Eden Fauna Modelling

A report undertaken for the NSW CRA/RFA Steering Committee

31 March 1998

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NEW SOUTH WALES NATIONAL PARKS AND WILDLIFE SERVICE

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EXECUTIVE SUMMARY

This report has been prepared for the joint Commonwealth/State Steering Committee which oversees the comprehensive regional assessments of forests in New South Wales.

The comprehensive regional assessments (CRAs) provide the scientific basis on which the State and Commonwealth governments will sign regional forest agreements (RFAs) for the major forests of New South Wales. These agreements will determine the future of the State's forests, providing a balance between conservation and ecologically sustainable use of forest resources.

The Eden fauna modelling project was undertaken to produce valid fauna models to predict the range of, and quality habitat for, fauna species of the area. These fauna models would then be used for the assessment of high quality habitat for significant priority species, and to provide digital information for other project areas for use in satisfying JANIS criteria (see Commonwealth of Australia, 1997) relating to centres of endemism, significant refugia, and areas of high biodiversity.

External fauna survey data, collected during the Eden CRA fauna audit process, and data collected on the Eden CRA summer 1996/97 surveys, were collated and then validated by contracted experts in preparation for the modelling process. Abiotic and biotic environmental Geographic Information System (GIS) layers for the Eden CRA area were obtained. Various biotic and abiotic indices were calculated by contracted experts and contextual variables derived. All fauna species survey data were designated as formal (presence-absence) or incidental (presence-only) and survey method and effort covariates assigned to the formal data.

Using S-PLUS and the completed fauna dataset and GIS layers, predictive distribution models were fitted for each species and their distributions extrapolated across the entire Eden area.

For each model, statistics were derived indicating the degree of fit of the model to the data and the significance of each predictor (variable) used in the model. The maps produced indicated the probability of occurrence of each species across the Eden area from 1-100%.

Models and maps for priority species (i.e. threatened and forest-dependent species) were evaluated by expert modellers and ecologists and revisions to the models made as necessary. The probability classes for each species' modelled distribution were grouped by the experts to reflect areas considered to be core, intermediate or marginal habitat. A number of species did not produce viable models due to lack of data or poor quality data.

The final modelled distributions were later assessed and revised as needed by the CRA Response to Disturbance project expert workshops. The resultant modelled distributions from these workshops were used for the Conservation Requirements and Integration phases of the Eden CRA.

1. INTRODUCTION

1.1 BACKGROUND

In 1992 the Commonwealth, State and Territory governments agreed to the National Forest Policy Statement. Arising from that agreement, Comprehensive Regional Assessments (CRAs) are being conducted throughout Australia to assess the values of forested regions, with the aim of establishing a comprehensive, adequate and representative reserve system.

The first CRA region to be assessed in New South Wales was the Eden area, where vertebrate fauna surveys were conducted during the summer and autumn of 1997 (see NSW NPWS, in prep.). Data collected during these surveys and additional data collated from previous surveys have been analysed as part of the current Eden fauna modelling project.

1.2 STUDY AREA

The Eden CRA region, comprising 813 760 hectares, extends from the Victorian border in the south, north to Bermagui, east to the coast and west to Bombala and the Monaro and Cann River Highways (figure 1a). In the west, the region borders the southern tablelands at around 1000 metres altitude. From there, to the east the escarpment drops away down to the Bega Valley and the coastal areas of Eden and Narooma.

The vegetation of the area predominantly comprises wet and dry sclerophyll forests, with small patches of rainforest on the escarpment and southern facing gullies, coastal and plateau heathlands, and scattered patches of grasslands and grassy woodlands.

Mean annual temperatures of the region range from 8°C on the tablelands to 15°C at the coast.

The Eden study area comprises 551 763 hectares of vegetated areas and 261 997 hectares of cleared land. Much of the forested area is contained in State Forest land (199 350 hectares) or National Parks (210 019 hectares) (figure 1b).

1.3 PROJECT OBJECTIVES

The aim of the Eden fauna modelling project was to produce models to predict the distribution of habitat for vertebrate fauna species of the area. These models were required to satisfy JANIS Biodiversity Criteria number five relating to the protection of high quality fauna habitat, centres of endemism, natural refugia and areas of high diversity.

Figure 1a

Figure 1b

2. METHODOLOGY

2.1   INTRODUCTION

The principle objective of the fauna modelling project was to spatially extend (or interpolate) fauna survey results throughout the whole study area, based on modelled relationships between fauna and remotely mapped environmental attributes. The models were produced on an individual species basis to enable definition and evaluation of explicit conservation goals for each species. This also enabled weighting of species according to vulnerability and conservation need, and allowed consideration of specific needs for individual species. These elements were crucial for the response to disturbance and conservation requirements phases of the CRA process.

The methodology and results of the data audit and survey phases of the Eden CRA project, which generated data used in the current modelling project, are described in detail in NSW NPWS (in prep.).

2.2   PRIORITY SPECIES

Through a series of workshops and expert consultation, a list of priority species was compiled. These priority species were targeted in the collation of existing data, the design of the new field surveys, and the derivation of models. Data for non-priority species were also collected and collated in the data audit and survey phases of the project, and analysed, but were of lower priority for editing and validation.

The 49 priority species, listed in table 2a, include all threatened and forest-dependent vertebrate fauna species for the area, and some species considered vulnerable to forest disturbance (23 mammals, 18 birds, 4 reptiles and 4 amphibians). Forest dependency was determined in the same expert workshops. The species were sorted by functional groups (i.e. arboreal mammals / nocturnal birds; ground mammals; bats; diurnal

birds; and reptiles and amphibians) for the purposes of data validation and model processing. Further information on the compilation of the priority species list is documented in the data audit and survey report (NSW NPWS, in prep.).

2.3   DATA SOURCES

The data used in the fauna modelling project were collated from three sources: systematic survey data from previous survey work; new survey data collected as part of the Eden CRA project; and non-systematic data.

The systematic data collated from previous survey work included survey data from completed studies that were collected using documented field sampling techniques at a series of precise site locations. Such data needed to include presence and absence records for species and have a well defined survey method and effort that was preferably compatible to that of the CRA surveys. Data from previous surveys were particularly sought for the priority species and where large data gaps were identified (see NSW NPWS, in prep.).

The new survey data collected as part of the Eden CRA project were collected throughout the Eden area using an environmentally stratified sampling regime, based on three environmental variables (lithology, temperature and rainfall). Specified field techniques were used for sampling each functional group of fauna species at precisely located sites (see NSW NPWS, in prep.). These survey data were the major source of presence/absence data for the species modelling project, having consistent method and effort across the area. Due to the relatively small size of the Eden CRA area, some sites were surveyed to the north of the area to provide more data to enhance the modelling analysis.

TABLE 2A: PRIORITY SPECIES FOR THE EDEN FAUNA MODELLING

Functional group	Species	Common Name	Forest dependency ranking[1]	TSC Act[2]	ESP Act[3]
Arboreals/Nocturnals[4]	*Ninox connivens*	Barking Owl	3		
Arboreals/Nocturnals	*Phascogale tapoatafa*	Brush-tailed Phascogale	3	V	
Arboreals/Nocturnals	*Petauroides volans*	Greater Glider[5]			
Arboreals/Nocturnals	*Phascolarctus cinereus*	Koala	3	V	
Arboreals/Nocturnals	*Tyto novaehollandiae*	Masked Owl	3	V	
Arboreals/Nocturnals	*Ninox strenua*	Powerful Owl	3	V	
Arboreals/Nocturnals	*Tyto tenebricosa*	Sooty Owl	3	V	
Arboreals/Nocturnals	*Petaurus norfolcensis*	Squirrel Glider	3	V	
Arboreals/Nocturnals	*Petaurus australis*	Yellow-bellied Glider	3	V	
Ground Mammals	*Potorous longipes*	Long-footed potoroo	3	E	E
Ground Mammals	*Perameles nasuta*	Long-nosed Bandicoot	3		
Ground Mammals	*Potorous tridactylus*	Long-nosed potoroo	3	V	
Ground Mammals	*Pseudomys fumeus*	Smoky Mouse	3	E	
Ground Mammals	*Isoodon obesulus*	Southern Brown Bandicoot	3	E	
Ground Mammals	*Dasyurus maculatus*	Tiger Quoll	3	V	
Ground Mammals	*Sminthopsis leucopus*	White-footed Dunnart	3	V	
Bats	*Miniopterus shreibersii*	Common Bent-wing Bat	2	V	
Bats	*Falsistrellus tasmaniensis*	Eastern False Pipistrelle	2	V	
Bats	*Rhinolophus megaphyllus*	Eastern Horseshoe Bat[5]			
Bats	*Mormopterus norfolkensis*	Eastern Little Mastiff-bat	2	V	
Bats	*Kerivoula papuensis*	Golden-tipped Bat	3	V	
Bats	*Scoteanax rueppellii*	Greater Broad-nosed Bat	2	V	
Bats	*Pteropus poliocephalus*	Grey-headed Flying Fox[5]			
Bats	*Myotis adversus*	Large-footed Myotis	3	V	
Bats	*Miniopterus australis*	Little Bent-winged Bat	2	V	
Bats	*Pteropus scapulatus*	Little Red Flying Fox	2		
Bats	*Saccolaimus flaviventris*	Yellow-bellied Sheath-tail Bat	2	V	
Diurnal Birds	*Botaurus poiciloptilus*	Australasian Bittern	1	V	
Diurnal Birds	*Burhinus magnirostris*	Bush Stone Curlew		E	
Diurnal Birds	*Falcunculus frontalis*	Crested Shrike Tit	3		
Diurnal Birds	*Calyptorhynchus lathami*	Glossy Black Cockatoo	3	V	
Diurnal Birds	*Chalcophaps indica*	Emerald Dove	1		
Diurnal Birds	*Pachycaphala olivacea*	Olive Whistler	3	V	
Diurnal Birds	*Petroica rodinogaster*	Pink Robin	3	V	
Diurnal Birds	*Climacteris erythrops*	Red-browed Treecreeper	3		
Diurnal Birds	*Xanthomyza phrygia*	Regent Honeyeater	3	E	E
Diurnal Birds	*Lophoictinia isura*	Square-tailed kite	2	V	
Diurnal Birds	*Lathamus discolor*	Swift Parrot	3	V	V
Diurnal Birds	*Neophema pulchella*	Turquoise Parrot	2	V	
Diurnal Birds	*Daphoenositta chryoptera*	Varied Sittella	3		
Diurnal Birds	*Calyptorhyncus funereus*	Yellow-tailed black Cockatoo	2		
Reptiles/Amphibians	*Litoria booroolongensis*	Booroolong Frog	3		
Reptiles/Amphibians	*Acanthophis antarticus*	Common Death Adder[5]			
Reptiles/Amphibians	*Pygopus lepidopodus*	Common Scaly-foot[5]			
Reptiles/Amphibians	*Morelia spilota spilota*	Diamond Python	3		
Reptiles/Amphibians	*Helioporus australiacus*	Giant Burrowing Frog	3	V	
Reptiles/Amphibians	*Litoria littlejohni*	Heath Frog	1		
Reptiles/Amphibians	*Varanus varius*	Lace Monitor	3		
Reptiles/Amphibians	*Mixophyes balbus*	Stuttering Barred Frog	3	V	

[1] 1 = common and widespread, found in forests, low priority; 2 = common but dependent on ecologically mature forests, possibly affected by forestry operations, medium priority; 3 = critical species requiring conservation intervention, high priority.

[2] Threatened Species Conservation Act 1996 (NSW): E = endangered; V = vulnerable.

[3] Endangered Species Protection Act 1992 (Commonwealth): E = endangered; V = vulnerable.

[4] Arboreal mammals and nocturnal birds.

[5] Species considered vulnerable to forest disturbance by the Response to Disturbance workshop, and added to list after forest dependency ranking list was compiled.

The non-systematic data included simple locality records for species from a variety of sources. These data could only be classified as presence-only, opportunistic or incidental due to there being no systematic sampling methodology or survey design and thus no species absence records. However, such records could still be used separately for modelling, and were useful for species where there was insufficient systematic data. This was often the case for rare or cryptic species which need to be surveyed using targeted non-systematic (or often more specialised) methods to increase chance of detection without wasted survey effort in inappropriate areas. The primary source of incidental data was the Atlas of NSW Wildlife (NSW NPWS, 1997), but some opportunistic data were also collected on the CRA systematic surveys. Data from many external sources were also classified as incidental due to a lack of quantifiable or systematic survey methodology.

The sources of all data used in the Eden modelling are listed in appendix 2.1 which includes' whether data were classified as presence/absence or presence-only for modelling. Further details on the methods of classifying the data in this way are given in section 2.5.1. The data audit and survey report (NSW NPWS, in prep.) contains more information on the data audit process and sources of records.

2.4   DATA MANAGEMENT

Data management procedures for the data audit process and new survey data are described in full in NSW NPWS (in prep.).

Collated data were initially stored in a flat file in MS EXCEL due to the unavailability of an appropriate relational database. After the data validation and cleaning process (see below) data were transferred into a basic database in MS ACCESS, for manipulation and preparation for modelling.

A separate file was established in MS EXCEL to store all information about the sources of the raw data. Such information included details on the survey design, methodology and effort, which were later used to classify the data and derive covariates for the modelling (see section 2.5.1).

2.4.1   Data Validation

Data collected for the priority species in the data audit and survey phases of the Eden CRA project (NSW NPWS, in prep.) underwent a rigorous validation process. A number of recognised scientific experts (from CSIRO, State Forests of NSW, universities and private consultants) were contracted to validate individual records of the functional group(s) of species within their particular field of expertise (see Acknowledgements section).

The validation process involved checking the validity of point locations (against known geographical spread of a species) and species identification (using location, observer expertise and observation method). Thus some records were rejected because:

■ they were located outside the known distribution of the species, and were in an inappropriate habitat or area, or the accuracy of the identification was questionable;

■ the species identification was questionable due to:

 − observer inexperience;
 − the record being from hair analysis which was designated 'probable' or 'possible';
 − the record being from a predator scat, and either would have been difficult to accurately identify or may not indicate the true location of the species; or
 − having an inappropriate method of observation for that species.

Once the validated data were imported into MS ACCESS, duplicate records were identified and rejected. Many such duplicates were encountered when data had been received directly from a data source but had also been earlier entered into the Atlas of NSW Wildlife. In such circumstances, the record from the raw data source was retained as the accompanying survey information enabled the record to be accurately designated as presence/absence.

Extensive problems were encountered with 'pseudo-' or 'hidden' duplicates which occurred when data was received from more than one source (usually Atlas and one other) but one data field was different between the records, suggesting a possible duplicate. The differing fields were usually the observer name or data source description, but sometimes were Australian Map Grid references (AMGs) with variations of tens of

metres. These differences reflected variations in data entry methods or accuracy. The original collector of the data was contacted in such cases to confirm which were the most accurate records to retain. These problems highlighted the need for even more rigorous quality control when collating external sources of data.

TABLE 2B: FIELDS CONTAINED IN THE EDEN FAUNA MODELLING DATABASE

Data Table

Field Name	Description
Table ID	Identifies the source of the data. Combined with Record ID, forms the primary field for this table.
Record ID	With Table ID gives each record an individual identifier
Species code	Numeric identifier for each species according to Census of Australian Vertebrate Species (CAVS). Used to link with the species table.
Number	Observed abundance of species
Start date	Start date of survey or date of observation
Start day	Start day of survey or day of observation
Start month	Start month of survey or month of observation
Start year	Start year of survey or year of observation
Finish date	Finish date of survey
Easting	Australian Map Grid easting (converted to zone 55)
Northing	Australian Map Grid northing (converted to zone 55)
Source	Text identifier for distinct surveys
Model	Data type (presence/absence, presence-only or rejection)
Observation type	Type of observation of the species, e.g. trapped, observed, heard etc. Categories and code used are from the Atlas of NSW Wildlife
Reliability type	Numeric code for reliability of species identification: specimen in a public museum specimen in other collections voucher specimen used specialist reliability standard reliability record under question
Accuracy index	Numeric code for precision of geographic location: within 10 metres within 100 metres within 1 kilometre within 10 kilometres within 100 kilometres
Observer name	Surname of observer
Observer initial	Initials of observer
Survey length	Indicates whether survey period is greater or less than one season (i.e. 90 days); calculated from start and end dates
Duplicates	Identifies duplicate records
Group	Identifies functional group / data type (i.e. formal/incidental) category
Effort	Numeric code for effort of survey
Method	Numeric code for method of survey

Species Table

Field Name	Description
Scientific name	Scientific name (genus, species)
Common name	Common name of species
Species code	Numeric identifier for each species according to Census of Australian Vertebrate Species (CAVS). This field is the primary field and used to link with the data table.
Animal type	Functional group the species belongs to
Priority species	Identifies species regarded as being of high priority for modelling and conservation consideration

A second check was also run on the 'observation type' field (mostly contained in records from the Atlas and CRA surveys) to reject types that could give inaccurate species identification or imprecise geographical and thus environmental location of the species. The observation types that were rejected were (terminology from the Atlas of NSW Wildlife): road, cat, dog or fox kill; tracks/scratchings; scat (except koalas and wombats); 'in scat'; 'in raptor/owl pellet'; fossil/sub-fossil remains; miscellaneous; and 'not located'.

Records with an 'accuracy of geographic location' code of four or more (i.e. +/- 10 and 100 kilometres) (see table 2b) were also rejected. Records with poor 'reliability type' (as per Atlas of NSW Wildlife) were rejected at the expert validation stage.

2.4.2 Database

Due to the restricted time frame and funding, and lack of an established relational survey database, the collated validated data were imported into a single table, the 'data table', in MS ACCESS which contained the fields required for modelling. Another smaller table, the 'species table', was constructed to enable assigning species code, functional group and priority status to individual species. The two tables were linked by the 'species code' field.

The fields in the two MS ACCESS tables are listed and explained in table 2b. The fields 'start day', 'start month', 'start year' and 'survey length' were calculated within MS ACCESS for use in the modelling program. The 'model', 'effort', 'method' and 'precision' fields were assigned as described in section 2.5.1 below, or using the rejection decisions from the validation process described above.

2.5 PREPARATION OF BIOLOGICAL DATA

2.5.1 Derivation of method and effort covariates

Due to variation in survey method and effort between the various external sources of systematic data and the CRA surveys, covariates were derived that would enable detection of any effect this variation may be having on the detectability of species. The covariates were derived in consultation with scientific experts and only used

for presence/absence modelling as method and effort are not considered in presence-only modelling.

Before deriving the covariates, all data were classified as either formal (presence/absence) or incidental (presence-only) as different modelling techniques were to be performed on each. As evident in appendix 2.1, many external data could not be classified as presence/absence due to systematic survey methods not being used, either in the selection of sites or in the survey techniques employed at the sites. Some data were collected using methods that were too different to the CRA data to be accounted for in the covariates (e.g. transects instead of sites), and other data did not have enough supporting information to determine accurately the methods and effort employed. These data were therefore classified as incidental. Additionally, because species are processed in the modelling software by functional groups (although individual species models are produced), any survey that only sampled a subset of species in any one functional group had to be designated incidental, otherwise the model would incorrectly treat all the sites as absence records for the other species in the functional group.

The wide variation in survey effort across all the data used necessitated the use of a broad effort covariate with three levels:

1. long term, in-depth study i.e. intensive study over a long time;

2. substantial general study i.e. basic study with greater than one visit over time, or extensive study with only one visit;

3. formal study but brief in scope i.e. only one point in time and small area of study.

The method covariates were derived separately for each functional group and based on the survey techniques used for detecting species in each.

Ground mammals:
1. Elliott trap
2. hair tube
3. pitfall trap &/or cage trap

Bats:
1. harp trapping
2. Anabat (ultrasonic recording)
3. mist netting
4. mist netting and harp trapping

Arboreal mammals and nocturnal birds:
1. spotlighting transects (walking or vehicle)

2. call playback
3. spotlighting transects and call playback

Diurnal birds:
1. observation plots 1-2 hectares
2. observation plots 4-5 hectares

Reptiles and Amphibians:
1. call playback
2. visual search
3. pitfall trap
4. habitat search

These covariates were assigned to the formal records in the MS ACCESS database. In the modelling they were used as factor covariates (as opposed to continuous variables described in 2.6) to determine whether they produced any effect on the model results.

2.5.2 Exporting data from MS Access

The fauna species modelling was performed by functional group (five groupings) and by data type (either presence-only or presence/absence). This separation of data gave ten modelling categories. For each modelling category, data needed to be extracted from the MS ACCESS database into three tables to be used by S-PLUS (StatSci, 1993) and ARCVIEW Spatial Analyst (ESRI, 1996) to generate the final models:

- a 'species seen' table detailing each species within the functional group;

- a 'site/visit' table detailing each visit for a functional group; and

- a 'species data' table which links the other two tables by detailing which species were recorded at each specific site/visit.

The 'species seen' table contained a record for each species recorded for the functional group / data type in the database. Each record detailed the common and scientific name, the species code and a unique record identifier.

The 'site/visit' table contained records giving details of each unique visit to a site. That is, each record had a unique combination of survey date (day, month and year), site location (AMG), observer, and method and effort. Each record was given a unique numeric identifier (visit code). Two fields were added, one to give each record a functional group identifier and the other to give each record a data type identifier (i.e. formal or incidental).

The 'species data' table contained the species code from the species table and matched it with the visit code from the site table. Thus one record is given for every unique combination of species and site visit. Two additional fields were added, one to give each record the same data type identifier, the other to give each record a constant abundance (as required by the model). (Abundance modelling was not run in this project due to the lack of sufficient, good quality abundance data).

Modelling was only performed on seasonal data (i.e. where the survey period was less than ninety days) so any data with long survey periods were rejected before export to S-PLUS. However, for a few species, the non-seasonal data were included to boost the number of available records. This was done for the high priority arboreal mammals and nocturnal birds (due to the nature of the data), the Common Death Adder and the Lace Monitor.

2.6 PREPARATION OF ENVIRONMENTAL DATA

The fauna modelling project relied on the development of adequate environmental layers that are representative of the environmental variables known to influence species' distribution. A number of workshops were convened with experts familiar with the environmental needs of the species being modelled and experienced in the process of statistical modelling. The role of the workshops was to derive a series of habitat indices related to resource availability and structural complexity of forest types in the study area. From these workshops, various indices and variables were chosen to be used in the modelling. Other variables selected were based on those used in the North East Forests Biodiversity Study (NEFBS) (NSW NPWS, 1994a) and recommendations from NSW National Parks and Wildlife Service (NSW NPWS) modelling and ecology experts.

The variables used for modelling can be divided into three categories; habitat indices, contextual landscape variables and abiotic variables. The separate variables for each of these categories and their scales and sources are listed in table 2c and discussed in more detail below.

TABLE 2C: VARIABLES USED FOR EDEN FAUNA MODELLING

VARIABLE		SOURCE DATA	DEFINED BY
Habitat indices	**Grid size**		
tree hollows (actual)	100m	KBS[1] / CSIRO 20[2] vegetation mapping	Wayne Braithwaite, CSIRO
tree hollows (potential)	100m	KBS[1] / CSIRO 20[2] vegetation mapping	Wayne Braithwaite, CSIRO
nectar	100m	KBS[1] / CSIRO 20[2] vegetation mapping	Wayne Braithwaite, CSIRO
decorticating bark	100m	KBS[1] / CSIRO 20[2] vegetation mapping	Wayne Braithwaite, CSIRO
foliage nutrient	100m	KBS[1] / CSIRO 20[2] vegetation mapping	Wayne Braithwaite, CSIRO
ground cover	100m	KBS[1] / CSIRO 20[2] vegetation mapping	CSIRO consultants workshop
shrubs	100m	KBS[1] / CSIRO 20[2] vegetation mapping	CSIRO consultants workshop
oldgrowth 1	100m	IAP growth staging[3]	Nick Gellie, NSW NPWS
oldgrowth 2	100m	IAP growth staging[3]	Daniel Connolly, NSW NPWS
Contextual landscape variables			
% clearing within 1km	100m	Eastern Bushlands Database[4]	expert panel, also used in NEFBS[5]
% clearing within 2km	100m	Eastern Bushlands Database[4]	expert panel, also used in NEFBS[5]
% old growth within 1km	100m	IAP growth staging[3]	expert panel, also used in NEFBS[5]
% old growth within 2km	100m	IAP growth staging[3]	expert panel, also used in NEFBS[5]
% high quality old growth within 1km	100m	IAP growth staging[3]	Simon Clarke, Environment & Heritage Technical Committee
% high quality old growth within 2km	100m	IAP growth staging[3]	Simon Clarke, Environment & Heritage Technical Committee
% rainforest within 2km	100m	KBS[1] / IAP[3] growth staging	expert panel, also used in NEFBS[5]
% rainforest within 1km	100m	KBS[1] / IAP[3] growth staging	expert panel, also used in NEFBS[5]
Abiotic variables			
digital elevation model (DEM)	25m	Land Information Centre (LIC), DLWC	Land Information Centre, DLWC
mean annual rainfall	100m	LIC DEM / ESOCLIM	Australian National University
mean annual temperature	100m	LIC DEM / ESOCLIM	Australian National University
ruggedness 1km	25m	LIC DEM	Michael Drielsma, NSW NPWS
ruggedness 500m	25m	LIC DEM	Michael Drielsma, NSW NPWS
solar radiation index	25m	LIC DEM / ESOCLIM	Michael Drielsma, NSW NPWS / Australian National University
terrain position	25m	LIC DEM	Michael Drielsma, NSW NPWS
topographic position 1km	25m	LIC DEM	Michael Drielsma, NSW NPWS
topographic position 500m	25m	LIC DEM	Michael Drielsma, NSW NPWS
wetness index	100m	LIC DEM	Michael Drielsma, NSW NPWS
fertility index	100m	geology, geochemcial and fertility data	CSIRO, Division of Wildlife and Ecology, Canberra

[1] Keith *et al.* (1996); [2] CSIRO (1996); [3] NSW NPWS (1996); [4] NSW NPWS (in prep.); [5] NSW NPWS (1994a)

2.6.1 Habitat indices

The expert workshop participants decided that the following indices of fauna habitat were required: tree hollows (actual), tree hollows (potential), nectar, decorticating bark, foliage nutrient, ground cover, shrub cover, and old growth.

The flora plot data from the South East vegetation mapping project (Keith *et al*., 1995) (referred to as the KBS vegetation map) was used to assign values for all these indices (except old growth) to the mapped (modelled) vegetation types of the second version map of that project (Keith *et al.,* 1996). These indices and values are listed in table 2d. The old growth indices were derived using

growth stage codes from the Interim Forestry Assessment Process (IAP) (NSW NPWS, 1996).

Wayne Braithwaite (CSIRO) derived the hollow, nectar, bark and nutrient indices by firstly assigning values to individual tree species (as relative scores for trees in 'mature' forests) then using the KBS plot data for tree species frequencies, deriving indices for the individual KBS forest types. The individual methods are discussed below.

The ground and shrub indices were calculated by a small workshop of CSIRO consultants (Mike Austin, Peter Catling and Mike Doherty) using the KBS plot data (structure and cover of shrub and

ground layers). These and the old growth indices
are described further below.

TABLE 2D: HABITAT INDICE VALUES ASSIGNED TO THE SOUTH EAST FORESTS VEGETATION CLASSES

Class no.	Vegetation class (Keith et al., 1996)	Foliage nutrient[1]	Decorti-cating bark[1]	Actual hollows[1]	Potential hollows[1]	Nectar[1]	Shrubs[2]	Ground cover[3]
1(38)	Dry Rainforest	8	1	2	1	1	1	2
3(37)	Rocky Tops Dry Shrub Forest	4	3	3	3	2	3	1
4(39)	Acacia Scrub	3	0	0	0	1	1	1
5(58)	Bunga Head Rainforest	8	0	1	1	1	1	2
6(40)	Coastal Warm Temperate Rainforest	8	0	0	0	1	2	3
7(41)	Hinterland Warm Temperate Rainforest	8	0	0	0	0	2	4
8(44)	Cool Temperate Rainforest	8	2	1	1	1	2	3
9(43)	Mountain Wet Layered Forest	7	4	1	1	3	5	2
10(42)	Mountain Wet Layered Forest	7	6	2	4	4	4	3
11(45)	Tantawangalo Wet Shrub Forest	6	6	4	6	4	4	3
12(46)	Mountain Wet Fern Forest	5	9	4	6	4	2	4
13(47)	Hinterland Wet Fern Forest	4	7	6	4	4	3	3
14(48)	Hinterland Wet Shrub Forest	3	8	6	5	6	4	4
15(49)	Mountain Wet Herb Forest	4	8	5	4	4	1	3
16(50)	Basalt Wet Herb Forest	7	8	3	6	6	1	3
17(51)	Flats Wet Herb Forest	8	7	4	7	6	1	4
18(52)	Brogo Wet Vine Forest	7	1	2	2	8	3	4
19(53)	Bega Wet Shrub Forest	10	3	4	6	5	3	4
20(54)	Bega Dry Grass Forest	9	4	3	4	7	3	2
21(55)	Candelo Dry Grass Forest	8	2	3	2	10	3	2
22(68)	Bombala Dry Shrub Forest	4	5	6	4	5	1	3
23(64)	Monaro Grassland (no trees)	0	0	0	0	0	0	0
24(27)	Subalpine Dry Shrub Forest	8	10	4	10	4	2	2
25(26)	Sandstone Dry Shrub Forest	4	4	4	3	2	2	2
26(25)	Tableland Dry Shrub Forest	5	6	6	6	2	2	2
27(28)	Waalimma Dry Grass Forest	6	3	7	3	10	2	3
28(24)	Wog Wog Dry Grass Forest	4	8	8	8	3	2	2
29(23)	Nalbaugh Dry Grass Forest	5	8	7	7	2	2	3
30(22)	Wallagaraugh Dry Grass Forest	5	6	5	7	4	2	3
31	North Hinterland Dry Grass Forest	3	4	7	4	3	1	3
31	South Hinterland Dry Grass Forest	3	4	7	4	3	0	0
32(11)	Coastal Dry Shrub Forest	3	4	5	5	10	3	2
33(12)	Coastal Dry Shrub Forest	2	4	6	3	5	3	2
34(13)	Brogo Dry Shrub Forest	5	4	4	6	9	3	2
35(15)	Escarpment Dry Grass Forest	5	7	3	5	5	3	3
36(16)	Dune Dry Shrub Forest	7	3	3	5	8	0	4
37(17)	Coastal Dry Shrub Forest	5	4	5	5	8	4	3
38(18)	Southern Riparian Scrub	10	7	1	1	0	2	2
39(19)	Northern Riparian Scrub	6	6	5	6	3	4	3
40(20)	Riverine Forest	6	0	0	0	0	2	2
41(10)	Mountain Dry Shrub Forest	5	4	5	2	1	1	2
42(9)	Coastal Dry Shrub Forest	3	5	8	3	2	2	3
43(7)	Mountain Dry Shrub Forest	3	6	9	5	2	2	3
44(6)	Foothills Dry Shrub Forest	3	4	9	3	1	1	2
45(8)	Mountain Dry Shrub Forest	3	3	8	2	1	2	3
46(3)	Lowland Dry Shrub Forest	1	2	7	2	3	2	3
47(4)	Eden Dry Shrub Forest	4	2	8	3	6	3	3
48(1)	Bega Dry Shrub Forest	2	1	8	1	2	1	2
49(2)	Coastal Dry Shrub Forest	2	2	9	1	1	1	3
50(5)	Genoa Dry Shrub Forest	4	1	8	2	1	2	2

Class no.	Vegetation class (Keith *et al.,* 1996)	Foliage nutrient[1]	Decorti-cating bark[1]	Actual hollows[1]	Potential hollows[1]	Nectar[1]	Shrubs[2]	Ground cover[3]
51(29)	Rock Scrub	4	3	5	1	1	2	2
52(59)	Mountain Rock Scrub (no trees)	0	0	0	0	0	0	0
53(36)	Montane Heath	4	3	5	5	1	3	1
54(34)	Mt Nadgee Heath	2	1	7	2	1	2	4
55(33)	Coastal Lowland Heath	1	1	5	1	3	2	3
56(32)	Swamp Heath	6	5	5	5	4	2	4
57(35)	Lowland Swamp (no trees)	0	0	0	0	0	3	4
58(31)	Swamp Forest	7	9	4	10	7	1	4
59(30)	Sub-Alpine Bog	6	5	4	10	3	2	4
60(63)	Floodplain Wetlands (no trees)	0	0	0	0	0	0	0
61(56)	Coastal Scrub	5	1	4	3	8	2	3
62(57)	Beach Strand Grassland (no trees)	0	0	0	0	0	0	0
63-66	Estuarine Wetlands (no trees)	0	0	0	0	0	0	0
67-70	Seagrass Meadows (no trees)	0	0	0	0	0	0	0
71	Subalpine Basalt Grass Forest	9	8	4	10	6	1	3

[1] Scores range from 0 - 10; [2] Scores from 0 - 5; [3] Scores from 1 - 4.

The major difficulty in deriving these indices was the lack of a reliable vegetation layer that covered the entire Eden study area. The four vegetation maps available at the time were:

- the Keith, Bedward and Smith (KBS) vegetation mapping (Keith *et al.,* 1996) i.e. version two of the 1995 map;

- the CSIRO 120 unit vegetation mapping (CSIRO, 1996);

- the CSIRO 20 class vegetation mapping (CSIRO, 1996); and

- the Eastern Bushlands Database (NSW NPWS, in prep.).

The KBS vegetation mapping did not extend fully to the far north-eastern corner of the Eden study area. Furthermore, as it was desirable to extend the study area boundary further to the north for modelling purposes (to encompass more survey sites), the KBS mapping was deemed to be insufficient on its own.

The algorithm used to produce the two CSIRO maps was known to be flawed. Where the shape of the DEM was used to identify areas as being either a ridge or a gully, those features were incorrectly identified. That is, ridges were labelled gullies and vice-versa, although where these features' identification was based on the presence of a watercourse they were correctly identified. It was felt by CSIRO staff, however, that this mis-identification would have a minimal effect on the

broader 20 class vegetation map (Austin, M., consultant, pers. comm., July 1997).

The Eastern Bushlands database is a broad-scale map derived from Landsat satellite imagery. The broad scale of this mapping type made it an undesirable feature to be used.

All the above maps were checked against each other using the WIN-ERMS GIS (NSW NPWS, 1995). The different mapping types were overlaid and a report run on all the categories of each to produce a matrix of the hectares of each category from each map against that of the other maps. In doing this, it was hoped that direct correlations could be found between the mapped vegetation types of the different maps, so the derived habitat indices could be easily assigned to the other vegetation maps outside the KBS coverage. However, numerous inconsistencies were found between the matching of all four mapping types against each other, which was not surprising considering the differences in the scale, methods and classifications of each mapping type. Therefore, the KBS vegetation mapping was used where available, for deriving the habitat indices, and the CSIRO 20 class layer used where the KBS was lacking. CSIRO staff derived habitat indice values for the 20 CSIRO vegetation classes to be used in those areas.

Actual/potential tree hollow indices

The actual tree hollow index reflects the characteristic amount of hollows found in a

particular vegetation type. Values were assigned to individual trees species using information from Braithwaite *et al.* (1984) and L. W. Braithwaite (consultant, pers. comm., June 1997) and then assigned to the KBS vegetation types.

The potential tree hollow index is the characteristic amount of rot found in the boles or limbs of trees. Hollows eventuate only if the animals are present to carve the rot out. Forest types with high potential hollows can have low actual hollows if the foliage polyphenol levels are high. It has been found (Braithwaite L. W., consultant, pers. comm., June 1997) that forest types with high polyphenol levels support lower densities of arboreal mammals. Consequently hollows are not bored out but can be considered potential hollows.

Nectar index

The nectar index is compiled from tree scores derived from apiarists' perceptions of relative values for nectar production (from Cocks and Dennis, 1978; Clemson, 1985; and Braithwaite L.W., consultant, pers. comm., June 1997).

Decorticating bark index

The decorticating bark index is an indication of the propensity of bark for peeling. Information used for these derivations was from Braithwaite (1991) and Braithwaite *et al.* (1989).

Foliage nutrient index

The foliage nutrient index is derived from foliage nitrogen values collated from largely unpublished work conducted by State Forests New South Wales and CSIRO Division of Wildlife and Ecology, Canberra (S. Cork and L.W. Braithwaite). Some of the information is contained in Braithwaite (1996) and Braithwaite *et al.* (1983).

Ground cover index

The ground cover index was derived at the small workshop of CSIRO consultants using the raw plot data from the KBS vegetation map (Keith *et al,.* 1995). The index is a scale of one to four and is calculated from the median height of the tallest ground layer (<=1.0 metre) of each vegetation type (grouped into <= 0.3m or >= 0.3m) and the median percent ground cover for each type (grouped into <30%, 31-69%, or >70%) (table 2e).

TABLE 2E: CALCULATION OF GROUND COVER INDEX

Height	Ground cover		
	<30%	31 - 69%	>70%
<=0.3m	1	2	3
>=0.3m	2	3	4

Shrub index

The shrub index was also derived at the small workshop using the raw KBS plot data. It is a scale from one to five, calculated from the median number of shrub layers (> 1.0 metre) for each vegetation type (grouped into 1.0-1.4, 1.4-1.8, or 1.8-2.2) and the median percent shrub cover for each type (grouped into <30%, 31-69%, or >70%) (table 2f).

TABLE 2F: CALCULATION OF SHRUB INDEX

No. Layers	Shrub cover		
	<30%	31 - 69%	>70%
1.0-1.4	1	2	3
1.4-1.8	2	3	4
1.8-2.2	3	4	5

Old growth indices

There were two schools of thought amongst experts about deriving old growth indices, therefore two indices were used.

The first old growth index was designed to take into account habitat value (primarily hollow abundance) for fauna species. A simple numerical ranking of the old growth growth stage codes from the IAP (NSW NPWS, 1996) in terms of increasing fauna value was defined. The ranking of these codes is contained in table 2g.

The second old growth index is almost identical to the first except that the sA and tB values have been swapped. Values for this second index are also shown in table 2g.

Although a number of inaccuracies have been identified in the IAP growth stage map layer (see Eden CRA API Mapping project report) no other layer was available to use as an alternative at the time. This will be rectified once the Eden layers are complete and the fauna models will be refined in subsequent CRA projects.

TABLE 2G: OLD GROWTH INDICES GROWTH STAGE RANKINGS

Old growth growth stage code[1]	Old growth index no. 1	Old growth index no. 2
tA	9	9
tB	8	7
sA	7	8
sB	6	6
tC	5	5
sC	4	4
eA	3	3
eB	2	2
eC	1	1
e	1	1
O	0	0
R	0	0
L	0	0

[1] Growth stage codes are from the IAP (NSW NPWS, 1996)

Contextual landscape variables

Contextual landscape variables were used as measures of spatial context surrounding each individual 100 metre grid cell by providing an indication of the environment within a specified radius, for example the percentage of old growth within a one kilometre radius. The usefulness of these variables for many species, particularly those with large home ranges (e.g. owls) has been noted by Ferrier (1991) and also during the NEFBS (NSW NPWS, 1994a).

The derivation of these variables was performed using a focal statistic procedure in ARCVIEW Spatial Analyst. The expression used was:

([agrid]). focalstats (#GRID_STATYPE_SUM, Nbrhood.MakeCircle(X,true),false),

where X = the radius in metres of the analysis.

The output values from this analysis were a count of the number of grid cells returning a positive value. This figure was converted to a percentage occurrence of positive values.

The following variables were produced in this manner:

■ percent clearing within one kilometre;

■ percent clearing within two kilometres;

■ percent old growth within one kilometre;

■ percent old growth within two kilometres;

■ percent high quality old growth within one kilometre;

■ percent high quality old growth within two kilometres;

■ percent rainforest within one kilometre;

■ percent rainforest within two kilometres.

Percent clearing within one and two kilometres

The percent clearing within one and two kilometre variables were derived from cleared land as mapped by the Eastern Bushlands Database (NSW NPWS, in prep.).

Percent old growth within one and two kilometres

The growth staging and site quality data from the IAP (NSW NPWS, 1996) were combined to identify likely old growth, as different growth stages constitute old growth on differing site qualities. Table 2h, taken from the IAP report (NSW NPWS, 1996) formed the basis for this classification. All of the categories in table 2h were merged to produce a layer called 'likely old growth'.

TABLE 2H: OLD GROWTH FOREST CLASSIFICATION (FROM NSW NPWS, 1996)

	Environmental Site Quality			
	High and Moderate (typical)	High and Moderate (atypical)	Low	Very Low
Likely old growth forest	sA, tA, tB	sA, tA, tB, tC	sA, tA, tB, tC, tU	uA, uB, uC, uU, sA, tA, tB, tC, tU

For details of codes, see NSW NPWS (1996). All site qualities classifications with 'y' (y = disturbed) were included if the area was logged greater than 30 years ago.

Percent high quality old growth within one or two kilometres

The percent high quality old growth variable was requested by a stakeholder due to concerns regarding the reliability of the IAP site quality layer and the possibility of areas being mis-identified as old growth. Consequently the classification of old growth was restricted to

growth staging categories sA, tA and tB for all environmental site qualities. These categories were merged to produce a 'high quality old growth' layer.

Percent rainforest within one and two kilometres

The rainforest layer used for calculation of these variables was a combination of the KBS remnant vegetation map (Keith *et al.,* 1996) and the rainforest category from the IAP growth stage mapping (NSW NPWS, 1996). Most areas of rainforest were found to be confined to narrow riparian strips.

2.6.2   Abiotic variables

The majority of the 'base' abiotic variables were developed by NSW NPWS GIS staff. Either site variables or contextual variables were used depending on the nature of the feature under consideration. The following variables were developed, and all except the DEM were used as predictors in the species modelling:

■ digital elevation model (DEM);

■ mean annual rainfall;

■ mean annual temperature;

■ ruggedness 1 kilometre;

■ ruggedness 500 metres;

■ solar radiation index;

■ terrain position;

■ topographic position 1 kilometre;

■ topographic position 500 metres; and

■ wetness index.

Digital elevation model (DEM)

The digital elevation model is a 25 metre grid cell coverage with values representing metres above sea level. This layer was supplied by the Land Information Centre (LIC) of the Department of Land and Water Conservation (NSW).

Mean annual rainfall and mean annual temperature

These variables were derived using the ESOCLIM component of ANUCLIM, a predictive software package composed of six Fortran programs provided to NSW NPWS by the Centre for

Research and Environmental Studies (CRES) at the Australian National University, Canberra. Using rainfall and temperature weather station data provided by the Bureau of Meteorology, Sydney, CRES derived rainfall and temperature surfaces to be used with the ESOCLIM software.

The climatic surfaces and the DEM were entered into ESOCLIM which output a series of monthly mean estimates of temperature and rainfall. The rainfall estimates were supplemented by updated rainfall surface data, processed through ESOCLIM by the Bureau of Resource Sciences and provided to NSW NPWS. The mean monthly temperature grids and updated rainfall grids were then combined using ARC/INFO GIS to produce mean annual rainfall and mean annual temperature coverages for the Eden study area.

Ruggedness one kilometre and 500 metres

The ruggedness index (NSW NPWS, 1994a, 1994b) assigned to a cell is the value returned from calculating the standard deviation of elevation values within a window of given dimension centred on the cell, i.e:

$$R = STD\{e_1 + e_2 + e_3 + \ldots e_n\}$$

where R is the ruggedness index, STD is the standard deviation and $e_1, e_2, e_3 \ldots e_n$ are the elevations of the cells in the window. It follows that the greater the ruggedness of the terrain the more spread out the elevation values will be and therefore the greater the standard deviation.

A rugged terrain therefore can be an area of significant rises and falls in elevation, or a single hillside or part thereof (figure 2a). Areas that receive low ruggedness values tend to be flat or undulating.

The ruggedness index has been calculated using the ARC/INFO GRID module as follows:

grid: rough_grd = INT(FOCALSTD(dem_grd, rectangle, 10, 10, DATA))

where rough_grd is the roughness grid, FOCALSTD is the GRID function for calculating the standard deviation for the input grid dem_grd using a moving rectangle shaped window of dimensions 10 cells by 10 cells. (The 'INT' function converts the output to integer values; 'DATA' directs the function to ignore NODATA values).

The example above can be easily modified by changing the size of the window from 10 x 10 cells to other sizes.

FIGURE 2A: RUGGED TERRAIN

A. Multiple Hillsides

B. Single Hillside
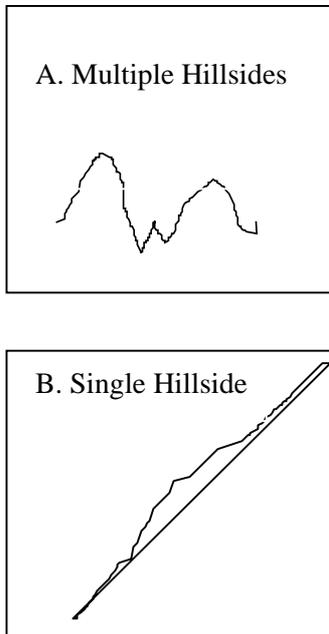
Solar radiation index

The solar radiation index (Nunez, 1980) is produced by modelling the passage of the sun over the digital elevation model (DEM) and calculating the amount of solar radiation that falls on each grid cell by allowing for shade and shadow due to terrain as well as scattering by the atmosphere. See figure 2b for a simple description of the process.

The major components of the method are:

■ the DEM - which provides a grid-based model of the terrain;

■ sample times - which are the times at which the solar radiation will be sampled. In this case the program was run seven times per day (at two hourly intervals between 7am and 7pm) for one day each month of the year;

■ solar azimuth - the angle between the sun and north;

■ solar altitude - the angle between the sun and the horizon;

■ flat solar radiation - a measure of how much solar radiation reaches the earth's surface without the influence of terrain;

■ hillshade - the process by which the effects of terrain, shade and shadow are calculated for the area;

■ diffuse solar radiation - an estimation of the amount of solar radiation that reaches a cell indirectly due to scattering;

■ ESOCLIM flat surface radiation - a climatic surface which provides a measure of flat surface radiation based on time of year and average atmospheric conditions.

The process has been implemented using a combination of MS EXCEL and ARCVIEW Spatial Analysis using the Avenue programming language. The list of sample times is inserted into the EXCEL spreadsheet from which the solar altitude and solar azimuth are calculated automatically. These outputs are transferred to a text file which the Avenue code reads as inputs for the calculation of hillshade. The hillshade function is then applied. In parallel the process is applied to a flat shade-free cell. Using the value obtained from the hillshaded flat cell the results from the hillshaded terrain are transformed into appropriate units and a value for diffuse radiation (Nunez, 1980) is added (equation 1). The process is repeated and summed over the sample day (representing a month). The monthly values are then transformed into correction factors by dividing them by the monthly values for a flat shadow-free cell . The correction factors are then applied to the ESOCLIM values for flat solar radiation to derive the final values for solar radiation (equation 2).

EQUATION 1

$$S_C = S_H \left(F_N \middle/ F_H \right) + S_D$$

EQUATION 2

$$S_R = S_C \cdot F_E$$

where S_C is the correction factor for a given month, S_H is the value for one month calculated using hillshade, F_N is the calculated value for flat surface radiation for that month (Nunez, 1980), F_H is the value for flat surface radiation calculated using hillshade, S_D is the value for diffuse solar radiation (Nunez, 1980), F_E is the ESOCLIM monthly value for flat surface radiation, and S_R is the final value for monthly solar radiation.

FIGURE 2B: SIMPLIFIED PROCESS FOR THE DERIVATION OF THE SOLAR RADIATION INDEX
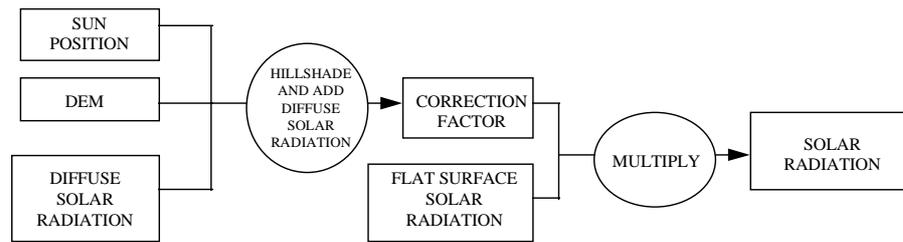
Terrain position

Terrain position, as described in detail in Skidmore (1990), is a measure of the position of each grid cell on a continuum between ridge (value = 1) and gully (value = 0). In broad terms the algorithm has three stages. The first two, the identification of ridges and gullies, is purely an analysis of the elevation of each cell in relation to its immediate neighbours. The third step involves an interpolation of midslope positions using Euclidean distance between each cell and their closest ridge and gully (figure 2c).

FIGURE 2C: FLOW CHART ILLUSTRATING THE PROCESS FOR THE DERIVATION OF TERRAIN POSITION
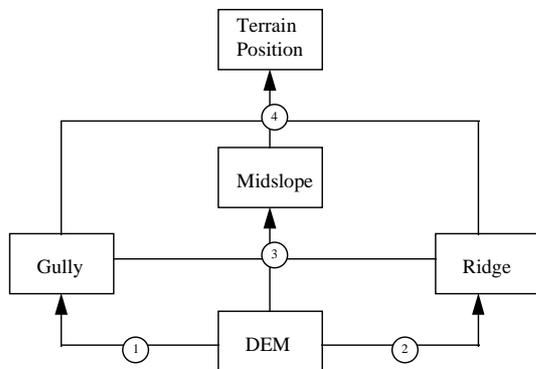
The first step is to tag gullies. A cell is defined as a gully if left and right neighbours in one direction are higher in elevation than the cell while with the two orthogonal neighbours one is higher and one is lower. Gully cells are allocated a value of '0'.

The second step is to tag ridges. A cell is defined as a ridge if the left and right neighbours in one direction are lower while with the two orthogonal neighbours one is higher and one in lower. Ridge cells are allocated a value of '1'. Peaks are also treated as ridges.

Steps one and two are repeated for all north-south, east-west, northeast-southwest, and northwest-southeast directions. If adjacent cells are equal in elevation to the test cell then the algorithm searches outwards until a cell of different elevation is found.

The third step is the identification of midslopes. After steps one and two, the remaining cells are defined as midslope cells. The Euclidean distance function in Arc/Grid is used to find the distance between each midslope cell and its nearest ridge cell and nearest gully cell. The ratio between the distance to gully (Dg) and the sum of the distance to gully (Dg) and the distance to ridge (Dr) returns the value for midslope i.e.

$$M = \frac{D_g}{D_g + D_R}$$

The algorithm was implemented as an AML program within the ARC/INFO Grid module.

Topographic position one kilometre and 500 metres

The topographic position of a cell (NSW NPWS, 1994a, 1994b) is a measure of the elevation of a cell in relation to the mean elevation value for a window of given dimension centred on the cell i.e.

$$T = e - \bar{e}$$

where 'T' is the topographic position, 'e' is the elevation at any point and $\bar{e}$ is the mean elevation for the window.

Values can range from positive indicating a cell with above average elevation for the window, to negative indicating a cell with below average elevation for the window. Unlike the Skidmore (1990) method the values are not confined to any range. The method therefore provides a measure of the degree to which the cell's elevation conforms or deviates from its neighbours.

FIGURE 2D: SIMPLIFIED FLOW CHART OF THE PROCESS FOR CALCULATING THE WETNESS INDEX
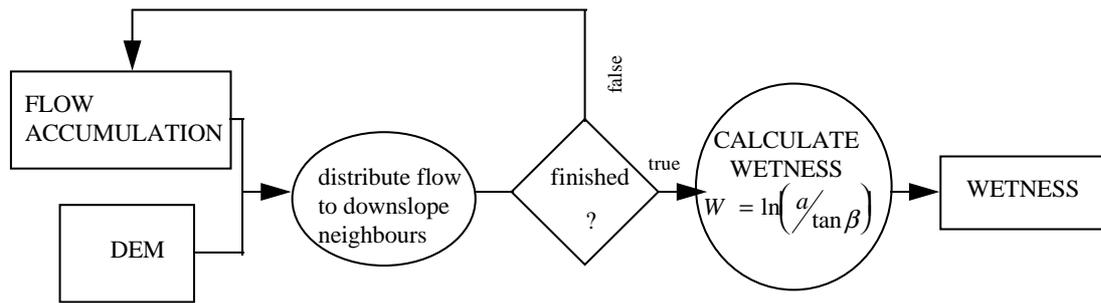
This method has no direct link to the geometry of the DEM as the Skidmore (1990) method has. It does not therefore derive ridges and gullies as such although local high positive values are indicative of ridges and local high negative values of gullies. This method has the advantage of allowing variable resolution by varying the size of the analysis window around each cell.

Since there is likely to be a need for a variety of outputs based on varying window sizes, a prompt for the selection of a window size is provided. Windows of 1000, 500 and 250 metres are likely to be useful.

The algorithm was applied within ARCVIEW Spatial Analyst using the Avenue programming language.

Wetness index

The wetness index produces an indication of the volume of water draining to each part of the landscape as well as the landscape's ability to retain water due to slope. The process (figure 2d) employs a depressionless digital elevation model (DEM) to derive the flow from each cell to its downslope neighbours based on relative slopes. Multiple iterations allow the flow over the landscape to be simulated and a cumulative value of flow through each cell to be calculated i.e. flow accumulation. With this it is possible to derive the wetness index (Moore *et al.,* 1993) for all cells in the grid as follows:

$$W = \ln(a)/\tan ß$$

where W is the wetness index , *a* is the flow accumulation and tan ß is the slope gradient.

There are two alternative algorithms for the derivation of *a*:

■ Single flow direction (SFD), which is based on the methods reported by Jenson and Domingue (1988). With this approach all flow from a cell is allocated to the downslope cell with the greatest drop in elevation. This approach is relatively quick and suits the modelling of stream flow. It also contains a useful method for determining a flow direction in flat areas by progressively searching outwards until a cell of lower elevation is found;

■ Multiple flow direction (MFD) (Wolock and McCabe, 1995) where flow is allocated to all downslope cells in proportion to their relative slopes. This process is computationally intensive but greatly increases the quality of the outputs on overland areas. Within well defined channels however, the advantages of MFD over SFD do warrant the extra computational effort required.

In the approach used here, the two approaches have been combined in order to adequately model overland flow with the MFD algorithm and to optimise the efficiency of the program by modelling stream flow with the SFD algorithm.

The SFD method is also adopted in flat areas i.e. a flat cell is one where the elevation of all surrounding cells equals the elevation of the cell.[†]

The index was calculated using an AML program within the ARC/INFO Grid module.

[†] The extent of flatness in the DEM is dependent on the quality of the DEM as well as any generalising of the DEM, e.g. converting float to integer. Flat areas of small size can occur anywhere in the DEM especially along drainage lines. Larger areas often occur near the coast. Large dams and inland waters are identified as flat.

Fertility Index

The fertility index was calculated by CSIRO Division of Wildlife and Ecology, Canberra, using mapped geology and existing geochemical and fertility data (CSIRO, 1997).

2.7 DERIVATION OF SPECIES MODELS

2.7.1 Introduction to modelling methodology

The fundamental aim of the modelling process was to spatially interpolate known occurrences of fauna species from field surveys throughout the study area by finding statistical relationships between the biota and the environmental variables outlined in section 2.6. A module developed by Watson (1996) running under the S-PLUS statistical software (StatSci, 1995) was used with ARCVIEW Spatial Analyst (ESRI, 1996) to conduct the modelling. The values of the environmental variables at each survey site were determined and related to recorded presences and absences (pseudo-absences for presence-only modelling). This relationship was then statistically analysed to produce a model predicting likelihood of occurrence across the Eden Study area for each species. Figure 2f shows the general analysis and modelling pathway used, which is explained in the following pages.

The predictive species modelling package provides the user with a choice between the two most commonly used logistic regression procedures, generalised linear modelling (referred to as GLM) and generalised additive modelling (referred to as GAM) (Watson, 1996). GLM is essentially an extension of ordinary linear regression, a technique which fits linear (straight line) functions relating a response (dependent) variable to one or more predictor (independent) variables. Two of the basic assumptions of linear regression are that the relationship between response and predictor variables can be approximated by a straight line and that the variance associated with the response is homogenous throughout the full range of the response variables. GLMs overcome these assumptions by allowing a class of models that provide non-linearity and heterogeneous variance in response functions (NSW NPWS, 1994a).

GAMs are essentially an extension of GLMs, the major difference being that GAMs use a non-parametric smooth function relating the response to the predictor. The functions are smooth curves estimated from the data using techniques originally developed for smoothing scatterplots. The GAMs derived by this software use cubic splines to fit smooth functions. Hence the principal difference between the two modelling techniques is that GAMs allow the survey data to determine the shape of the response curves, whereas GLMs are constrained by parametric forms, that is, cubic and quadratic polynomial response curves (NSW NPWS, 1994a; Watson, 1996). An example of these differences is shown in figure 2e.

The outputs from both modelling techniques are in two forms:

■ A digital map across the Eden Study area with values indicating the probability of occurrence of the modelled species (in the case of presence-only modelling this is a relative likelihood scale - see below).

FIGURE 2E: COMPARISON OF GAM (A) AND GLM (B) MODELLING OUTPUTS

Exactly the same data was used for both a & b. Note the constraint in the GLM output to a polynomial curve as opposed to the data-fitted GAM curve.
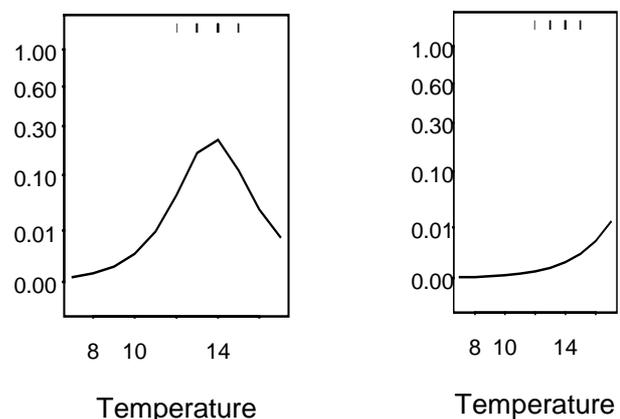
(a) GAM   (b) GLM

FIGURE 2F: GENERAL ANALYSIS AND MODELLING PATHWAY USED IN THE EDEN FAUNA MODELLING
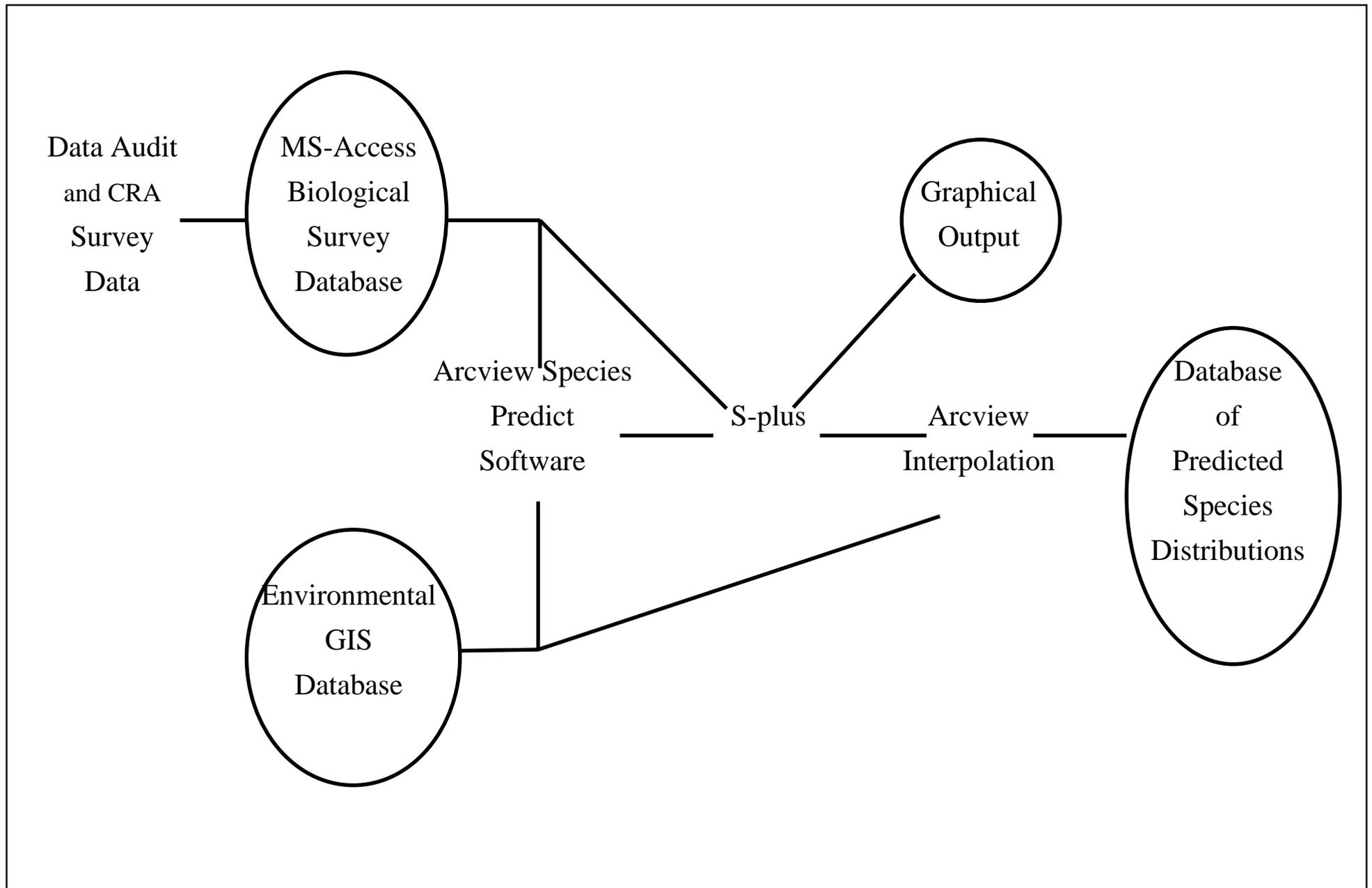
■ A postscript file containing information about the model, for example; deviance, model type and degrees of freedom, as well as a graphical plot of each variable found to be significant in indicating the probability of occurrence of the species for the range of values of the variable.

A detailed discussion of the theory and mathematical detail of these modelling techniques is beyond the scope of this report. Further details are contained in Yee and Mitchell (1991) (detailed theoretical account of GAMs) and Hastie and Tibshirani (1990) or Hastie (1992) (further mathematical detail). Watson (1996) details the modelling software used for this study. Further explanation of the model outputs are contained in section 3.2.1.

Within each of the GLM and GAM modelling processes, two types of modelling could be performed:

■ presence/absence modelling, which utilises systematic survey data and produces models based on recorded presences of a species in relation to recorded absences. Unlike presence-only models these models produce upper and lower standard error maps and the graphical outputs contain three additional diagnostic plots portraying model discrimination, calibration and refinement (Murphy and Winkler, 1992) (see section 3.2.1 for explanations of these);

■ presence-only modelling which uses both systematic and opportunistic sightings but does not use positive absence data. Presence-only data were modelled in relation to 1000 'pseudo-absences' which were randomly chosen from all forested land within the study area. Pseudo-absence points were given a weighting of n/1000 where n = the number of presence records for each species. This manner of weighting facilitated approximation of degrees of freedom, deviances and significance levels appropriate to presence-only modelling. The weightings also enabled predictions to be expressed in terms of an index of relative likelihood of occurrence ranging from 0 to 1 (later converted to a percentage). Unlike presence/absence modelling this is only a relative index and not an estimation of the probability of occurrence. Confidence limits could not be applied to these models due to the weightings and approximations involved (NSW NPWS, 1994a).

2.7.2 Species groups and variables

The statistical modelling software required that individual species be placed together in functional groups. The functional groups for Eden modelling were: bats; reptiles/amphibians; ground mammals; arboreal mammals / nocturnal birds; passerine diurnal birds; and non-passerine diurnal birds.

Each functional group was run through the modelling as a batch with the user able to specify which species were to be modelled and which environmental variables were to be used. Four basic runs were completed for each functional group: presence/absence GLM and GAM, and presence-only GLM and GAM.

Most of the variables outlined in section 2.6 were used initially for every functional group, but due to time and monetary constraints, further refinement of many models was not possible, although this was originally intended. However for those species where all four models were deemed inadequate during the first round of expert model evaluation, attempts were made to improve models by removing certain environmental variables, or incorporating new data where available.

Concern was expressed over the initial use of all habitat indices for every functional group. On occasion, a variable was identified by a model as being significant to a species but it had no true known ecological basis for that relationship. For example the decorticating bark index was found to be significant for the White-footed Dunnart. However, it was felt that these variables could remain if the predicted distributions for the species were consistent with where experts felt the species should be occurring. As the habitat indices were essentially a numerical grouping of vegetation types, any correlations found with these indices were really correlations with vegetation types. Furthermore, the index selected may be acting as a surrogate for another variable(s).

Certain additional variables were deemed to be inappropriate to the modelling process. These included latitude, longitude and elevation as they are essentially surrogates for rainfall and temperature within the Eden study area (Ferrier, S., NSW NPWS, pers. comm., July 1997).

The two clearing contextual variables (one and two kilometres) were also excluded, after their occurrence in early runs indicated that the only effect they were having was to strongly predict the occurrence of species across all forested lands.

2.7.3 Initiation of a run

The first and most important file required for the running of a batch was the 'sites' file. This file contained all the sites for the functional group and the covariate values for each site (a site was defined as any unique location, date and methodology). Linked to this file were a number of 'species' files (one for each species) which contained all the presence sites for each species. All other sites within the 'sites' file were treated as absences for that species. These files were extracted from the MS ACCESS database but some processing was then performed on the 'species' files in MS EXCEL.

The sites file was imported into ARCVIEW Spatial Analyst where it was intersected with all the environmental variables. This step produced as an output a file called 'envars', the environmental variables file, which contained the value of each variable at each site. Other files coming out of ARCVIEW included 'varfiles' which contained the range of each variable across the study area, and 'outlines', an ASCII file of the coordinates of the study area. The final file was a 'pseudo-absences' file which contained 1000 random points across the study area and was required for presence-only modelling. Cleared land was removed at this point to prevent pseudo-absence points occurring on cleared land, as this would have led to certain biases due to survey efforts being concentrated on forested land.

The above files combined with 'sitfiles', a file identifying the covariates being used, and a species index file 'spcseen', were imported into S-PLUS for analysis.

The first task within S-PLUS was to establish the 'variable classes' data frame. This comprised a matrix with 100 rows and a column for each variable, with the values in each cell determined by the data ranges file ('varfiles'). The next major task was to test for collinearity between variables. The procedure employed for this task tests for collinearity in three ways: between continuous variables; between continuous and categorical variables; and between categorical variables (Watson, 1996). Once it has decided which variables are collinear, the variables are placed into groups such that:

- a group of collinear variables can contain more than just a pair of variables but if it does, then all the variables within the group must be correlated;

- a variable may have membership of more than one group; and

- any single variable that is not correlated with any other variable is put into a group of its own (Watson, 1996).

Once the variables have been grouped the software moves to the stepwise variable selection procedure. The initial test involves the evaluation of all univariate models. Any variable which does not significantly ($p < 0.15$) reduce the null deviance is discarded permanently. Any variable which reduces the significance less than a variable with which it has found to be correlated with, is permanently discarded. If no univariate models significantly ($p < 0.15$) improve the null fit, then a null model results. Species with fewer than 10 positive observations also result in a null model. After this stage, the forward-backward stepwise selection procedure begins with a pool of non-correlated variables each represented by one term expression. The starting model is the univariate model which achieved the most significant reduction in null deviance (Watson, 1996).

Each of the other variables is added to the starting model. The bivariate model which affords the most significant ($p < 0.15$) reduction in deviance becomes the new interim model. A similar process produces the best trivariate model whereupon backwards stepwise selection is invoked to determine whether a bivariate model comprised of the most recently added variable, and either of the two already included, significantly ($p < 0.20$) reduces the deviance of the trivariate model. If so, the bivariate model becomes the new interim model, otherwise the trivariate model enters a new cycle where a fourth variable is tested for inclusion on the same basis as the previous cycles. After each addition, backward selection is performed to explore whether it is possible to revert to a simpler model. When six variables are chosen or when no variable significantly reduces the deviance of the interim model, further selection ceases (Watson, 1996).

2.8 INTERPOLATION OF SPECIES MODELS

Once the model for a species has been created, the predicted occurrence of that species across the study area is derived. The values in the variable classes dataframe (see above) are assigned prediction values (on the logit scale) (Watson, 1996). These values are imported into ARCVIEW Spatial Analyst and used to spatially interpolate a map of predicted species distribution. At this point the values are converted from a probability scale of 0 - 1 into a percentage value (for data storage and manipulation purposes). The output for presence-absence modelling comprises three maps; a predicted, and upper and lower confidence limit maps with values ranging from 0 - 100. For presence-only modelling a single map is produce with values from 0 - 100 indicating a *relative* likelihood of occurrence across the study area.

The other output from S-PLUS is a postscript file which contains graphs of the functions fitted to each variable used plotting the probability of occurrence across the range of values for that variable. The order in which the variables are displayed is indicative of the level of significance of each variable, that is, the most significant variable is displayed first. In the case of presence/absence modelling three additional graphs relating to model discrimination, calibration and refinement (see section 3.2.1 for explanations) are also produced.

2.9 MODEL EVALUATION

Contracted and in-house scientific and modelling experts evaluated the models of the priority species, selecting the best model and map for each and suggesting necessary changes to the modelling process. Some stakeholders of the CRA process also had the opportunity at this stage to review and comment on the models. Some models were subsequently re-run but time restrictions prohibited this being done for many species.

The probability classes for each species' modelled distribution were grouped by the experts to reflect areas considered to be core, intermediate and marginal habitat, however some of these classifications were then revised in the Response to Disturbance workshops.

As there was no time to run any statistical cross-validation (e.g. jackknifing) or conduct field validation, acceptance of the models was based on the experts' evaluation. Hence, a number of models were rejected in the Response to Disturbance workshops and alternative means of assessment recommended (see report for that project).

3. RESULTS

3.1 SPECIES DATA

After data validation, the total number of sites for which there were data available for modelling was 13 182 (2 639 with presence/absence data and 10543 with incidental data). The totals of these for each functional group are shown in table 3a. Figures 3a to 3e show the distribution of all presence/absence and incidental sites for each functional group.

TABLE 3A: TOTAL NUMBER OF SURVEY SITES USED IN THE EDEN FAUNA MODELLING

Functional Group	Number of presence/ absence sites[1]	Number of presence only sites	Total number of sites
Arboreal mammals / nocturnal birds	1 092	3 190	4 282
Bats	391	212	603
Diurnal birds	485	2 748	3 233
Ground mammals	238	3 519	3 757
Reptiles and amphibians	433	874	1 307
Total	2 639	10 543	13 182

[1] At each presence/absence site there are multiple species records.

The total number of species with records after the validation process was 493. However, as the model program only uses species with >= 10 records, the total number of species with records suitable for modelling was 295 (44 495 records in total). These species and the number of records that were available for presence/absence and presence-only modelling are listed in appendix 3.1.

3.2 SPECIES MODELS

Table 3b shows the number of presence/absence and total prerecords for each priority species and the best model selected by the experts for each. (All records for a species were used in the presence-only modelling). Some of the selected models were later revised or rejected in the Response to Disturbance (RtD) workshops, due to the low numbers of records or poor quality data, and are indicated as such in the table. The annotations in this table show the following:

- species which had too few records to be modelled (i.e less than 10 records, or if more, some were rejected by the model as located outside the modelling domain (e.g. cleared land));

- species which were subsequently removed from the priority list by the RtD workshop;

- the number of records contributing to the favoured model for each species;

- records that were modelled but produced an inadequate model, according to the experts;

- records that produced a suitable model that was later rejected or revised by the RtD workshop.

The Response to Disturbance workshops involved a larger number of experts than was used in the original model evaluation, therefore some previous decisions regarding acceptable models were revised.

The decisions made in the workshops regarding changes to models and proposed new models based on vegetation and species point locations are documented in the separate Eden Conservation Requirements report. The composition of the core, intermediate and marginal habitats for each species are also contained in that report, as they were also modified in the workshops.

Figure 3a

Figure 3b

Figure 3c

Figure 3d

Figure 3e

TABLE 3B: SELECTED MODELS AND NUMBER OF RECORDS FOR PRIORITY SPECIES

Scientific name[1]	Common name[1]	Functional group[2]	Total no. records / presence-only modelling[3, 4]	Presence/ absence records[4]	Best model selected[5]
Petauroides volans	Greater Glider	AM/NB	*993*	**154**	PA GAM
Petaurus australis	Yellow-bellied Glider	AM/NB	*956*	**389**	PA GAM
Ninox strenua	Powerful Owl	AM/NB	*638*	**262**	PA GLM
Tyto tenebricosa	Sooty Owl	AM/NB	*394*	**166**	PA GAM
Phascolarctos cinereus	Koala	AM/NB	*390*	*13*	nsm
Tyto novaehollandiae	Masked Owl	AM/NB	*151*	**52**	PA GAM
Ninox connivens	Barking Owl	AM/NB	*24*	8	nsm
*Petaurus norfolcensis**	Squirrel Glider*	AM/NB	*11*	0	(P GLM)
*Phascogale tapoatafa**	Brush-tailed Phascogale*	AM/NB	*2*	0	-
Sminthopsis leucopus	White-footed Dunnart	GM	**104**	*71*	(P GLM) / P GAM
Perameles nasuta	Long-nosed Bandicoot	GM	**138**	4	P GAM
Potorous tridactylus	Long-nosed Potoroo	GM	**68**	1	P GAM
Pseudomys fumeus	Smoky Mouse	GM	*58*	0	(P GAM)
Dasyurus maculatus	Tiger Quoll	GM	*52*	0	(P GLM)
Potorous longipes	Long-footed Potoroo	GM	*31*	0	(P GAM)
Isoodon obesulus	Southern Brown Bandicoot	GM	*22*	0	P GLM
Miniopterus schreibersii	Common Bent-wing Bat	B	*82*	50	(P GLM)
Falsistrellus tasmaniensis	Great Pipistrelle	B	*66*	51	nsm
Pteropus poliocephalus	Grey-headed Flying-fox	B	*60*	0	(P GAM)
Rhinolophus megaphyllus	Eastern Horseshoe-bat	B	*57*	41	(P GAM)
Scoteanax rueppellii	Greater Broad-nosed Bat	B	*39*	29	(P GLM)
Myotis adversus	Large-footed Mouse-eared Bat	B	*14*	6	nsm
Kerivoula papuensis	Golden-tipped Bat	B	*12*	3	nsm
Mormopterus norfolkensis	Eastern Little Mastiff-bat	B	6	2	-
Pteropus scapulatus	Little Red Flying-fox	B	*4*	0	-
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	B	*1*	0	-
Miniopterus australis	Little Bent-wing Bat	B	0	0	-
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo	DB	**490**	*67*	P GLM
Calyptorhynchus lathami	Glossy Black-Cockatoo	DB	**366**	*18*	P GLM
Falcunculus frontatus	Crested Shrike-tit	DB	*137*	*39*	(P GAM)
Climacteris erythrops	Red-browed Treecreeper	DB	*99*	*63*	(P GAM)
Daphoenositta chrysoptera	Varied Sittella	DB	**72**	*26*	(PA GLM) / P GAM
Pachycephala olivacea	Olive Whistler	DB	**54**	*15*	P GLM
Lophoictinia isura	Square-tailed Kite	DB	*19*	2	(P GLM)
Petroica rodinogaster	Pink Robin	DB	*13*	1	nsm
Neophema pulchella	Turquoise Parrot	DB	**10**	0	-
Botaurus poiciloptilus	Australasian Bittern	DB	**7**	0	-
Xanthomyza phrygia	Regent Honeyeater	DB	**7**	0	-
Lathamus discolor	Swift Parrot	DB	**6**	0	-
Chalcophaps indica	Emerald Dove	DB	**5**	0	-
Burhinus grallarius	Bush Stone-curlew	DB	**2**	1	-
*Varanus varius**	Lace Monitor*	R/A	*168*	*38*	nsm
Acanthophis antarcticus	Common Death Adder	R/A	**133**	2	P GAM
Heleioporus australiacus	Giant Burrowing Frog	R/A	**21**	8	P GLM
Morelia spilota spilota	Diamond Python	R/A	*17*	2	(P GAM)
Mixophyes balbus	Stuttering Barred Frog	R/A	**15**	5	P GAM
Litoria booroolongensis	Booroolong Frog	R/A	4	3	-
Pygopus lepidopodus	Common Scaly-foot	R/A	*4*	0	-
Litoria littlejohni	Heath Frog	R/A	*1*	0	-

[1] * = species later rejected as priority species by RtD workshop.

[2] AM/NB = Arboreal Mammals/Nocturnal Birds; B = Bats; DB = Diurnal Birds; GM = Ground Mammals; R/A = Reptiles/ Amphibians.

[3] Presence-only modelling was conducted using all records.

[4] *Italics* = modelled but model unsuitable or not selected as the best; **bold** = favoured model; shading = less than or equal to ten records and therefore no model produced.

[5] ( ) = model produced and validated but later rejected by RtD workshop; PA = presence/absence; P = presence-only; GAM = generalised additive model; GLM = generalised linear model; nsm = no suitable model.

The model results, statistics and predictive maps for each of the 16 priority species where S-PLUS models were accepted by the Response to Disturbance workshops are shown in figures 3g to 3v. A guide to interpreting the results is provided below. The maps show the probability of occurrence classes from 1 - 100% and the location of *all* presences for each species. Note that not all presences shown were used in deriving the model, as they include all presence/absence and presence-only records and non-seasonal data. Additionally, the maps shown here only cover the Eden area and not the extra area to the north which was also used for modelling (see figures 3a-e), thus not all records used in the modelling are shown, as some were further to the north.

3.2.1 Guide to interpreting species models

There are two outputs from the modelling process. The first is a map of the study area with values corresponding to a probability of occurrence expressed as a percent (relative probability for presence-only). The second is a postscript file with data relating to the chosen model. There are two components to the postscript file: the table at the top left; and a graphical display of the variables used in the model, and in the case of presence/absence modelling three additional graphs describing the performance of the model.

The table

The table provides a statistical summary of the model. The species common and scientific names are displayed, followed by the number of presence sites for that species and the total sites for the functional group.

The null, residual and explained deviance of the model follows. Deviance is a measure of the closeness of the fit of a model to the data used to derive that model. It measures the deviation between the site data (presence or absence of a species) and the probability of presence as predicted by the model (NSW NPWS, 1994a). Null deviance is a measure of the deviance of the null model before any environmental variables are used as predictors. In this way a measure of the inherent variation or noise in the data is provided.

Residual deviance is the amount of deviance remaining after a model has been fitted (NSW NPWS, 1994a). Deviance explained is the percentage of the null deviance explained by the

model. Deviance explained is calculated using the following equation:

$$\frac{100 \times (\text{null deviance - residual deviance})}{\text{null deviance}}$$

A perfectly fitted model would explain 100% of the deviance. Actual values are usually much lower and in the current case were consistently below 50%. This indicates that much of the variation within the data could not be accounted for by the model which could be due to a variety of reasons including: sampling error resulting from incorrect identification of the species; errors in the biological or environmental data; the influence of unmeasured variables such as microhabitat; imperfect sampling techniques; or the presence of spatial autocorrelation in the distribution of species (NSW NPWS, 1994a).

The environmental predictors and covariates used in the model are presented as tabular data in order of decreasing importance. The degrees of freedom for each variable are displayed followed by two columns, deviance and significance which provide an indication of the importance of each variable to the model. Deviance is measured by calculating the difference between the deviance of the final model with all environmental variables and a model containing all variables except the variable of interest (NSW NPWS, 1994a). This provides a measure of the contribution of each variable to the final model. An approximate significance level for this contribution (i.e. change in deviance) is also provided. This significance level is not always less than 0.05 which is the cut off for inclusion of any one variable during the stepwise selection procedure. This is because a variable selected early in the forward stepwise procedure may cease to make a significant contribution once further variables are added to, and controlled for, in the model (NSW NPWS, 1994a).

The graphs

The second component of the postscript file is a graphical output of the environmental variables and covariates used in the model. Each variable that is chosen in the model appears as a graph. As a maximum of six variables can be chosen there is a maximum of six graphs, the minimum number of graphs being one (i.e. a univariate model). Each graph depicts the modelled relationship between the variable (environmental or covariate) and the probability of occurrence for the range of values for each variable. This is plotted on a cube root

scale to highlight the variation at the lower end of the probability range, allowing interpretation of environmental relationships of rarer species that would be indiscernible on an untransformed scale (NSW NPWS, 1994a).

Each graph plots the modelled effect of a single variable while controlling for (i.e. holding constant) the effects of all other variables in the model. The effect of each of the other environmental variables is always held at a mean value calculated across all surveyed sites.

Examples of the graphs are shown in figure 3f.

The tick marks across the top of each graph indicate the locations at which the species was recorded as present in relation to the environmental variable or covariate. Each tick represents a single site. The ticks across the bottom of each graph represent those sites at which the species was recorded as absent in the case of presence/absence modelling. For presence-only modelling they represent the 1000 pseudo-absence sites which were chosen randomly from forested land across the study area.

The fitted function relating the occurrence of a species to an environmental variable or covariate is plotted as a solid curve. This curve represents a 'best estimate' of the relationship. For presence/absence modelling upper and lower 95% confidence limits for the fitted function are

presented as dashed curves. If an environmental variable or covariate is treated as a factor rather than a continuos variable then the fitted value for each factor level is plotted as a short horizontal line and the 95% confidence limits are indicated by a vertical line.

The graphs should be interpreted with care. In particular the reader should be aware of the following considerations:

■ Each graph depicts the effect of only one variable within a multivariate model. This effect is produced by mathematically controlling for the effects of all other variables (i.e. holding each of the other effects at their mean value). This means that the graphs cannot be interpreted in isolation from one another. The effect of a variable in a multivariate model can be very different to the univariate effect of that variable if analysed on its own in the absence of the other variables. The plotted functions depict multivariate, not univariate, effects. It should be noted however that the tickmarks at the top and bottom of each graph reflect the univariate distribution of sites in relation to the environmental variable, without controlling for other variables. This may account for any obvious discrepancy between a fitted function and the distribution of presence versus absence tickmarks; one is controlling for effects of other variables while the other is not.

FIGURE 3F: FEATURES OF GRAPHS DEPICTING THE MODELLED RELATIONSHIP BETWEEN LIKELIHOOD OF OCCURRENCE OF A SPECIES AND AN ENVIRONMENTAL PREDICTOR, FOR (A) A CONTINUOUS PREDICTOR AND (B) A FACTOR (CATEGORICAL) PREDICTOR

sites where species was
recorded as present

upper 95% confidence limit

fitted function

lower 95% confidence limit

sites where species was
recorded as absent

(a)   (b)
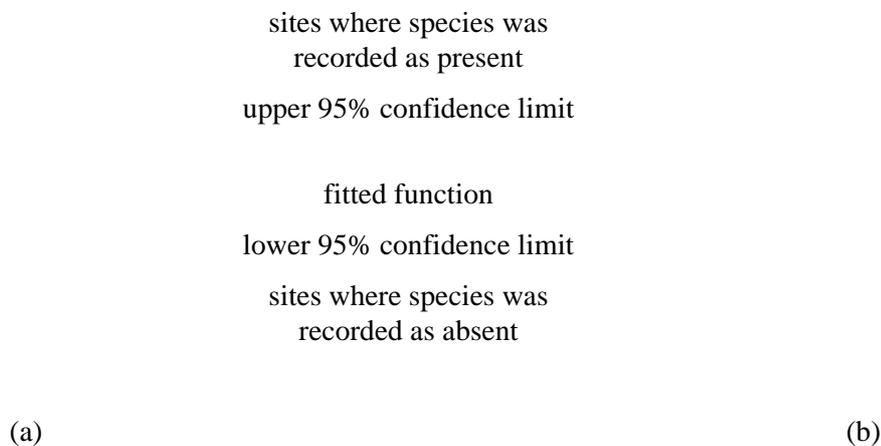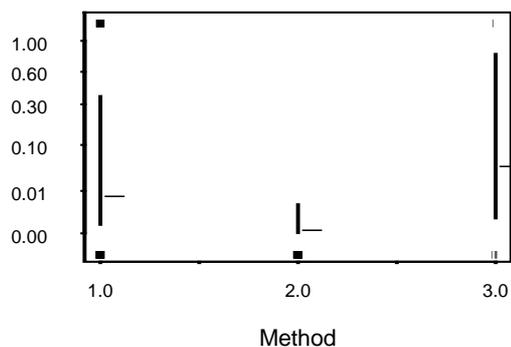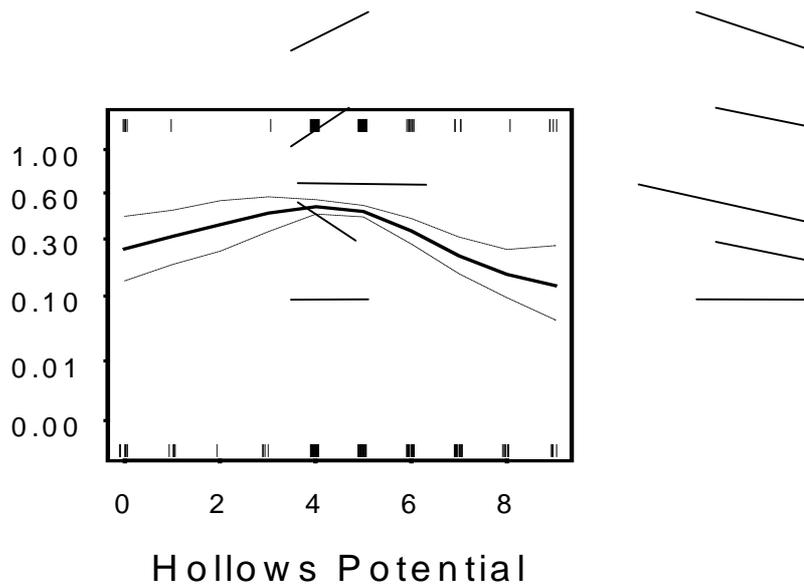
■ The 95% confidence limits need to be considered when assessing the significance of a fitted function. The fitted function is only a best estimate and therefore has associated error. The magnitude of this error varies both within and between functions, depending partly on the density of sampling within different environments and partly on the strength of the species-environment relationships being modelled. The plotted confidence limits provide an indication of the error associated with a fitted function. The confidence limits can be interpreted as follows: at a given value of the environmental variable we are 95% confident that the true value of the function (a probability in the case of presence versus absence models) lies between the upper and lower confidence limits. The significance of a

fitted function should be assessed by observing not only the magnitude of change in the fitted function with changing values of the environmental variable, but also the magnitude of the error associated with this change. A highly significant function is one in which there is little or no overlap between the confidence limits for different parts of the function (i.e. the error bands are narrow).

As previously mentioned, for presence versus absence modelling three additional graphs are produced which describe the performance of the model in terms of model discrimination, calibration and refinement respectively. Note that these graphs measure performance of the model in relation to the data used in fitting the model, not independent data.

'Discrimination measures the extent to which the proportion of all the positive observations falling in separate classes of predicted probabilities, differs from the proportion of all negative observations falling in those same classes of predicted probabilities. In other words, it is the extent to which the model predicts higher probabilities for the positive observations than it does for the negative observations. Good discrimination is illustrated in the plot by the separation of the line joining the respective proportions of positive observations and negative observations across the defined classes of predicted probabilities.' (Watson, 1996)

'Model calibration is a measure of the extent to which the model is either over-predicting or under-predicting. The plot shows, for the survey points occurring in each class of predicted probabilities, the proportion of which returned positive observations. The 95% confidence intervals around these proportions is also provided. In a perfectly calibrated model these proportions would lie along the dotted line. A curve fitted to the proportions is displayed to highlight the regions of the predicted probability range which are not well calibrated. In those parts of the range where the fitted curve rises above the line of the ideal model, the model is overpredicting and in those parts of the range where the fitted curve falls below that line, the model is underpredicting.' (Watson, 1996)

'Refinement is related to discrimination and is evaluated by the use of the receiver operating

curve (ROC) (Cox, 1958). The ROC provides a measure of the extent to which the model is correctly predicting the likelihood of a true positive (presence) and a false positive (absence) across the range of the probability scale. It does this by portraying the heterogeneity of prediction, that is, that the model is predicting outcomes which are spreading across the range of the probability scale. The points on the curve are calculated by plotting, for 100 predicted probability thresholds, the proportion of absence records falling below each threshold against the proportion of presence records falling below those thresholds. A well refined model produces a curve which is distant from the dotted 45 degree line. A curve close to the dotted line indicates that the model has little or no predictive reliability.' (Watson, 1996)

The maps

The first map shown for each species depicts the predicted distribution of the species based on the fitted model. The colour scale indicates the likelihood of occurrence of the species, with lighter colours representing lower likelihood and darker colours representing higher likelihood. If the model is based on presence/absence data the likelihood is the predicted probability of recording the species in an area. If the model is based on presence-only data then the likelihood is a relative index of occurrence. The values and ranges of the classes in the scales are those automatically generated by the modelling program. These scales were later modified by the experts in the response to disturbance workshop. The final maps, showing core, intermediate and marginal habitat areas are shown in the JANIS and Natural National Estate Conservation Requirements report (NSW NPWS, 1998.).

If a model is based on presence/absence data, two more maps are produced depicting the lower and upper 95% confidence limits for the predicted distribution. These are derived using the estimated error bands associated with functions of the fitted model.

The confidence limit maps can be interpreted as follows: at a given location within the region we are 95% confident that the true probability of recording the species lies between the probability depicted on the lower confidence limit map and the probability on the upper confidence limit map. The lower confidence limit map is useful for

identifying an area where we are highly confident
a species exists, and the upper confidence limit
map is useful for identifying areas where high
confidence of the absence of a species is required
(NSW NPWS, 1994a).

FIGURE 3G: MODEL RESULTS FOR *PETAUROIDES VOLANS* (GREATER GLIDER)

FIGURE 3H: MODEL RESULTS FOR *PETAURUS AUSTRALIS* (YELLOW-BELLIED GLIDER)

FIGURE 3I: MODEL RESULTS FOR *NINOX STRENUA* (POWERFUL OWL)

FIGURE 3J: MODEL RESULTS FOR *TYTO TENEBRICOSA* (SOOTY OWL)

FIGURE 3K: MODEL RESULTS FOR *TYTO NOVAEHOLLANDIAE* (MASKED OWL)

FIGURE 3L: MODEL RESULTS FOR *SMINTHOPSIS LEUCOPUS* (WHITE-FOOTED DUNNART)

FIGURE 3M: MODEL RESULTS FOR *PERAMELES NASUTA* (LONG-NOSED BANDICOOT)

FIGURE 3N: MODEL RESULTS FOR *POTOROUS TRIDACTYLUS* (LONG-NOSED POTOROO)

FIGURE 3O: MODEL RESULTS FOR *ISOODON OBESULUS* (SOUTHERN BROWN BANDICOOT)

**FIGURE 3P: MODEL RESULTS FOR *CALYPTORHYNCHUS FUNEREUS*
(YELLOW-TAILED BLACK-COCKATOO)**

FIGURE 3Q: MODEL RESULTS FOR *CALYPTORHYNCHUS LATHAMI* (GLOSSY BLACK COCKATOO)

FIGURE 3R: MODEL RESULTS FOR *DAPHOENOSITTA CHRYSOPTERA* (VARIED SITTELLA)

FIGURE 3S: MODEL RESULTS FOR *PACHYCEPHALA OLIVACEA* (OLIVE WHISTLER)

FIGURE 3T: MODEL RESULTS FOR *ACANTHOPHIS ANTARCTICUS* (COMMON DEATH ADDER)

FIGURE 3U: MODEL RESULTS FOR *HELEIOPORUS AUSTRALIACUS* (GIANT BURROWING FROG)

FIGURE 3V: MODEL RESULTS FOR *MIXOPHYES BALBUS* (STUTTERING BARRED FROG)

4. CONCLUSIONS

4.1 ACHIEVEMENTS OF THE EDEN CRA FAUNA MODELLING PROJECT

The Eden CRA fauna modelling project has exemplified the important role that predictive modelling can have in regional conservation evaluation and planning. Field survey data, which is often limited or disjunct in geographical spread, has been spatially extended by such modelling techniques to produce predicted species distributions.

The project has resulted in a comprehensive digital database containing validated vertebrate fauna species distribution data from across and around the Eden area. From this database, predictive models and interpolated distribution maps for all fauna species of the area have been provided for other phases of the CRA process and stakeholder use.

The project has clarified the known and predicted distributions of many threatened and forest-dependent species, enabling specific conservation prescriptions and management recommendations to be made for each (see the Eden Conservation Requirements report).

The digital survey database and models now provide a valuable information base for future use in regional and state-wide conservation planning and management.

In future CRA projects, second and third generation fauna models will provide ongoing validation and refinement of the Eden models.

4.2 FUTURE DIRECTIONS

The modelling project has highlighted some significant areas or species where there still exist gaps in quality data. As shown in table 3b, a large number of the priority species were lacking enough valid systematic records to enable presence-absence modelling. Although there were generally more incidental records for each, some species still had insufficient records for valid modelling of any type. Such species tended to be those that are cryptic or difficult to survey. In the future, it is recommend that further effort is put into systematic targeted surveying of these priority species to enable better presence-absence modelling.

It would be desirable for future surveys to collect accurate abundance data wherever practical, as the technology and ability to model abundance data continues to improve. If this is not possible, sampling effort should at least be intense enough to ensure that sufficient true presence-absence data are collected.

From the Eden modelling process, a number of recommendations for future modelling projects have arisen:

- For any species that is to be modelled, there needs to be adequate numbers of records once the data is split into systematic and incidental, seasonal and non-seasonal, and allowing for the process rejecting records falling outside the chosen domain e.g. excluding cleared/non-forested areas.

- A detailed, valid and extensive vegetation map is important, as the derivation of many variables are dependent on it.

- The precision of site data and spatially mapped data needs to be improved to at least 50m if possible, although this is often limited by the quality of external data being used.

- For a project which has wide stakeholder vetting, extensive expert consultation is vital at every stage of the process. Although this was implemented in the Eden project, a number of disputes still arose over some matters, the basis of which were often differences in personal/professional opinions and perceptions. Such problems could be alleviated by more extensive discussion of issues in workshops, involving stakeholders and a range of experts,

and thus arriving at agreed consensus at regular stages in the process. This is envisaged as being necessary for:

– defining spatial layers of potential predictive significance, based on species habitat requirements and response to disturbance information;

– deriving predictive variables and identifying subsets of them that are useful for individual species or groups;

– validation of species record data;

– examining the availability, quality and spatial distribution of site and mapped data, to determine for each priority species what process and techniques should be used to generate models and maps;

– evaluation, refinement and validation of models.

Sufficient time is necessary in the modelling process to allow adequate evaluation and re-processing of models i.e. for adjusting variables, layers and domains used. Additional time is needed for application of statistical cross-validation techniques (e.g. jackknifing) and field validation.

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APPENDICES

APPENDIX 2.1   SOURCES OF DATA USED IN THE EDEN FAUNA MODELLING

Source / Survey	Total No. of Records	Arboreal Mammals / Nocturnal Birds		Bats		Diurnal Birds		Ground Mammals		Reptiles / Amphibians	
		Presence/ absence	Presence-only	Presence/ absence	Presence-only	Presence/ absence	Presence-only	Presence/ absence	Presence-only	Presence/ absence	Presence-only
Atlas of NSW Wildlife (NSW NPWS)	43155	0	2957	0	416	0	32762	0	4483	801	1736
Brogo Bush Heritage Block Survey (Nick Graham-Higgs & Associates)	331	34	0	0	0	236	0	0	61	0	0
Broome (NSW NPWS) (smoky mouse & potoroo)	42	0	0	0	0	0	0	0	42	0	0
Claridge (Australian National University) (potoroo & bandicoot surveys)	57	0	0	0	0	0	0	0	57	0	0
Coombes (SFNSW)	97	0	96	0	0	0	0	0	0	1	0
CSIRO Division of Wildlife and Ecology	863	23	820	0	0	0	3	15	2	0	0
Eden CRA survey (NSW NPWS)	9538	215	837	2073	15	3547	1397	328	201	509	416
Eden district historic records (SFNSW)	121	0	101	0	0	0	20	0	0	0	0
Eden district observation survey records (SFNSW)	83	0	0	0	12	0	0	0	0	35	36
Eden district research historic records (SFNSW)	298	0	172	0	0	0	6	0	119	0	1
Eden district trapping survey records (SFNSW)	638	0	53	0	100	0	0	0	485	0	0
Eurobodalla National Park survey (Charles Sturt University)	1252	76	34	0	132	627	75	162	31	115	0
Incidental sightings (SFNSW)	174	0	139	0	4	0	18	0	6	0	7
Kavanagh (SFNSW)	4842	2485	0	0	0	2354	3	0	0	0	0
Lunney (NSW NPWS) (mammals & reptiles)	2420	0	362	625	0	0	0	988	0	445	0
Mills (Australian National University)	1584	0	0	1361	223	0	0	0	0	0	0
Nadgee (CSIRO Division of Wildlife and Ecology)	752	34	0	0	0	0	343	107	108	20	140
Narooma district harvesting plan surveys (SFNSW)	51	0	36	0	10	0	3	0	0	0	2
Narooma district historic records (SFNSW)	228	0	204	0	4	0	12	0	4	0	4
Narooma district pilot database records (SFNSW)	117	0	89	0	3	0	20	0	3	0	2
Neave (Australian National University)	3020	0	1	0	0	3019	0	0	0	0	0
Queanbeyan/Badja Management Area Environmental Impact Statement (SFNSW)	462	0	0	0	0	0	462	0	0	0	140
Smith (NSW NPWS)	4	0	4	0	0	2050	0	0	0	0	0
South East Koala Research Project	74	0	74	0	0	0	0	0	0	0	0
Stanton (SFNSW)	247	247	0	0	0	0	0	0	0	0	0
Totals	70590	3114	5979	4059	919	11833	35124	1600	5602	2073	2337

APPENDIX 3.1 SPECIES AND NUMBER OF RECORDS USED IN THE EDEN FAUNA MODELLING

Scientific Name	Common Name	Functional Group *	Presence/ absence	Presence-only	Total records
Ninox novaeseelandiae	Southern Boobook	AM/NB	24	349	373
Ninox connivens	Barking Owl	AM/NB	8	16	24
Ninox strenua	Powerful Owl	AM/NB	262	376	638
Tyto alba	Barn Owl	AM/NB	1	16	17
Tyto novaehollandiae	Masked Owl	AM/NB	52	99	151
Tyto tenebricosa	Sooty Owl	AM/NB	166	228	394
Podargus strigoides	Tawny Frogmouth	AM/NB	3	108	111
Aegotheles cristatus	Australian Owlet-nightjar	AM/NB	17	301	318
Eurostopodus mystacalis	White-throated Nightjar	AM/NB	6	59	65
Trichosurus vulpecula	Common Brushtail Possum	AM/NB	25	346	371
Trichosurus caninus	Mountain Brushtail Possum	AM/NB	0	114	114
Pseudocheirus peregrinus	Common Ringtail Possum	AM/NB	17	309	326
Petauroides volans	Greater Glider	AM/NB	154	839	993
Petaurus australis	Yellow-bellied Glider	AM/NB	389	567	956
Petaurus norfolcensis	Squirrel Glider	AM/NB	0	11	11
Petaurus breviceps	Sugar Glider	AM/NB	54	601	655
Acrobates pygmaeus	Feathertail Glider	AM/NB	3	47	50
Cercartetus nanus	Eastern Pigmy-possum	AM/NB	1	23	24
Phascolarctos cinereus	Koala	AM/NB	13	377	390
Vespadelus darlingtoni	vespadelus darlingtoni	B	109	36	145
Pteropus poliocephalus	Grey-headed Flying-fox	B	0	60	60
Rhinolophus megaphyllus	Eastern Horseshoe-bat	B	41	16	57
Nyctinomus australis	White-striped Mastiff-bat	B	62	33	95
Nyctophilus gouldi	Gould's Long-eared Bat	B	152	53	205
Nyctophilus geoffroyi	Lesser Long-eared Bat	B	164	61	225
Miniopterus schreibersii	Common Bent-wing Bat	B	50	32	82
Chalinolobus gouldii	Gould's Wattled Bat	B	39	16	55
Chalinolobus morio	Chocolate Wattled Bat	B	264	93	357
Myotis adversus	Large-footed Mouse-eared Bat	B	6	8	14
Scoteanax rueppellii	Greater Broad-nosed Bat	B	29	10	39
Scotorepens orion	Eastern Broad-nosed Bat	B	64	15	79
Kerivoula papuensis	Golden-tipped Bat	B	3	9	12
Falsistrellus tasmaniensis	Great Pipistrelle	B	51	15	66
Vespadelus regulus	King River Eptesicus	B	93	57	150
Vespadelus vulturnus	Little Forest Eptesicus	B	308	97	405
Dromaius novaehollandiae	Emu	DB	0	24	24
Eudyptula minor	Little Penguin	DB	0	26	26
Coturnix pectoralis	Stubble Quail	DB	0	16	16
Coturnix ypsilophora	Brown Quail	DB	1	11	12
Lopholaimus antarcticus	Topknot Pigeon	DB	0	19	19
Columba leucomela	White-headed Pigeon	DB	0	11	11
Macropygia amboinensis	Brown Cuckoo-Dove	DB	9	33	42
Geopelia striata	Peaceful Dove	DB	8	44	52
Phaps chalcoptera	Common Bronzewing	DB	6	70	76
Phaps elegans	Brush Bronzewing	DB	5	84	89
Ocyphaps lophotes	Crested Pigeon	DB	0	13	13
Leucosarcia melanoleuca	Wonga Pigeon	DB	64	193	257
Gallinula tenebrosa	Dusky Moorhen	DB	0	24	24
Porphyrio porphyrio	Purple Swamphen	DB	0	41	41
Fulica atra	Eurasian Coot	DB	0	41	41
Tachybaptus novaehollandiae	Australasian Grebe	DB	0	43	43
Poliocephalus poliocephalus	Hoary-headed Grebe	DB	0	40	40
Puffinus tenuirostris	Short-tailed Shearwater	DB	0	14	14
Phalacrocorax carbo	Great Cormorant	DB	1	122	123
Phalacrocorax sulcirostris	Little Black Cormorant	DB	0	76	76

| *Phalacrocorax varius* | Pied Cormorant | DB | 0 | 37 | 37 |
| *Phalacrocorax melanoleucos* | Little Pied Cormorant | DB | 3 | 164 | 167 |

Scientific Name	Common Name	Functional Group *	Presence/ absence	Presence- only	Total records
Anhinga melanogaster	Darter	DB	0	19	19
Morus serrator	Australasian Gannet	DB	0	27	27
Pelecanus conspicillatus	Australian Pelican	DB	2	109	111
Sterna caspia	Caspian Tern	DB	0	24	24
Sterna bergii	Crested Tern	DB	2	57	59
Sterna albifrons	Little Tern	DB	0	48	48
Larus novaehollandiae	Silver Gull	DB	4	139	143
Haematopus longirostris	Pied Oystercatcher	DB	0	112	112
Haematopus fuliginosus	Sooty Oystercatcher	DB	0	29	29
Vanellus miles	Masked Lapwing	DB	4	180	184
Thinornis rubricollis	Hooded Plover	DB	1	88	89
Charadrius ruficapillus	Red-capped Plover	DB	0	66	66
Elseyornis melanops	Black-fronted Dotterel	DB	0	36	36
Numenius madagascariensis	Eastern Curlew	DB	1	30	31
Numenius phaeopus	Whimbrel	DB	0	14	14
Limosa lapponica	Bar-tailed Godwit	DB	0	19	19
Tringa nebularia	Common Greenshank	DB	0	12	12
Calidris ferruginea	Curlew Sandpiper	DB	0	11	11
Calidris ruficollis	Red-necked Stint	DB	0	13	13
Calidris acuminata	Sharp-tailed Sandpiper	DB	0	11	11
Gallinago hardwickii	Latham's Snipe	DB	0	26	26
Threskiornis molucca	Australian White Ibis	DB	1	104	105
Threskiornis spinicollis	Straw-necked Ibis	DB	0	25	25
Platalea regia	Royal Spoonbill	DB	0	37	37
Platalea flavipes	Yellow-billed Spoonbill	DB	0	11	11
Egretta garzetta	Little Egret	DB	0	13	13
Ardea alba	Great Egret	DB	0	68	68
Egretta novaehollandiae	White-faced Heron	DB	2	184	186
Ardea pacifica	White-necked Heron	DB	1	23	24
Chenonetta jubata	Australian Wood Duck	DB	0	103	103
Cygnus atratus	Black Swan	DB	0	128	128
Tadorna tadornoides	Australian Shelduck	DB	0	21	21
Anas superciliosa	Pacific Black Duck	DB	4	128	132
Anas castanea	Chestnut Teal	DB	0	95	95
Anas gracilis	Grey Teal	DB	0	57	57
Anas rhynchotis	Australasian Shoveler	DB	0	11	11
Malacorhynchus membranaceus	Pink-eared Duck	DB	0	17	17
Aythya australis	Hardhead	DB	0	23	23
Biziura lobata	Musk Duck	DB	0	23	23
Circus approximans	Swamp Harrier	DB	1	36	37
Accipiter novaehollandiae	Grey Goshawk	DB	3	46	49
Accipiter fasciatus	Brown Goshawk	DB	4	40	44
Accipiter cirrhocephalus	Collared Sparrowhawk	DB	2	17	19
Aquila audax	Wedge-tailed Eagle	DB	6	185	191
Hieraaetus morphnoides	Little Eagle	DB	2	18	20
Haliaeetus leucogaster	White-bellied Sea-Eagle	DB	3	240	243
Haliastur sphenurus	Whistling Kite	DB	12	154	166
Lophoictinia isura	Square-tailed Kite	DB	2	17	19
Elanus axillaris	Black-shouldered Kite	DB	0	28	28
Falco longipennis	Australian Hobby	DB	1	16	17
Falco peregrinus	Peregrine Falcon	DB	0	26	26
Falco berigora	Brown Falcon	DB	2	55	57
Falco cenchroides	Nankeen Kestrel	DB	0	54	54
Trichoglossus haematodus	Rainbow Lorikeet	DB	67	155	222
Glossopsitta concinna	Musk Lorikeet	DB	18	54	72
Glossopsitta pusilla	Little Lorikeet	DB	11	45	56
Calyptorhynchus lathami	Glossy Black-Cockatoo	DB	18	348	366
Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo	DB	67	423	490
Callocephalon fimbriatum	Gang-gang Cockatoo	DB	102	269	371
Cacatua galerita	Sulphur-crested Cockatoo	DB	20	95	115

| *Cacatua roseicapilla* | Galah | DB | 8 | 140 | 148 |

Scientific Name	Common Name	Functional Group *	Presence/ absence	Presence- only	Total records
Alisterus scapularis	Australian King-Parrot	DB	61	221	282
Platycercus elegans	Crimson Rosella	DB	271	419	690
Platycercus eximius	Eastern Rosella	DB	12	132	144
Pezoporus wallicus	Ground Parrot	DB	0	375	375
Eurystomus orientalis	Dollarbird	DB	3	36	39
Alcedo azurea	Azure Kingfisher	DB	0	35	35
Dacelo novaeguineae	Laughing Kookaburra	DB	111	361	472
Todiramphus sanctus	Sacred Kingfisher	DB	21	80	101
Hirundapus caudacutus	White-throated Needletail	DB	17	74	91
Cuculus pallidus	Pallid Cuckoo	DB	16	47	63
Cacomantis flabelliformis	Fan-tailed Cuckoo	DB	128	164	292
Cacomantis variolosus	Brush Cuckoo	DB	12	30	42
Chrysococcyx basalis	Horsfield's Bronze-Cuckoo	DB	16	36	52
Chrysococcyx lucidus	Shining Bronze-Cuckoo	DB	67	54	121
Eudynamys scolopacea	Common Koel	DB	1	12	13
Scythrops novaehollandiae	Channel-billed Cuckoo	DB	2	33	35
Menura novaehollandiae	Superb Lyrebird	DB	167	340	507
Hirundo neoxena	Welcome Swallow	DB	16	202	218
Hirundo nigricans	Tree Martin	DB	8	38	46
Hirundo ariel	Fairy Martin	DB	13	20	33
Rhipidura fuliginosa	Grey Fantail	DB	477	422	899
Rhipidura rufifrons	Rufous Fantail	DB	53	133	186
Rhipidura leucophrys	Willie Wagtail	DB	9	172	181
Myiagra rubecula	Leaden Flycatcher	DB	29	46	75
Myiagra cyanoleuca	Satin Flycatcher	DB	13	30	43
Myiagra inquieta	Restless Flycatcher	DB	9	44	53
Monarcha melanopsis	Black-faced Monarch	DB	70	137	207
Microeca fascinans	Jacky Winter	DB	27	101	128
Petroica multicolor	Scarlet Robin	DB	43	112	155
Petroica phoenicea	Flame Robin	DB	26	80	106
Petroica rodinogaster	Pink Robin	DB	1	12	13
Petroica rosea	Rose Robin	DB	51	83	134
Eopsaltria australis	Eastern Yellow Robin	DB	322	325	647
Pachycephala pectoralis	Golden Whistler	DB	324	244	568
Pachycephala rufiventris	Rufous Whistler	DB	156	201	357
Pachycephala olivacea	Olive Whistler	DB	15	39	54
Colluricincla harmonica	Grey Shrike-thrush	DB	349	310	659
Grallina cyanoleuca	Magpie-lark	DB	17	139	156
Falcunculus frontatus	Crested Shrike-tit	DB	39	98	137
Psophodes olivaceus	Eastern Whipbird	DB	221	311	532
Coracina novaehollandiae	Black-faced Cuckoo-shrike	DB	75	189	264
Coracina papuensis	White-bellied Cuckoo-shrike	DB	12	14	26
Coracina tenuirostris	Cicadabird	DB	19	58	77
Lalage sueurii	White-winged Triller	DB	2	19	21
Cinclosoma punctatum	Spotted Quail-thrush	DB	13	106	119
Zoothera dauma	Unidentified Ground Thrush	DB	6	44	50
Epthianura albifrons	White-fronted Chat	DB	1	46	47
Gerygone olivacea	White-throated Gerygone	DB	9	36	45
Gerygone mouki	Brown Gerygone	DB	71	72	143
Smicrornis brevirostris	Weebill	DB	3	12	15
Acanthiza lineata	Striated Thornbill	DB	367	201	568
Acanthiza nana	Yellow Thornbill	DB	5	55	60
Acanthiza pusilla	Brown Thornbill	DB	506	355	861
Acanthiza reguloides	Buff-rumped Thornbill	DB	15	41	56
Acanthiza chrysorrhoa	Yellow-rumped Thornbill	DB	2	106	108
Sericornis frontalis	White-browed Scrubwren	DB	363	255	618
Sericornis citreogularis	Yellow-throated Scrubwren	DB	1	20	21
Sericornis magnirostris	Large-billed Scrubwren	DB	17	16	33
Calamanthus fuliginosus	Striated Fieldwren	DB	0	53	53
Origma solitaria	Rockwarbler	DB	0	27	27

| *Pycnoptilus floccosus* | Pilotbird | DB | 57 | 53 | 110 |

Scientific Name	Common Name	Functional Group *	Presence/absence	Presence-only	Total records
Dasyornis brachypterus	Eastern Bristlebird	DB	0	111	111
Megalurus gramineus	Little Grassbird	DB	1	10	11
Acrocephalus stentoreus	Clamorous Reed-Warbler	DB	0	17	17
Cisticola exilis	Golden-headed Cisticola	DB	0	27	27
Stipiturus malachurus	Southern Emu-wren	DB	4	34	38
Malurus cyaneus	Superb Fairy-wren	DB	205	395	600
Malurus lamberti	Variegated Fairy-wren	DB	8	44	52
Artamus cyanopterus	Dusky Woodswallow	DB	21	109	130
Daphoenositta chrysoptera	Varied Sittella	DB	26	46	72
Climacteris picumnus	Brown Treecreeper	DB	5	8	13
Cormobates leucophaeus	White-throated Treecreeper	DB	538	296	834
Climacteris erythrops	Red-browed Treecreeper	DB	63	36	99
Dicaeum hirundinaceum	Mistletoebird	DB	75	71	146
Pardalotus punctatus	Spotted Pardalote	DB	268	215	483
Zosterops lateralis	Silvereye	DB	129	217	346
Melithreptus lunatus	White-naped Honeyeater	DB	205	134	339
Melithreptus brevirostris	Brown-headed Honeyeater	DB	46	43	89
Myzomela sanguinolenta	Scarlet Honeyeater	DB	3	32	35
Acanthorhynchus tenuirostris	Eastern Spinebill	DB	376	353	729
Phylidonyris melanops	Tawny-crowned Honeyeater	DB	1	20	21
Meliphaga lewinii	Lewin's Honeyeater	DB	128	265	393
Lichenostomus fuscus	Fuscous Honeyeater	DB	6	9	15
Lichenostomus chrysops	Yellow-faced Honeyeater	DB	343	369	712
Lichenostomus leucotis	White-eared Honeyeater	DB	97	83	180
Lichenostomus melanops	Yellow-tufted Honeyeater	DB	38	68	106
Phylidonyris pyrrhoptera	Crescent Honeyeater	DB	92	81	173
Phylidonyris novaehollandiae	New Holland Honeyeater	DB	94	293	387
Phylidonyris nigra	White-cheeked Honeyeater	DB	1	15	16
Manorina melanophrys	Bell Miner	DB	135	185	320
Manorina melanocephala	Noisy Miner	DB	3	21	24
Anthochaera chrysoptera	Little Wattlebird	DB	43	189	232
Anthochaera carunculata	Red Wattlebird	DB	106	216	322
Philemon corniculatus	Noisy Friarbird	DB	23	164	187
Anthus novaeseelandiae	Richard's Pipit	DB	0	110	110
Stagonopleura bella	Beautiful Firetail	DB	0	30	30
Taeniopygia guttata	Zebra Finch	DB	0	11	11
Neochmia temporalis	Red-browed Finch	DB	86	254	340
Oriolus sagittatus	Olive-backed Oriole	DB	67	100	167
Ailuroedus crassirostris	Green Catbird	DB	0	26	26
Ptilonorhynchus violaceus	Satin Bowerbird	DB	71	264	335
Corcorax melanorhamphos	White-winged Chough	DB	3	179	182
Strepera graculina	Pied Currawong	DB	211	347	558
Strepera versicolor	Grey Currawong	DB	33	74	107
Cracticus torquatus	Grey Butcherbird	DB	80	205	285
Gymnorhina tibicen	Australian Magpie	DB	37	301	338
Zoothera lunulata	Bassian Thrush	DB	5	43	48
Corvus coronoides	Australian Raven	DB	71	253	324
Corvus mellori	Little Raven	DB	6	11	17
Pardalotus striatus	Striated Pardalote	DB	56	63	119
Ardea ibis	Cattle Egret	DB	0	25	25
Ornithorhynchus anatinus	Platypus	GM	0	32	32
Tachyglossus aculeatus	Short-beaked Echidna	GM	2	114	116
Dasyurus maculatus	Tiger Quoll	GM	0	52	52
Antechinus stuartii	Brown Antechinus	GM	181	397	578
Antechinus swainsonii	Dusky Antechinus	GM	26	49	75
Sminthopsis leucopus	White-footed Dunnart	GM	71	33	104
Isoodon obesulus	Southern Brown Bandicoot	GM	0	22	22
Perameles nasuta	Long-nosed Bandicoot	GM	4	134	138
Vombatus ursinus	Common Wombat	GM	6	493	499

Scientific Name	Common Name	Functional Group *	Presence/ absence	Presence- only	Total records
Potorous tridactylus	Long-nosed Potoroo	GM	1	67	68
Potorous longipes	Long-footed Potoroo	GM	0	31	31
Wallabia bicolor	Swamp Wallaby	GM	37	1581	1618
Macropus rufogriseus	Red-necked Wallaby	GM	0	130	130
Macropus giganteus	Eastern Grey Kangaroo	GM	0	212	212
Macropus robustus	Common Wallaroo	GM	0	11	11
Rattus fuscipes	Bush Rat	GM	151	699	850
Rattus lutreolus	Swamp Rat	GM	8	74	82
Pseudomys fumeus	Smoky Mouse	GM	0	58	58
Chelodina longicollis	Eastern Long-necked Tortoise	R/A	14	14	28
Amphibolurus muricatus	Jacky Lizard	R/A	44	56	100
Eulamprus heatwolei	eulamprus heatwolei	R/A	142	43	185
Physignathus lesueurii	Eastern Water Dragon	R/A	15	48	63
Varanus varius	Lace Monitor	R/A	38	130	168
Ctenotus taeniolatus	Copper-tailed Skink	R/A	6	19	25
Egernia cunninghami	Cunningham's Skink	R/A	7	11	18
Egernia saxatilis	Black Rock Skink	R/A	16	39	55
Egernia whitii	White's Skink	R/A	15	13	28
Hemiergis decresiensis	hemiergis decresiensis	R/A	12	3	15
Nannoscincus maccoyi	McCoy's Skink	R/A	45	3	48
Lampropholis delicata	Grass Skink	R/A	180	44	224
Lampropholis guichenoti	Garden Skink	R/A	215	74	289
Saproscincus mustelinus	Weasel Skink	R/A	60	32	92
Niveoscincus coventryi	Coventry's Skink	R/A	42	1	43
Pseudemoia entrecasteauxii	Tussock Skink	R/A	20	4	24
Bassiana platynota	Red-throated Skink	R/A	9	3	12
Pseudemoia spenceri	pseudemoia spenceri	R/A	53	1	54
Eulamprus quoyii	Eastern Water Skink	R/A	2	39	41
Eulamprus tympanum	Highland Water Skink	R/A	103	60	163
Tiliqua nigrolutea	Blotched Blue-tongued Lizard	R/A	14	9	23
Tiliqua scincoides	Eastern Blue-tongued Lizard	R/A	10	34	44
Morelia spilota	Carpet or Diamond Python	R/A	2	14	16
Austrelaps superbus	Copperhead	R/A	21	13	34
Rhinoplocephalus nigrescens	Eastern Small-eyed Snake	R/A	9	16	25
Drysdalia coronoides	White-lipped Snake	R/A	7	12	19
Notechis scutatus	Eastern Tiger Snake	R/A	12	27	39
Pseudechis porphyriacus	Red-bellied Black Snake	R/A	33	231	264
Pseudonaja textilis	Eastern Brown Snake	R/A	5	14	19
Drysdalia rhodogaster	drysdalia rhodogaster	R/A	3	8	11
Physignathus lesueurii howittii	Gippsland Water Dragon	R/A	7	16	23
Heleioporus australiacus	Giant Burrowing Frog	R/A	8	13	21
Limnodynastes dumerilii	Eastern Banjo Frog	R/A	15	28	43
Limnodynastes peronii	Brown-striped Frog	R/A	28	48	76
Limnodynastes tasmaniensis	Spotted Grass Frog	R/A	12	6	18
Mixophyes balbus	Stuttering Barred Frog	R/A	5	10	15
Pseudophryne bibronii	Brown Toadlet	R/A	21	21	42
Pseudophryne dendyi	Dendy's Toadlet	R/A	5	8	13
Crinia signifera	Common Eastern Froglet	R/A	85	146	231
Litoria aurea	Green and Golden Bell Frog	R/A	3	18	21
Litoria citropa	Blue Mountains Tree Frog	R/A	11	24	35
Litoria dentata	Bleating Tree Frog	R/A	2	16	18
Litoria ewingii	Brown Tree Frog	R/A	6	9	15
Litoria lesueuri	Lesueur's Frog	R/A	25	53	78
Litoria peronii	Peron's Tree Frog	R/A	23	62	85
Litoria phyllochroa	Leaf Green Tree Frog	R/A	16	34	50
Litoria verreauxii	litoria verreauxii	R/A	23	42	65
Uperoleia tyleri	Tyler's Toadlet	R/A	8	6	14

* Functional Group: AM/NB = Arboreal Mammals/Nocturnal Birds; B = Bats; DB = Diurnal Birds; GM = Ground Mammals; R/A = Reptiles/Amphibians.