertaken for FMIP and the Coastal IFOA monitoring program. Other projects should be undertaken as funding opportunities arise. The suggestions here are in addition to the ongoing and future work already recommended above in Section 9.1.

- This project resurrected significant and data-rich corporate fauna survey records, which were in danger of being lost. However, given our selective approach and the identification of priority species, much of the newly accessible data has not been analysed to date. Much more work on species occupancy can be achieved with this data, for species not on our priority list. Some of these are hollow-dependent.
- Improvements are needed in the quality, accuracy and availability of environmental and disturbance history covariates (e.g. extent and intensity of fire events and harvesting activities), which are needed for improved species modelling and comparisons between the

results of future surveys and baselines. The disturbance layers created for the FMIP under Project 1 should be examined in this regard. Disturbance layers need to be regularly updated (e.g. annually) so that they are available for modelling progress in species occupancy or habitat suitability as required.

- There is a need for ongoing modelling based on changes to the accuracy and resolution of covariates, including improved disturbance data, using new remote-sensing equipment such as airborne and satellite-derived information. There is also a need to continually improve the statistical basis for spatial modelling. Ultimately, most species models assume that various environmental variables provide a useful surrogate for the distribution of habitat for modelled species, yet there are many reasons why the models can be wrong and the species are absent – so a continual process of model validation, including ground-truthing, is required.
- For some fauna, metrics other than occupancy (e.g. counts, activity) are likely to be more sensitive for detecting trends (e.g. the calls of frogs). It is important to establish which metrics will be used to monitor each species as sampling effort required for detecting trends in occupancy may be different to the requirements of other metrics.
- For highly localised species that are difficult to detect, the number of sites needed for monitoring is unlikely to be a feasible option (Table 25). These species may benefit from targeted monitoring programs that focus on high quality habitat.
- Rerunning ENMs using the full range of occurrence records for species with distributions that extend beyond the limits of the study region of the current project will substantially improve model outputs for these species. These ENMs should be used as a decision-support tool to identify areas of refugia and areas of stress for species sensitive to various types of disturbance.
- Additional climate change modelling using the GCM-RCM variants, and their future revisions will allow better assessment of a range of climate scenarios. As indicated in Section 6.1.4, additional climate modelling using one other GCM (e.g. ECHAM, hot-dry), or the full suite of NARCliM GCMs can complement the current MIROC (warm-wet) scenario. The use of these scenarios will help to identify refugia from, and regions of stress under, climate change.
- Methods are needed to integrate baseline, trends and projections in order to provide forest biodiversity assessment that links past, present and future states (i.e. ‘long-now’ assessment; Carpenter 2002).

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11. References cited

Aiello-Lammens, M. E., Boria, R. A., Radosavljevic, A., Vilela, B., and Anderson, R. P. (2015). spThin: an R package for spatial thinning of species occurrence records for use in ecological niche models. *Ecography* **38**, 541-545.

Anderson, R. P., and Gonzalez Jr, I. (2011). Species-specific tuning increases robustness to sampling bias in models of species distributions: an implementation with Maxent. *Ecological Modelling* **222**, 2796-2811.

Andren, M., Forward, L., Gott, M., Lock, T., and Madden, K. (1998). Vertebrate Fauna Survey. A Project Undertaken as Part of the NSW Comprehensive Regional Forest Assessments. (NSW National Parks and Wildlife Service: Sydney.)

Austin, M. P., and Van Niel, K. P. (2011). Improving species distribution models for climate change studies: variable selection and scale. *Journal of Biogeography* **38**, 1–8. doi: 10.1111/j.1365-2699.2010.02416.x.

Barbet-Massin, M., Albert, C. H., and Thuiller, W. (2012). Selecting pseudo-absences for species distribution models: how, where and how many? *Methods in Ecology and Evolution* **3**, 327-338.

Baumgartner, J. B., Esperón-Rodríguez, M., and Beaumont, L. J. (2018). Identifying *in situ* climate refugia for plant species. *Ecography* **41**, 1850-1863. doi: https://doi.org/10.1111/ecog.03431.

Baur, G. N. (1965). Forest Types in New South Wales. Research Note 17. (Forestry Commission of NSW: Sydney.)

Beaumont, L. J., Esperón-Rodríguez, M., Nipperess, D. A., Wauchope-Drumm, M., and Baumgartner, J. B. (2019). Incorporating future climate uncertainty into the identification of climate change refugia for threatened species. *Biological Conservation* **237**, 230-237. doi: https://doi.org/10.1016/j.biocon.2019.07.013.

Binns, D. (1991) Vegetation dynamics of *Eucalyptus microcorys – E. saligna* wet sclerophyll forest in response to logging. Unpublished MResSc Thesis. (University of New England, Armidale: Armidale.)

Binns, D. (1995a). Flora Survey, Dorrigo Three-Year Environmental Impact Statement Area, Northern Region, New South Wales. Forest Resources Series No. 25. (State Forests of NSW: West Pennant Hills, NSW.)

Binns, D. (1995b). Flora Survey Tenterfield Management Area Northern Region, New South Wales. Forest Resources Series No. 30, 90 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Binns, D. (1995c). Flora Survey, Gloucester and Chichester Management Areas, Central Region, New South Wales. Forest Resources Series No. 34, 89 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Binns, D. (1996). Flora Survey, Morisset Forestry District, Central Region, New South Wales. Forest Resources Series No. 35, pp. 95. (State Forests of NSW: West Pennant Hills, NSW.)

Binns, D. and Kavanagh, R. P. (1990). Flora and Fauna Survey, Nullica State Forest (Part), Eden District, Eden Region. Forest Resources Series No. 10. (State Forests of NSW: West Pennant Hills, NSW.)

Birk, E. M., and Bridges, R. G. (1989). Recurrent fires and fuel accumulation in even-aged blackbutt (*Eucalyptus pilularis*) forests. *Forest Ecology and Management* **29**, 59-79. doi: https://doi.org/10.1016/0378-1127(89)90056-X.

Boer, M. M., De Dios, V. R., and Bradstock, R. A. (2020). Unprecedented burn area of Australian mega forest fires. *Nature Climate Change* **10**, 171-172.

Booth, T. H., Nix, H. A., Busby, J. R., and Hutchinson, M. F. (2014). BIOCLIM: the first species distribution modelling package, its early applications and relevance to most current MAXENT studies. *Diversity and Distributions* **20**, 1-9.

Boria, R. A., Olson, L. E., Goodman, S. M., and Anderson, R. P. (2014). Spatial filtering to reduce sampling bias can improve the performance of ecological niche models. *Ecological Modelling* **275**, 73-77.

Bradstock, R. A., Keith, D. A., and Auld, T. D. (1995). Fire and conservation: imperatives and constraints on managing for diversity. In 'Conserving Biodiversity: Threats and Solutions' (eds R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney, and D. P. Sivertsen) pp. 323-333. (Surrey Beatty & Sons: Chipping Norton, NSW.)

Brodie, S. J., Thorson, J. T., Carroll, G., Hazen, E. L., Bograd, S., Haltuch, M. A., Holsman, K. K., Kotwicki, S., Samhouri, J. F., and Willis-Norton, E. (2020). Trade-offs in covariate selection for species distribution models: a methodological comparison. *Ecography* **43**, 11-24.

Bunnell, F. L., and Dunsworth, G. B. (2010). 'Forestry and Biodiversity: Learning How to Sustain Biodiversity in Managed Forests.' (UBC Press: Vancouver.)

Burns, H., Gibbons, P., and Claridge, A. (2021). Quantifying variations in browsing pressure caused by feral deer for a range of threatened ecological communities and plant growth forms. *Austral Ecology* **46**, 1156-1169 doi: https://doi.org/10.1111/aec.13050.

Carpenter, S. R. (2002). Ecological futures: building an ecology of the long now. *Ecology* **83**, 2069-2083. doi: https://doi.org/10.1890/0012-9658(2002)083[2069:EFBAEO]2.0.CO; 2.

Catling, P. C. (1991). Ecological effects of prescribed burning practices on the mammals of southeastern Australia. In 'Conservation of Australia's Forest Fauna' (ed. D. Lunney) pp. 353-363. (Royal Zoological Society of New South Wales: Mosman, NSW.)

Centre for Invasive Species Solutions (2021). Weeds Australia. https://weeds.org.au/.

Chapman, A. D. (2009). Numbers of Living Species in Australia and the World. 2nd ed. (Department of Environment, Water, Heritage and the Arts: Canberrra.)

Cherubin, R. C., Venn, S. E., Driscoll, D. A., Doherty, T. S., and Ritchie, E. G. (2019). Feral horse impacts on threatened plants and animals in sub-alpine and montane environments in Victoria, Australia. *Ecological Management & Restoration* **20**, 47-56. doi: https://doi.org/10.1111/emr.12352.

Claridge, A. W., Paull, D. J., and Welbourne, D. J. (2019). Elucidating patterns in the occurrence of threatened ground-dwelling marsupials using camera-traps. *Animals* **9**(11), 913. doi: 10.3390/ani9110913.

Clark, S. S. (1988). Effects of hazard-reduction burning on populations of understorey plant species on Hawkesbury sandstone. *Australian Journal of Ecology* **13**, 473-484. doi: https://doi.org/10.1111/j.1442-9993.1988.tb00996.x.

Collins, L., Bradstock, R. A., Clarke, H., Clarke, M. F., Nolan, R. H., and Penman, T. D. (2021). The 2019/2020 mega-fires exposed Australian ecosystems to an unprecedented extent of high-severity fire. *Environmental Research Letters* **16**, 044029.

Comte, L., and Grenouillet, G. (2013). Species distribution modelling and imperfect detection: comparing occupancy versus consensus methods. *Diversity and Distributions* **19**, 996-1007.

Cooke, B. D. (2012). Rabbits: manageable environmental pests or participants in new Australian ecosystems? *Wildlife Research* **39**, 279-289. doi: https://doi.org/10.1071/WR11166.

Crase, B., Liedloff, A. C., and Wintle, B. A. (2012). A new method for dealing with residual spatial autocorrelation in species distribution models. *Ecography* **35**, 879-888.

Crase, B., Liedloff, A., Vesk, P. A., Fukuda, Y., and Wintle, B. A. (2014). Incorporating spatial autocorrelation into species distribution models alters forecasts of climate-mediated range shifts. *Global Change Biology* **20**, 2566-2579.

Crisp, M. D., and Lange, R. T. (1976). Age structure, distribution and survival under grazing of the arid-zone shrub *Acacia burkittii*. *Oikos* **27**, 86-92. doi: 10.2307/3543436.

Cummings, J., Reid, N., Davies, I., and Grant, C. (2005). Adaptive restoration of sand-mined areas for biological conservation. *Journal of Applied Ecology* **42**, 160-170. doi: https://doi.org/10.1111/j.1365-2664.2005.01003.x.

Curtis, D., and Wright, T. (1993). Natural regeneration and grazing management – a case study. *Australian Journal of Soil and Water Conservation* **6**(4), 30-34.

Daly, G., and Hoye, G. (2016). Survey of the reptiles of the montane forests near Dorrigo on the north coast of New South Wales. *Australian Zoologist* **38**, 26-42.

Daly, G., and Lemckert, F. (2011). Survey of the reptiles and amphibians of the montane forests near Tenterfield on the north coast of New South Wales. *Australian Zoologist* **35**, 957-972.

Davey, S. M., and Sarre, A. (2020). Editorial: the 2019/20 Black Summer bushfires. *Australian Forestry* **83**, 47-51. doi: 10.1080/00049158.2020.1769899.

Davis, N. E., Bennett, A., Forsyth, D. M., Bowman, D. M. J. S., Lefroy, E. C., Wood, S. W., Woolnough, A. P., West, P., Hampton, J. O., and Johnson, C. N. (2016). A systematic review of the impacts and management of introduced deer (family Cervidae) in Australia. *Wildlife Research* **43**, 515-532. doi: https://doi.org/10.1071/WR16148.

De Oliveira, G., Rangel, T. F., Lima-Ribeiro, M. S., Terribile, L. C., and Diniz-Filho, J. A. F. (2014). Evaluating, partitioning, and mapping the spatial autocorrelation component in ecological niche modeling: a new approach based on environmentally equidistant records. *Ecography* **37**, 637-647.

Debus, S. J. S. (1995). Surveys of large forest owls in northern New South Wales: methodology, calling behaviour and owl responses. *Corella* **19**, 38-50.

Department of Environment Climate Change and Water (2009). Border Ranges Rainforest Biodiversity Management Plan. (DECCW: Sydney.)

Department of Planning, Industry and Environment (2020a). NSW Fire and the Environment 2019–2020: Summary. (Ed. Department of Planning Industry and Environment). (NSW Government: Sydney.)

Department of Planning, Industry and Environment (2020b). Biodiversity Assessment Method. (NSW Department of Planning Industry and Environment: Sydney.)

Department of Planning, Industry and Environment (2021a). Climate data for NSW and the ACT from the NARCliM Project delivered in 2014. https://datasets.seed.nsw.gov.au/dataset/nsw-and-act-regional-climate-modelling-narclim-project-raw-and-postprocessed-model-output.

Department of Planning, Industry and Environment (2021b). Fire Extent and Severity Mapping (FESM). In 'The Central Resource for Sharing and Enabling Environmental Data in NSW'. https://datasets.seed.nsw.gov.au/dataset/fire-extent-and-severity-mapping-fesm.

Department of Planning, Industry and Environment (2021c). State Vegetation Type Map (SVTM) Modelling Grid Collection. In 'The Central Resource for Sharing and Enabling Environmental Data in NSW'. https://datasets.seed.nsw.gov.au/dataset/fire-extent-and-severity-mapping-fesm.

Department of Urban Affairs and Planning, and Department of Prime Minister and Cabinet (1999). North-East CRA/RFA Project Summaries. (Commonwealth of Australia: Canberra.)

Diniz-Filho, J. a. F., Nabout, J. C., Bini, L. M., Loyola, R. D., Rangel, T. F., Nogues-Bravo, D., and Araujo, M. B. (2010). Ensemble forecasting shifts in climatically suitable areas for *Tropidacris cristata* (Orthoptera: Acridoidea: Romaleidae). *Insect Conservation and Diversity* **3**, 213-221. doi: 10.1111/j.1752-4598.2010.00090.x.

Dixon, K. M., Cary, G. J., Worboys, G. L., and Gibbons, P. (2018). The disproportionate importance of long-unburned forests and woodlands for reptiles. *Ecology and Evolution* **8**, 10952-10963.

Dodson, J. R., Kodlea, P. G. and Myers, C. A. (1988). Vegetation Survey of the Tantawangalo Research Catchments in the Eden Forestry Region, New South Wales. Forest Resources Series No. 4, 61 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Dormann, C. F. (2020). Calibration of probability predictions from machine-learning and statistical models. *Global Ecology and Biogeography* **29**, 760-765.

Drielsma, M., and Ferrier, S. (2009). Rapid evaluation of metapopulation persistence in highly variegated landscapes. *Biological Conservation* **142**, 529-540.

Drielsma, M., and Love, J. (2021). An equitable method for evaluating habitat amount and potential occupancy. *Ecological Modelling* **440**, 109388. doi: https://doi.org/10.1016/j.ecolmodel.2020.109388.
Drielsma, M. J., and Ferrier, S. (2009). Rapid evaluation of metapopulation persistence in highly variable landscapes. *Biological Conservation* **142**, 529–540. doi: doi:10.1016/j.biocon.2008.11.018.
Drielsma, M. J., Love, J., Williams, K. J., Manion, G., Saremi, H., Harwood, T., and Robb, J. (2017). Bridging the gap between climate science and regional-scale biodiversity conservation in south-eastern Australia. *Ecological Modelling* **360**, 343-362.
Drielsma, M. J., Saremi, H., Beaumont, L. J., Baumgartner, J. B., Robb, J., Love, J., Stuart, S., and Wilson, P. D. (in prep.). Saving Our Species: Landscape-managed Threatened Species Modelling Project: Increasing Capacity to Support Species Across NSW, and Towards Priority Areas for Conservation Investment. Final report. (Department of Planning, Industry and Environment: Armidale, NSW.)
Eamus, D., Hatton, T., Cook, P., and Colvin, C. (2006) 'Ecohydrology: Vegetation Function, Water and Resource Management' (CSIRO Publishing: Melbourne.)
Einoder, L. D., Southwell, D. M., Lahoz-Monfort, J. J., Gillespie, G. R., Fisher, A., and Wintle, B. A. (2018). Occupancy and detectability modelling of vertebrates in northern Australia using multiple sampling methods. *PloS One* **13**, e0203304. doi: 10.1371/journal.pone.0203304.
Eldridge, D. J., Poore, A. G. B., Ruiz-Colmenero, M., Letnic, M., and Soliveres, S. (2016). Ecosystem structure, function, and composition in rangelands are negatively affected by livestock grazing. *Ecological Applications* **26**, 1273-1283. doi: https://doi.org/10.1890/15-1234.
Elith, J. (2000). Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. In 'Quantitative Methods for Conservation Biology' (eds S. Ferson and M. Bergman) pp. 39-58. (Springer: New York.)
Elith, J., Graham, C. H., P. Anderson, P. R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, J. R., Huettmann, F., R. Leathwick, R. J., and Lehmann, A. (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**, 129-151.
Elith, J., and Leathwick, J. R. (2009). Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution and Systematics* **40**, 677-697.
Elith, J., Leathwick, J. R., and Hastie, T. (2008). A working guide to boosted regression trees. *Journal of Animal Ecology* **77**, 802-813.
Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., and Yates, C. J. (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* **17**, 43-57.
Evans, J., Ji, F., Lee, C., Smith, P., Argüeso, D., and Fita, L. (2014). Design of a regional climate modelling projection ensemble experiment – NARCliM. *Geoscientific Model Development* **7**, 621-629.
Evans, J. P., and Ji, F. (2012). Choosing GCMs. NARCliM Technical Note 1. (NSW Office of Environment and Heritage: Sydney.)
Evans, J. P., and Ji, F. (2012). Choosing the RCMs to perform the downscaling. NARCliM Technical Note 2. (NSW Office of Environment and Heritage: Sydney.)
Faith, D. P., and Walker, P. A. (1996). Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas. *Biodiversity & Conservation* **5**, 399-415.
Fanning, F. D., and Clark, S. S. (1991). Flora and Fauna Survey of Jingo Creek Catchment, Nullica State Forest, Eden Region. Forest Resources Series No. 14, 147 pp. (State Forests of NSW: West Pennant Hills, NSW.)
Fanning, F. D., and Fatchen, T. J. (1990). The Upper Wog Wog River Catchment of Coolangubra and Nalbaugh State Forest (Mines Road Area) New South Wales: a Fauna and Flora Survey. Forest Resources Series No. 12, 315 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Fanning, F. D., and Mills, K. (1989). Natural Resource Survey of the Southern Portion of Rockton Section, Bondi State Forest. Forest Resources Series No. 6 (State Forests of NSW: West Pennant Hills, NSW.)

Fanning, F. D., and Mills, K. (1991). The Stockyard Creek Catchment of Coolangubra State Forest, New South Wales: a Flora and Fauna Survey. Forest Resources Series, No. 13, 263 pp. (State Forests of NSW: Sydney.)

Ferrier, S. (1994). Towards a Biological Information Base for Regional Forest Conservation Planning in North-East New South Wales. North-East Forests Biodiversity Study. (NSW National Parks and Wildlife Service: Armidale.)

Ferrier, S. (2002). Mapping spatial pattern in biodiversity for regional conservation planning: where to from here? *Systematic Biology* **51**, 331-363.

Fisher, A., Armston, J., Goodwin, N., and Scarth, P. (2020). Modelling canopy gap probability, foliage projective cover and crown projective cover from airborne Lidar metrics in Australian forests and woodlands. *Remote Sensing of Environment* **237**, 111520. doi: https://doi.org/10.1016/j.rse.2019.111520.

Fithian, W., Elith, J., Hastie, T., and Keith, D. A. (2015). Bias correction in species distribution models: pooling survey and collection data for multiple species. *Methods in Ecology and Evolution* **6**, 424-438. doi: https://doi.org/10.1111/2041-210X.12242.

Fithian, W., and Hastie, T. (2013). Finite-sample equivalence in statistical models for presence-only data. *Annals of Applied Statistics* **7**, 1917.

Fletcher Jr, R. J., Hefley, T. J., Robertson, E. P., Zuckerberg, B., Mccleery, R. A., and Dorazio, R. M. (2019). A practical guide for combining data to model species distributions. *Ecology* **100**, e02710. doi: https://doi.org/10.1002/ecy.2710.

Foster, C. N., and Scheele, B. C. (2019). Feral-horse impacts on corroboree frog habitat in the Australian Alps. *Wildlife Research* **46**, 184-190. doi: https://doi.org/10.1071/WR18093.

Fourcade, Y., Engler, J. O., Rödder, D., and Secondi, J. (2014). Mapping species distributions with MAXENT using a geographically biased sample of presence data: a performance assessment of methods for correcting sampling bias. *PLoS ONE* **9**, e97122.

Geyle, H. M., Tingley, R., Amey, A. P., Cogger, H., Couper, P. J., Cowan, M., *et al.* (2021). Reptiles on the brink: identifying the Australian terrestrial snake and lizard species most at risk of extinction. *Pacific Conservation Biology* **27**, 3-12.

Gill, A. M., and Bradstock, R. (1995). Extinction of biota by fires. In 'Conserving Biodiversity: Threats and Solutions' (eds R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney, and D. P. Sivertsen) pp. 309–322. (Surrey Beatty & Sons: Chipping Norton, NSW.)

Gill, A. M., Groves, R. H., and Noble, I. R. (1981). 'Fire and the Australian Biota' (Australian Academy of Science: Canberra.)

Goldingay, R., Daly, G., and Lemckert, F. (1996). Assessing the impacts of logging on reptiles and frogs in the montane forests of southern New South Wales. *Wildlife Research* **23**, 495-510.

Gonsalves, L., and Law, B. E. (2021a). Assessment of Trends in Southern Brown Bandicoot Occupancy in the Southern Forests of New South Wales (2009–2019). Unpublished. (NSW Department of Primary Industries: Sydney.)

Gonsalves, L., and Law, B. E. (2021b). Analysis of Yellow-bellied Glider PMP Data from Bago-Maragle Forests (1995–2019). Unpublished. (NSW Department of Primary Industries: Sydney.)

Guillera-Arroita, G., and Lahoz-Monfort, J. J. (2012). Designing studies to detect differences in species occupancy: power analysis under imperfect detection. *Methods in Ecology and Evolution* **3**, 960-869.

Guillera-Arroita, G., Lahoz-Monfort, J. J., Elith, J., Gordon, A., Kujala, H., Lentini, P. E., Mccarthy, M. A., Tingley, R., and Wintle, B. A. (2015). Is my species distribution model fit for purpose? Matching data and models to applications. *Global Ecology and Biogeography* **24**, 276-292. doi: https://doi.org/10.1111/geb.12268.

Gutierrez-Velez, V. H., and Wiese, D. (2020). Sampling bias mitigation for species occurrence modeling using machine learning methods. *Ecological Informatics* **58**, 101091. doi: https://doi.org/10.1016/j.ecoinf.2020.101091.

Hageer, Y., Esperon-Rodriguez, M., Baumgartner, J. B., and Beaumont, L. J. (2017). Climate, soil or both? Which variables are better predictors of the distributions of Australian shrub species? *PeerJ* **5**, e3446. doi: Artn E3446 10.7717/Peerj.3446.

Hamilton, S., Lawrie, A., Hopmans, P., and Leonard, B. (1991). Effects of fuel-reduction burning on a *Eucalyptus obliqua* forest ecosystem in Victoria. *Australian Journal of Botany* **39**, 203-217. doi: https://doi.org/10.1071/BT9910203.

Harrington, G. N., Wilson, A. D., and Young, M. D. (1984). 'Management of Australia's Rangelands.' (CSIRO: Melbourne.)

Hastie, T., Tibshirani, R. and Friedman, J. (2009). Unsupervised learning. In 'The Elements of Statistical Learning: Data Mining, Inference, and Prediction' pp. 485-585. (Springer: New York.)

Hatich, D. (1997). Bago/Maragle Management Area: a Case Study for Monitoring Ecologically Sustainable Management. Forest Resources Services No. 37, 53 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Hester, A. J., Edenius, L., Buttenschøn, R. M., and Kuiters, A. T. (2000). Interactions between forests and herbivores: the role of controlled grazing experiments. *Forestry: An International Journal of Forest Research* **73**, 381-391. doi: 10.1093/forestry/73.4.381.

Hirzel, A. H., Le Lay, G., Helfer, V., Randin, C., and Guisana, A. (2006). Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling* **199**, 142-152.

Hobbs, N. T. (1996). Modification of ecosystems by ungulates. *Journal of Wildlife Management* **60**, 695-713. doi: 10.2307/3802368.

Howland, B., Stojanovic, D., Gordon, I. J., Manning, A. D., Fletcher, D., and Lindenmayer, D. B. (2014). Eaten out of house and home: impacts of grazing on ground-dwelling reptiles in Australian grasslands and grassy woodlands. *PLoS One* **9**(12), doi: https://doi.org/10.1371/journal.pone.0105966.

Hu, Y., Urhus, J., Gillespie, G., Letnic, M., and Jessop, T.S. (2013). Evaluating the role of fire disturbance in structuring small reptile communities in temperate forests. *Biodiversity and Conservation* **22**, 1949-1963.

Inman, R., Franklin, J., Esque, T., and Nussear, K. (2021). Comparing sample bias correction methods for species distribution modeling using virtual species. *Ecosphere* **12**, e03422. doi: https://doi.org/10.1002/ecs2.3422.

Invasive Plants and Animals Committee (2016). Australian Weeds Strategy 2017–2027. (Department of Agriculture and Water Resources: Canberra.)

Iturbide, M., Bedia, J., and Gutiérrez, J. M. (2018). Background sampling and transferability of species distribution model ensembles under climate change. *Global and Planetary Change* **166**, 19-29. doi: 10.1016/j.gloplacha.2018.03.008.

International Union for the Conservation of Nature (2001). Red List Categories and Criteria: Version 3.1. (IUCN: Gland.)

Jarnevich, C. S., Stohlgren, T. J., Kumar, S., Morisette, J. T., and Holcombe, T. R. (2015). Caveats for correlative species distribution modeling. *Ecological Informatics* **29**, 6-15. doi: https://doi.org/10.1016/j.ecoinf.2015.06.007.

Jathanna, D., Karanth, K. U., Kumar, N. S., Goswami, V. R., Vasudev, D., and Karanth, K. K. (2015). Reliable monitoring of elephant populations in the forests of India: analytical and practical considerations. *Biological Conservation* **187**, 212-220.

Jaynes, E. T. (1957a). Information theory and statistical mechanics. *Physical Review* **106**, 620.

Jaynes, E. T. (1957b). Information theory and statistical mechanics. II. *Physical Review* **108**, 171.

Jiménez-Valverde, A., Aragón, P., and Lobo, J. M. (2021). Deconstructing the abundance–suitability relationship in species distribution modelling. *Global Ecology and Biogeography* **30**, 327-338.

Joss, P., Lynch, P., and Williams, O. (1986). 'Rangelands: A Resource Under Siege'. Proceedings of the Second International Rangeland Congress. (Cambridge University Press: Cambridge.)

Jurskis, V. (2005). Eucalypt decline in Australia, and a general concept of tree decline and dieback. *Forest Ecology and Management* **215**, 1-20.

Jurskis, V., Shiels, R. and Binns, D. (1995). Flora Survey, Queanbeyan/Badja Environmental Impact Statement Area, Southern Region, New South Wales. Forest Resources Services No. 32, 73 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Kanowski, J., Joseph, L., Kavanagh, R., and Fleming, A. (2018). Designing a monitoring framework for Australian Wildlife Conservancy, a national conservation organisation. In 'Monitoring Threatened Species and Ecological Communities' (eds S. Legge, D. B. Lindenmayer, N. M. Robinson, B. C. Scheele, D. M. Southwell, and B. A. Wintle) pp. 239-252. (CSIRO Publishing: Melbourne.)

Kavanagh, R. P. (2002). Comparative diets of the powerful owl (*Ninox strenua*), sooty owl (*Tyto tenebricosa*) and masked owl (*Tyto novaehollandiae*) in southeastern Australia. In 'Ecology and Conservation of Owls' (eds I. Newton, R. Kavanagh, J. Olsen, and I. Taylor) pp. 175-191. (CSIRO: Melbourne.)

Kavanagh, R. P., and Bamkin, K. L. (1995). Distribution of nocturnal forest birds and mammals in relation to the logging mosaic in south-eastern New South Wales, Australia. *Biological Conservation* **71**, 41-53. doi: https://doi.org/10.1016/0006-3207(94)00019-M.

Kavanagh, R. P., Debus, S. J. S., Tweedie, T., and Webster, R. (1995). Distribution of nocturnal forest birds and mammals in north-eastern New South Wales: relationships with environmental variables and management history. *Wildlife Research* **22**, 359-377.

Kavanagh, R. P., Loyn, R. H., Smith, G. C., Taylor, R. J., and Catling, P. C. (2004). Which species should be monitored to indicate ecological sustainability in Australian forest management? In 'Conservation of Australia's Forest Fauna' 2nd ed. (ed. D. Lunney) pp. 959-987. (Royal Zoological Society of NSW: Mosman, NSW.)

Kavanagh, R. P., and Stanton, M. A. (1998). Nocturnal forest birds and arboreal marsupials of the southwestern slopes, New South Wales. *Australian Zoologist* **30**, 449-466.

Kavanagh, R. P. and Stanton, M. A. (2005). Vertebrate species assemblages and species sensitivity to logging in the forests of north-eastern New South Wales. *Forest Ecology and Management* **209**, 309-341.

Keith, D. A. (2004). 'Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT.' (Department of Environment and Conservation: Hurstville.)

Kenny, B., Sutherland, E., Tasker, E., and Bradstock, R. (2004). Guidelines for Ecologically Sustainable Fire Management, 61 pp. (NSW National Parks and Wildlife Service: Hurstville, NSW.)

Korte, C. J. and Harris, W. (1987). Effects of grazing and cutting in managed grasslands. In 'Ecosystems of the World 17B, Managed Grasslands, Analytical Studies' (ed. R. W. Snaydon) pp. 71-79. (Elsevier: Amsterdam.)

Lahoz-Monfort, J. J., Guillera-Arroita, G., and Wintle, B. A. (2014). Imperfect detection impacts the performance of species distribution models. *Global Ecology and Biogeography* **23**, 504-515.

Lamb, D., Ash, D., and Landsberg, J. (1981). The effect of fire on understorey development and nitrogen cycling in *Eucalyptus maculata* forest of south-east Queensland. In 'Queensland Fire Research Workshop' (ed. B. R. Roberts) pp. 180-187. (Darling Downs Institute of Advanced Education: Toowoomba.)

Lange, R. T., and Graham, C. R. (1983). Rabbits and the failure of regeneration in Australian arid zone Acacia. *Australian Journal of Ecology* **8**, 377-381. doi: https://doi.org/10.1111/j.1442-9993.1983.tb01334.x.

Law, B., Brassil, T. and Gonsalves, L. (2016). Recent decline of an endangered, endemic rodent: does exclusion of disturbance play a role for Hastings River mouse (*Pseudomys oralis*)? *Wildlife Research* **43**, 482-491. doi: https://doi.org/10.1071/WR16097.

Law, B., Gonsalves, L., Mcconville, A., and Tap, P. (2021). Landscape monitoring reveals initial trends in occupancy and activity of bats in multiple-use forests. *Austral Ecology* **46**, 261-276. doi: https://doi.org/10.1111/aec.12976.

Law, B. S. (2018). Long-term research on forest bats: we have the technology. *Australian Zoologist* **39**, 658-668. doi: 10.7882/AZ.2018.028.

Law, B. S., Brassil, T., Gonsalves, L., Roe, P., Truskinger, A., and Mcconville, A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PloS one* **13**, e0205075.

Law, B. S., Chidel, M., Brassil, T., Turner, G., and Gonsalves, L. (2017). Winners and losers among mammals and nocturnal birds over 17 years in response to large-scale eucalypt plantation establishment on farmland. *Forest Ecology and Management* **399**, 108-119. doi: https://doi.org/10.1016/j.foreco.2017.05.022.

Law, B. S., Chidel, M., Brassil, T., Turner, G., and Kathuria, A. (2014). Trends in bird diversity over 12 years in response to large-scale eucalypt plantation establishment: implications for extensive carbon plantings. *Forest Ecology and Management* **322**, 58-68. doi: https://doi.org/10.1016/j.foreco.2014.02.032.

Legge, S., Woinarski, J. C. Z., Burbidge, A. A., Palmer, R., Ringma, J., Radford, J. Q., Mitchell, N., Bode, M., Wintle, B. A., and Baseler, M. (2018). Havens for threatened Australian mammals: the contributions of fenced areas and offshore islands to the protection of mammal species susceptible to introduced predators. *Wildlife Research* **45**, 627-644.

Leigh, J. H., and Holgate, M. D. (1979). The responses of the understorey of forests and woodlands of the southern tablelands to grazing and burning. *Australian Journal of Ecology* **4**, 25-45.

Leigh, J., Wimbush, D., Wood, D., Holgate, M., Slee, A., Stanger, M., and Forrester, R. (1987). Effects of rabbit grazing and fire on a sub-alpine environment. I. Herbaceous and shrubby vegetation. *Australian Journal of Botany* **35**, 433-464. doi: https://doi.org/10.1071/BT9870433.

Lemckert, F. (1999). Impacts of selective logging on frogs in a forested area of northern New South Wales. *Biological Conservation* **89**, 321-328. doi: https://doi.org/10.1016/S0006-3207(98)00117-7.

Lemckert, F., and Grigg, G. (2010). Living in the 80s – seasonality and phenology of frog calling activity at Darkes Forest from 1987–1989. *Australian Zoologist* **35**, 245-250.

Lemckert, F., Haywood, A., Brassil, T., and Mahony, M. (2005). Correlations between frogs and pond attributes in central New South Wales, Australia: what makes a good pond? *Applied Herpetology* **3**, 67.

Lemckert, F., and Mahony, M. (2008). Core calling periods of the frogs of temperate New South Wales, Australia. *Herpetological Conservation and Biology* **3**, 71-76.

Lemckert, F. L., Brassil, T., and Haywood, A. (2004). Effects of a low intensity fire on populations of pond breeding anurans in mid-northern New South Wales, Australia. *Applied Herpetology* **1**, 183-196.

Lemckert, F. L., and Morse, R. (1999). Frogs in the timber production forests of the Dorrigo escarpment in northern New South Wales: an inventory of species present and the conservation of threatened species. In 'Declines and Disappearances of Australian Frogs' (ed. A. Campbell) pp. 72-80. (Environment Australia: Canberra.)

Letnic, M., Ritchie, E. G. and Dickman, C. R. (2012). Top predators as biodiversity regulators: the dingo *Canis lupus dingo* as a case study. *Biological Reviews* **87**, 390-413. doi: https://doi.org/10.1111/j.1469-185X.2011.00203.x.

Lindenmayer, D. B., Dubach, J., and Viggers, K. L. (2002). Geographic dimorphism in the mountain brushtail possum (*Trichosurus caninus*): the case for a new species. *Australian Journal of Zoology* **50**, 369-393. doi: https://doi.org/10.1071/ZO01047.

Lodge, G. M., and Whalley, R. D. (1989). Native and Natural Pastures on the Northern Slopes and Tablelands of New South Wales: a Review and Annotated Bibliography. (NSW Agriculture & Fisheries: Sydney.)

Love, J., Drielsma, M. J., Williams, K. J., and Thapa, R. (2020a). Integrated Model–data Fusion Approach to Measuring Habitat Condition for Ecological Integrity Reporting: Implementation for Habitat Condition Indicators. Biodiversity Indicator Program Implementation Report. (Department of Planning, Industry and Environment: Sydney.)

Love, J., Thapa, R., Drielsma, M., and Robb, J. (2020b). Climate Change Impacts in the NSW and ACT Alpine Region: Impacts on Biodiversity. https://climatechange.environment.nsw.gov.au/-/media/NARCLim/Files/Climate-Change-Impact-Reports/Alpine-impacts/Climate-change-impacts-Alpine---Biodiversity.pdf?la=en&hash=2D2FC1C1DF3BE92785374B134706687F3A785A84 (Department of Planning, Industry and Environment: Sydney.)

Lunney, D., Predavec, M., Sonawane, I., Kavanagh, R., Barrott-Brown, G., Phillips, S., Callaghan, J., Mitchell, D., Parnaby, H., and Paull, D. C. (2017). The remaining koalas (*Phascolarctos cinereus*) of the Pilliga forests, north-west New South Wales: refugial persistence or a population on the road to extinction? *Pacific Conservation Biology* **23**, 277-294.

Lunt, I. D. (1991). Management of remnant lowland grasslands and grassy woodlands for nature conservation: a review. *Victorian Naturalist* **108**, 56-66.

Lunt, I. D. (1998). *Allocasuarina* (Casuarinaceae) invasion of an unburnt coastal woodland at Ocean Grove, Victoria: structural changes 1971–1996. *Australian Journal of Botany* **46**, 649-656.

Mac Nally, R. (2000). Regression and model-building in conservation biology, biogeography and ecology: The distinction between – and reconciliation of – 'predictive' and 'explanatory' models. *Biodiversity & Conservation* **9**, 655-671. doi: 10.1023/A:1008985925162.

Mac Nally, R. (2002). Multiple regression and inference in ecology and conservation biology: further comments on identifying important predictor variables. *Biodiversity & Conservation* **11**, 1397-1401.

Mac Nally, R., Bennett, A. F., Thomson, J. R., Radford, J. Q., Unmack, G., Horrocks, G., and Vesk, P. A. (2009). Collapse of an avifauna: climate change appears to exacerbate habitat loss and degradation. *Diversity and Distributions* **15**, 720-730.

Macadam, I. (2018). Directory structure and file naming convention for the NARCliM ANUCLIM 9 second dataset. (NSW Office of Environment and Heritage: Sydney.)

MacKenzie, D. I. (2021). RPresence. https://www.mbr-pwrc.usgs.gov/software/presence.html.

MacKenzie, D. I. and Bailey, L. L. (2004). Assessing the fit of site-occupancy models. *Journal of Agricultural, Biological, and Environmental Statistics* **9**, 300-318.

MacKenzie, D. I., Nichols, J. D., Hines, J. E., Knutson, M. G., and Franklin, A. B. (2003). Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* **84**, 2200-2207.

Makinson, R. O., Pegg, G. S., and Carnegie, A. J. (2020). Myrtle Rust in Australia, A National Action Plan. (Australian Government: Canberra.)

Manion, G., and Ridges, M. (2009). An optimisation of the survey gap analysis technique to minimise computational complexity and memory resources in order to accommodate fine grain environmental and site data. In 18th World IMACS / MODSIM Congress (eds R. S. Anderssen, R. D. Braddock and L. T. H. Newham) pp. 2514-2520. (Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation: Cairns, Australia.)

Margules Groome Pöyry (1994). Grafton Management Area. Proposed Forestry Operations: Environmental Impact Statement. Volume A – Main Report. (State Forests of NSW: Sydney.)

Martin, T. G., Catterall, C. P., Manning, A. D., and Szabo, J. K. (2012). Australian birds in a changing landscape: 220 years of European colonisation. In 'Birds and Habitat: Relationships in

Changing Landscapes' (ed. R. J. Fuller) pp. 453–480. (Cambridge University Press: Cambridge, UK.)

McCaw, W. (1993). Effects of fuel-reduction burning on a *Eucalyptus obliqua* forest ecosystem in Victoria. *Australian Journal of Botany* **41**, 413-414. doi: https://doi.org/10.1071/BT9930413.

McIntyre, S., and Lavorel, S. (1994). How environmental and disturbance factors influence species composition in temperate Australian grasslands. *Journal of Vegetation Science* **5**, 373-384.

McIntyre, S., and Lavorel, S. (1995). Predicting richness of native, rare, and exotic plants in response to habitat and disturbance variables across a variegated landscape. *Conservation Biology* **8**, 521-531. doi: https://doi.org/10.1046/j.1523-1739.1994.08020521.x.

Meehl, G. A., Senior, C. A., Eyring, V., Flato, G., Lamarque, J.-F., Stouffer, R. J., Taylor, K. E., and Schlund, M. (2020). Context for interpreting equilibrium climate sensitivity and transient climate response from the CMIP6 Earth system models. *Science Advances* **6**, eaba1981. doi: 10.1126/sciadv.aba1981.

Merow, C., Smith, M. J., and Silander Jr, J. A. (2013). A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography* **36**, 1058-1069. doi: 10.1111/j.1600-0587.2013.07872.x.

Mills, C. H., Waudby, H., Finlayson, G., Parker, D., Cameron, M., and Letnic, M. (2020). Grazing by over-abundant native herbivores jeopardizes conservation goals in semi-arid reserves. *Global Ecology and Conservation* **24**, e01384. doi: https://doi.org/10.1016/j.gecco.2020.e01384.

Mills, D. (2019). WildCount: broad scale, long-term monitoring of fauna in NSW National Parks 2012–2016. (NSW Department of Planning Industry and Environment: Sydney.)

Monamy, V., and Fox, B. J. (2005). Differential habitat use by a local population of subadult common dunnarts, *Sminthopsis murina*, following wildfire in coastal wet heath, New South Wales, Australia. *Wildlife Research* **32**, 617-624. doi: https://doi.org/10.1071/WR04105.

Moore, D. M., and Floyd, A. G. (1994). A Description of the Flora and an Assessment of Impacts of the Proposed Forestry Operations in the Grafton Forest Management Area. (State Forests of NSW: Sydney.)

Muscatello, A., Elith, J., and Kujala, H. (2020). How decisions about fitting species distribution models affect conservation outcomes. *Conservation Biology* **35**, 1309-1320.

Mutze, G., Cooke, B., and Jennings, S. (2016). Estimating density-dependent impacts of European rabbits on Australian tree and shrub populations. *Australian Journal of Botany* **64**, 142-152. doi: https://doi.org/10.1071/BT15208.

Naimi, B., Skidmore, A. K., Groen, T. A., and Hamm, N. A. S. (2011). Spatial autocorrelation in predictors reduces the impact of positional uncertainty in occurrence data on species distribution modelling. *Journal of Biogeography* **38**, 1497-1509.

Nakicenovic, N., Alcamo, J., Davis, G., Vries, B. D., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T. Y., and Kram, T. (2000). Special Report on Emissions Scenarios. (Intergovernmental Panel on Climate Change: Geneva.)

New South Wales Threatened Species Scientific Committee (2019). Infection of Native Plants by *Phytophthora cinnamomi* – Key Threatening Process Listing. https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/2000-2003/infection-of-native-plants-by-phytophthora-cinnamomi-key-threatening-process-listing.

Nilar, H., Maute, K., Dawson, M. J., Scarborough, R., Hudson, J., Reay, J., and Gooden, B. (2019). Effectiveness of different herbivore exclusion strategies for restoration of an endangered rainforest community. *Forest Ecology and Management* **435**, 18-26. doi: https://doi.org/10.1016/j.foreco.2018.12.041.

Nix, H. A. (1986). A biogeographic analysis of Australian elapid snakes. In 'Atlas of Elapid Snakes of Australia' (ed. R. Longmore) pp. 4-15. Australian Flora and Fauna Series No. 7. (Australian Government Publishing Service: Canberra.)

Noble, I. R. and Slatyer, R. O. (1980). The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* **43**, 5-21. doi: 10.1007/BF00121013.

Noss, R. F. (1999). Assessing and monitoring forest biodiversity: a suggested framework and indicators. *Forest Ecology and Management* **115**, 135-146. http://dx.doi.org/10.1016/S0378-1127(98)00394-6

Natural Resources Commission (2019). NSW Forest Monitoring and Improvement Program. Program Framework 2019–2014. (NSW Natural Resources Commission: Sydney.)

Office of Environment and Heritage (2016). Biodiversity Impacts and Adaptation Project (Final Report) – NSW and ACT Regional Climate Modelling Project. (NSW Office of Environment and Heritage: Armidale.)

O'Gara, E., Howard, K., Wilson, B., and Hardy, G. E. S. (2005). Management of *Phytophthora cinnamomi* for Biodiversity Conservation in Australia: Part 2. National Best Practice Guidelines. (Commonwealth Department of the Environment and Heritage: Canberra.)

Old, K. M., Kile, G. A., and Ohmart, C. P. (1981). Eucalypt Dieback in Forests and Woodlands. Proceeedinsg of a conference held at the CSIRO Divsiion of Forest Research, Canberra, 4–6 August 1980. (CSIRO: Melbourne.)

Owers, C. J., Kavanagh, R. P. and Bruce, E. (2015). Remote sensing can locate and assess the changing abundance of hollow-bearing trees for wildlife in Australian native forests. *Wildlife Research* **41**, 703-716.

Penman, T., Beukers, M., Kavanagh, R., and Doherty, M. (2011a). Are long-unburnt eucalypt forest patches important for the conservation of plant species diversity? *Applied Vegetation Science* **14**, 172-180.

Penman, T., Kavanagh, R., Binns, D., and Melick, D. (2007). Patchiness of prescribed burns in dry sclerophyll eucalypt forests in south-eastern Australia. *Forest Ecology and Management* **252**, 24-32. doi: https://doi.org/10.1016/j.foreco.2007.06.004.

Penman, T. D., Binns, D., Allen, R., Shiels, R., and Plummer, S. (2008a). Germination responses of a dry sclerophyll forest soil-stored seedbank to fire related cues. *Cunninghamia* **10**, 547–555.

Penman, T. D., Binns, D., Brassil, T., Shiels, R., and Allen, R. M. (2009). Long-term changes in understorey vegetation in the absence of wildfire in south-east dry sclerophyll forests. *Australian Journal of Botany* **57**, 533-540.

Penman, T. D., Binns, D., Shiels, R., Allen, R., and Penman, S. (2011b). Hidden effects of forest management practices: responses of a soil stored seed bank to logging and repeated prescribed fire. *Austral Ecology* **36**, 571-580.

Penman, T. D., Binns, D. L., Shiels, R. J., Allen, R. M., and Kavanagh, R. P. (2008b). Changes in understorey plant species richness following logging and prescribed burning in shrubby dry sclerophyll forests of south-eastern Australia. *Austral Ecology* **33**, 197-210.

Penman, T. D., Lemckert, F. L., and Mahony, M. J. (2006). Meteorological effects on the activity of the giant burrowing frog (*Heleioporus australiacus*) in south-eastern Australia. *Wildlife Research* **33**, 35-40.

Peterson, G. D., Cumming, G. S., and Carpenter, S. R. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology* **17**, 358-366. doi: https://doi.org/10.1046/j.1523-1739.2003.01491.x.

Phillips, S. (2017). Maxent: Fitting 'Maxent' Species Distribution Models with 'glmnet'. In 'R Package Version 0.1.2': https://cran.r-project.org/web/packages/maxnet/maxnet.pdf.

Phillips, S. J., Anderson, R. P., and Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**, 231-259.

Phillips, S. J., and Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* **31**, 161-175.

Phillips, S. J., Dudík, M., Elith, J., Graham, C. H., Lehmann, A., Leathwick, J., and Ferrier, S. (2009). Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. *Ecological Applications* **19**, 181-197.

Phillips, S. J., Dudík, M. and Schapire, R. E. (2021). Maxent software for modelling species niches and distributions (v3.4.4). https://biodiversityinformatics.amnh.org/open_source/maxent/.

Pickett, S. T. A., and White, P. S. (1985). 'The Ecology of Natural Disturbance and Patch Dynamics' (Academic Press Inc.: Orlando, FL.)

Prasad, A. M., Iverson, L. R., and Liaw, A. (2006). Newer classification and regression tree techniques: bagging and random forests for ecological prediction. *Ecosystems* **9**, 181-199. doi: 10.1007/s10021-005-0054-1.

Prober, S., and Thiele, K. (1995). Conservation of the grassy white box woodlands: relative contributions of size and disturbance to floristic composition and diversity of remnants. *Australian Journal of Botany* **43**, 349-366. doi: https://doi.org/10.1071/BT9950349.

Prowse, T. A. A., O'connor, P. J., Collard, S. J., and Rogers, D. J. (2019). Eating away at protected areas: total grazing pressure is undermining public land conservation. *Global Ecology and Conservation* **20**, e00754. doi: https://doi.org/10.1016/j.gecco.2019.e00754.

Qiao, H., Soberón, J., and Peterson, A. T. (2015). No silver bullets in correlative ecological niche modelling: insights from testing among many potential algorithms for niche estimation. *Methods in Ecology and Evolution* **6**, 1126-1136. doi: doi: 10.1111/2041-210X.12397.

Radford, J. Q., Woinarski, J. C., Legge, S., Baseler, M., Bentley, J., Burbidge, A. A., Bode, M., Copley, P., Dexter, N., and Dickman, C. R. (2018). Degrees of population-level susceptibility of Australian terrestrial non-volant mammal species to predation by the introduced red fox (*Vulpes vulpes*) and feral cat (*Felis catus*). *Wildlife Research* **45**, 645-657.

Reid, N., and Yan, Z. (2000). Mistletoes and other phanerogams parasitic on eucalypts. In: 'Diseases and Pathogens of Eucalypts' (eds P. J. Keane, G. A. Kile, F. D. Podger, and B. N. Brown) pp. 353-384. (CSIRO Publishing: Melbourne.)

Richardson, E., Nimmo, D. G., Avitabile, S., Tworkowski, L., Watson, S. J., Welbourne, D., and Leonard, S. W. J. (2018). Camera traps and pitfalls: an evaluation of two methods for surveying reptiles in a semiarid ecosystem. *Wildlife Research* **44**, 637-647.

Rose, S. (1997). Influence of suburban edges on invasion of *Pittosporum undulatum* into the bushland of northern Sydney, Australia. *Australian Journal of Ecology* **22**, 89-99.

Rose, S., and Fairweather, P. G. (1997). Changes in floristic composition of urban bushland invaded by *Pittosporum undulatum* in northern Sydney, Australia. *Australian Journal of Botany* **45**, 123-149.

Shcheglovitova, M., and Anderson, R. P. (2013). Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. *Ecological Modelling* **269**, 9-17. doi: https://doi.org/10.1016/j.ecolmodel.2013.08.011.

Shields, J. M., York, A., and Binns, D. (1992). Flora and Fauna Survey, Mt. Royal Management Area, Newcastle Region. Forest Resources Series No. 16. (State Forests of NSW: West Pennant Hills, NSW.)

Sivertsen, D. (1993). Conservation of remnant vegetation in the box and ironbark lands of New South Wales. *Victorian Naturalist* **110**, 24-29.

Slade, C., and Law, B. (2018). The other half of the coastal state forest estate in New South Wales; the value of informal forest reserves for conservation. *Australian Zoologist* **39**, 359-370. doi: 10.7882/az.2016.011.

Smith, A. P., Andrews, S. P., and Moore, D. M. (1994). Grafton-Casino Management Areas EIS Supporting Document No. 1. Terrestrial Fauna of the Grafton and Casino State Forest Management Areas: Description and Assessment of Forestry Impacts. (NSW Government: Sydney.)

Smith, A. P., Moore, D. M., and Andrews, S. P. (1992). Proposed Forestry Operations in the Glen Innes Forest Management Area. Fauna Impact Statement. (NSW Government: Sydney.)

Smith, P., and Smith, J. (2020). Future of the greater glider (*Petauroides volans*) in the Blue Mountains, New South Wales. *Proceedings of the Linnean Society of New South Wales* **142**, 55-66.

Specht, A., and Specht, R. (2005). Historical biogeography of Australian forests. In 'Australia and New Zealand forest histories: short overviews' (ed. S. Dovers) pp. 1-8. (Australian Forest History Society, Canberra.)

Stone, C., Kathuria, A., Carney, C., and Hunter, J. (2008). Forest canopy health and stand structure associated with bell miners (*Manorina melanophrys*) on the central coast of New South Wales. *Australian Forestry* **71**, 294-302. DOI: 10.1080/00049158.2008.10675048.

Tasker, E. M., and Bradstock, R. A. (2006). Influence of cattle grazing practices on forest understorey structure in north-eastern New South Wales. *Austral Ecology* **31**, 490-502. doi:10.1111/j.1442-9993.2006.01597.x.

Tasker, E. M., and Dickman, C. R. (2004). Small mammal community composition in relation to cattle grazing and associated burning in eucalypt forests of the northern tablelands of New South Wales. In 'Conservation of Australia's Forest Fauna' 2 ed. (ed. D. Lunney) pp. 721-740. (Royal Zoological Society of New South Wales: Mosman, NSW.)

Taylor, S., Drielsma, M. J., Taylor, R. J., and Kumar, L. (2016). Applications of rapid evaluation of metapopulation persistence (REMP) in conservation planning for vulnerable fauna species. *Environmental Mannagement* **57**, 1281-1291. doi: 10.1007/s00267-016-0681-7.

Tweedie, T. D., Bruskin, S., Chapman, W. S., and Heyward, R. W. (1995). Flora Survey, Urunga and Coffs Harbour Management Areas, Northern Region, New South Wales. Forest Resources Services No. 3, 104 pp. (State Forests of NSW: West Pennant Hills, NSW.)

Vanderwal, J., Shoo, L. P., Graham, C., and Williams, S. E. (2009). Selecting pseudo-absence data for presence-only distribution modeling: how far should you stray from what you know? *Ecological Modelling* **220**, 589-594. doi: https://doi.org/10.1016/j.ecolmodel.2008.11.010.

Venables, W. N., and Ripley, B. D. (1997) 'Modern Applied Statistics with S-PLUS' 2 ed. (Springer: New York.)

Wagner, B., Baker, P. J., Stewart, S. B., Lumsden, L. F., Nelson, J. L., Cripps, J. K., Durkin, L. K., Scroggie, M. P., and Nitschke, C. R. (2020). Climate change drives habitat contraction of a nocturnal arboreal marsupial at its physiological limits. *Ecosphere* **11**, e03262.

Wahren, C., Papst, W., and Williams, R. (1994). Long-term vegetation change in relation to cattle grazing in sub-alpine grassland and heathland on the Bogong high-plains: an analysis of vegetation records from 1945 to 1994. *Australian Journal of Botany* **42**, 607-639. doi: https://doi.org/10.1071/BT9940607.

Ward-Jones, J., Pulsford, I., Thackway, R., Bishwokarma, D., and Freudenberger, D. (2019). Impacts of feral horses and deer on an endangered woodland of Kosciuszko National Park. *Ecological Management & Restoration* **20**, 37-46. doi: https://doi.org/10.1111/emr.12353.

Ward, M., Tulloch, A. I., Radford, J. Q., Williams, B. A., Reside, A. E., Macdonald, S. L., Mayfield, H. J., Maron, M., Possingham, H. P., and Vine, S. J. (2020). Impact of 2019–2020 mega-fires on Australian fauna habitat. *Nature Ecology & Evolution* **4**, 1321-1326.

Wardell-Johnson, G., Stone, C., Recher, H., and Lynch, A. J. J. (2005). A review of eucalypt dieback associated with bell miner habitat in south-eastern Australia. *Australian Forestry* **68**, 231-236.

Whalley, R., Robinson, G., and Taylor, J. (1978). General effects of management and grazing by domestic livestock on the rangelands of the northern tablelands of New South Wales. *The Rangeland Journal* **1**, 174-190. doi: https://doi.org/10.1071/RJ9780174.

Williams, K. J., Belbin, L., Austin, M. P., Stein, J. L., and Ferrier, S. (2012). Which environmental variables should I use in my biodiversity model? *International Journal of Geographical Information Science* **26**, 2009-2047. doi: https://doi.org/10.1080/13658816.2012.698015.

Wilson, J. P., and Gallant, J. C. (Eds) (2000). 'Terrain Analysis: Principles and Applications' (John Wiley & Sons: New York.)
Wilson, P. D. (2006). The distribution of the greater broad-nose bat *Scoteanax rueppellii* (Microchiroptera: Vespertilionidae) in relation to climate and topography. *Australian Mammalogy* **28**, 77-85. doi: https://doi.org/10.1071/AM06009.
Wimbush, D., and Costin, A. (1979a). Trends in vegetation at Kosciusko. 1. Grazing trials in the subalpine zone, 1957–1971. *Australian Journal of Botany* **27**, 741-787. doi: https://doi.org/10.1071/BT9790741.
Wimbush, D., and Costin, A. (1979b). Trends in vegetation at Kosciusko. II. Subalpine range transects, 1959–1978. *Australian Journal of Botany* **27**, 789-831. doi: https://doi.org/10.1071/BT9790789.
Wintle, B. A., Legge, S., and Woinarski, J. C. (2020). After the megafires: what next for Australian wildlife? *Trends in Ecology & Evolution* **35**, 753-757.
Woinarski, J. C., Burbidge, A. A., and Harrison, P. L. (2015). Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences* **112**, 4531-4540.
Xu, T., and Hutchinson, M. (2011). ANUCLIM Version 6.1 User Guide. (Australian National University: Canberra.)
York, A., Binns, D., and Shields, J. (1991). Flora and Fauna Assessment in NSW State Forests v1.1. (Forestry Commission of NSW: Beecroft, NSW.)