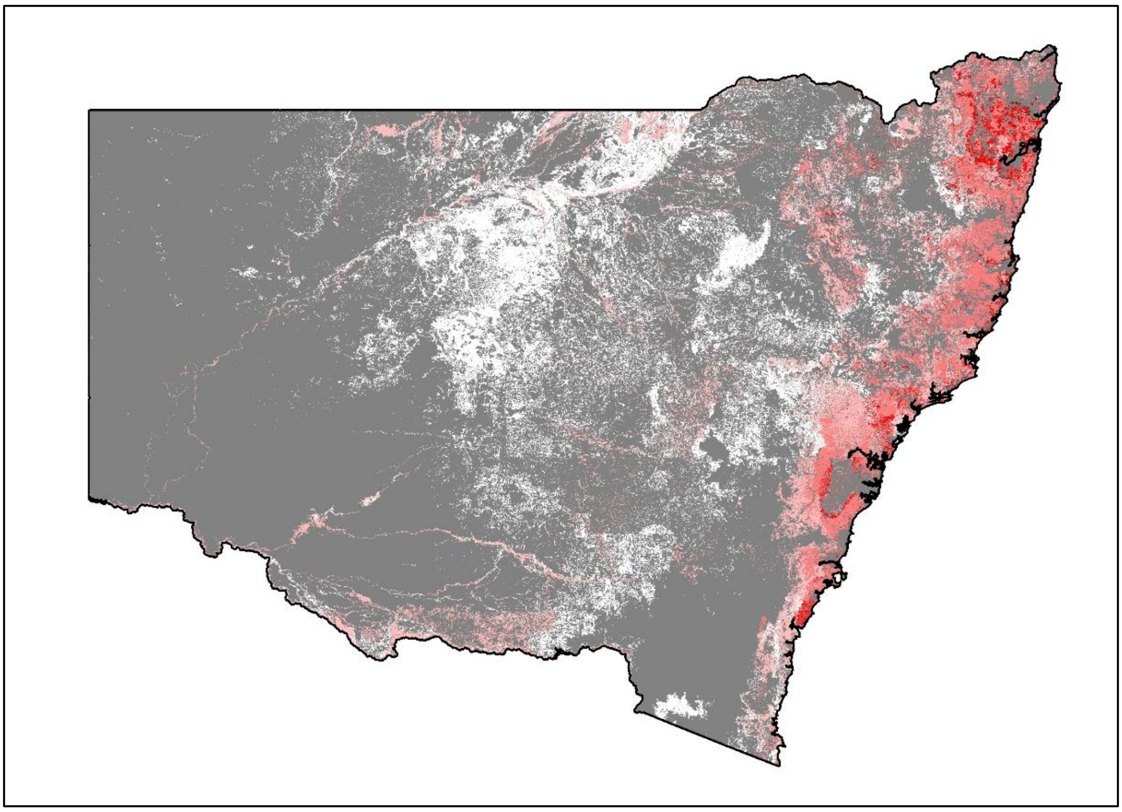

Flying-fox Foraging Habitat Mapping NSW

A seamless map for assessing temporal and spatial patterns of habitat quality for flying-foxes

Report to Local Government NSW

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Acknowledgements

This project was funded and assisted by the New South Wales Government through its Environmental Trust.

The project benefited from the support and collaborative efforts of a large number of people. We particularly acknowledge the contribution of Dr Bradley Law, NSW Primary Industries, whose work in conceptualising, developing and producing the Eby and Law (2008) nectar map was pivotal to this project as well. Numerous people assisted with compiling and validating the diet list and contributed to the process of scoring flower attributes by providing us with unpublished reports, field records and their expert advice. We owe a debt of gratitude to them all.

Chris Hudson of Local Government NSW managed this complex project with skill and immense patience. Members of the project Working Group, Matthew Mo, David Nipperess, Kerryn Parry-Jones, Mike Roache and Justin Welbergen consulted on methodology, project planning and commented on draft reports.

Jessica Meade and Justin Welbergen of the University of Western Sydney initiated and conducted the validation of the Eby and Law (2008) habitat ranks. Teresa Eyre, Geoff Smith, Tim Ryan, Don Butler, Melanie Venz and Luke Hogan (Queensland Department of Science and Environment) were generous with their time and expertise, discussing methods for assessing flowering characteristics and scoring habitats, and sharing information on the diet of flying-foxes in Queensland. Several people assisted us with sourcing spatial layers and technical reports. In particular, we would like to thank Will Dorrington (NSW Department of Planning, Industry and Environment data broker), Bill Larkin (Kempsey Council) and Rochelle Lawson (Central Coast Council). Adam Roff (Science Division, Department of Planning, Industry and Environment) supplied technical reports and user accuracy data associated with SVTM mapping.

Citation:

Eby, P., Sims, R. and Bracks, J. 2019. Flying-fox Foraging Habitat Mapping NSW: a seamless map for assessing temporal and spatial patterns of habitat quality for flying-foxes. Report to Local Government New South Wales.

Executive Summary

Flying-foxes are critical to Australian ecosystems, pollinating plants and dispersing seeds as they move long distances in response to fruiting and flowering. There are four species of flying-fox on the mainland, three of which occur in New South Wales: the grey-headed flying-fox (*Pteropus poliocephalus*), black flying-fox (*P. alecto)*, and little red flying-fox (*P. scapulatus*).

The grey-headed flying-fox is listed as a threatened species under state and Commonwealth legislation. A key threatening process for the species is loss and degradation of foraging habitat. It is likely that this threat impacts all three species of flying-foxes given their dietary overlap. Ongoing decline in native foraging habitat is also thought to be a key driver in the urbanisation of flying-foxes in NSW as they become more dependent on introduced plants for year-round food supplies. This decline has also been linked to disease prevalence within flying-fox populations.

Recovery actions to identify and protect key foraging areas for the grey-headed flying-fox were previously impeded by difficulties in defining these areas. To allow management actions for conserving flying-foxes to be incorporated into land use decisions, the New South Wales and Australian governments jointly funded the project *Ranking the feeding habitats of grey-headed flying-foxes for conservation management* (Eby and Law 2008). This work mapped foraging habitat within the range of the threatened grey-headed flying-fox.

The current project, funded by the New South Wales government and administered by Local Government New South Wales, expands the 2008 resource to provide contemporary mapping of potential foraging habitat for all three species across New South Wales. Digital maps and databases from the Eby and Law (2008) study were updated and methods consistent with the 2008 project were then applied across inland zones.

The state-wide native diet list for flying-foxes comprises 60 species in the blossom diet and 51 species in the fruit diet. Temporal and spatial flowering patterns and productivity of diet species are significant components of the assessment of foraging habitat. Species in the flower diet of flying-foxes were characterised using the productivity and reliability of flowering patterns and seasonal flowering phenology scored at bi-monthly intervals.

Habitats were defined by the vegetation types described in vegetation classifications and spatial layers. Digital vegetation maps from across NSW were compiled and merged to create a single, seamless habitat map. Ultimately 39 vegetation mapping projects were included. The state map was divided into 19 regional datasets distributed across three zones to create a final product with practical file sizes. Numeric assessments of flowering characteristics were combined with estimates of plant densities in the vegetation data to score the quality of nectar-producing habitat. Data on flowering phenology was used to produce bi-monthly maps illustrating spatial and temporal variations in food resources.

The accuracy and reliability of the habitat map is directly linked to the spatial accuracy and quality of floristic information and line work contained in the spatial layers and classifications available to the project. Every effort was made to use the best available data. Flying-fox records and data on diet and flowering characteristics become progressively sparse to the west, which introduces an unmeasured level of uncertainty to habitat assessments in these zones, particularly in the far west of the state.

Insufficient data were available on the characteristics of fleshy fruits to allow comparisons to be drawn between species. Fruit-producing habitats were assessed by a separate method based on the species richness of diet plants.

Broad spatial patterns of habitat quality illustrated in the map of total habitat scores are consistent with records of flying-fox distribution. Bi-monthly maps of nectar habitat illustrate the importance of coastal lowlands and ranges throughout the year, the near absence of productive habitat in the western zone and the relative productivity of small remnants of grassy woodlands in the central zone, particularly in colder bi-months. Summaries of seasonal habitat quality emphasise the paucity of foraging options during winter. These broad temporal and spatial patterns illustrated by the maps are consistent with the habitat requirements of various nectar-feeding birds, including species listed as threatened in NSW, and emphasise the potential utility of the maps for assessing habitats of other canopy-feeding nectarivores.

It is hoped that the outputs of this project will guide the protection and restoration of flying-fox foraging habitat across the state. This is key to conserving flying-foxes and the key ecosystem services they provide and will potentially contribute to alleviating and avoiding human/flying-fox conflict.

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1. Introduction

Flying-foxes play an important role in Australian ecosystems, pollinating plants and dispersing seeds as they move long distances in response to fruiting and flowering (see review in Eby 2016). There are four species of flying-foxes on the mainland, three of which occur in New South Wales: the grey-headed flying-fox (*Pteropus poliocephalus*); black flying-fox (*P. alecto)*; and little red flying-fox (*P. scapulatus*).

The grey-headed flying-fox is listed as a threatened species under state and Commonwealth legislation. A key threatening process for the species is loss and degradation of foraging habitat (Commonwealth of Australia 2017). This threat is likely to impact all three species of flying-foxes, given their dietary overlap, and is likely to continue with persistent pressures such as land clearing and climate change.

Recovery actions for the grey-headed flying-fox to identify and protect key foraging areas were previously impeded by difficulties in defining these areas. To allow these actions to be incorporated into land use decisions, the New South Wales and Australian governments jointly funded the project *Ranking the feeding habitats of grey-headed flying-foxes for conservation management* (Eby and Law 2008). This project mapped and ranked foraging habitat within the range of the threatened grey-headed flying-fox, covering the coastal area of Victoria, New South Wales and southern Queensland.

This project was initiated by Local Government NSW (LGNSW) to fulfil a requirement for contemporary mapping of flying-fox foraging habitat, to inform a ten-year program of flying-fox habitat restoration funded by the NSW Environmental Trust.

The project aims to identify and map the distribution and seasonal dynamics of potential foraging habitat for flying-foxes throughout New South Wales. The scope of the project is to update the NSW component of the existing habitat map for grey-headed flying-foxes, to expand that resource to incorporate the habitat requirements of all three *Pteropus* species occurring in NSW: the grey-headed flying-fox, black flying-fox (*P. alecto*; BFF) and little red flying-fox (*P. scapulatus*; LRFF), and to extend the map to cover the entire state.

The project outputs will contribute to flying-fox conservation by enabling foraging opportunities to be taken into consideration when identifying priority areas and vegetation communities for restoration, which may in turn reduce flying-fox dependence on urban food sources contributing to reduced human/flying-fox conflict. The outputs also provide land managers information on native feeding resources for flying-foxes in their local area and allow multi-scale habitat assessments throughout NSW.

Flying-foxes rely on highly variable patterns of nectar and fruit production in native vegetation. Therefore, the quality of forests and woodlands as foraging habitat varies substantially in space and time. The distribution of flower and fruit resources for flying-foxes can be conceptualised as a function of the flowering and fruiting characteristics of the plant species in their diet and the distribution of those species in vegetation communities across their range. This work integrates a diet list for flying-foxes in NSW validated by direct field observations; characterisations of flowering traits of diet species based on expert elicitation, published research and reports; and vegetation classifications and digital maps that describe the distribution and relative abundance of canopy trees and lianas throughout the state.

The methods are based on those developed by Eby and Law (2008) to generate digital maps of foraging habitat for GHFFs in eastern NSW. The 2008 digital maps and databases were updated as part of this project and the methods were then applied across inland NSW to generate a state-wide map of potential feeding habitat for all three species of flying-foxes. The methods are described in detail in the reports that accompany the 2008 project and are appended to this report (see Appendix 1). Short descriptions are provided in the text below and variations to the Eby and Law (2008) methods are identified and described in the sections below.

Preliminary validation of Eby and Law (2008)

No suitable data were available for validating the methods and output of Eby and Law (2008) at the time the project was completed. This left the outputs of the work, particularly habitat scores and conservation ranks attributed to vegetation types, open to question. However, various telemetry and observational studies since that time have documented long-distance movements and feeding patterns of GHFFs in the 2008 study area that can be related to habitat scores and rankings (e.g. Roberts *et al.* 2012, Tidemann and Nelson 2004). They include a major satellite telemetry study undertaken in 2012 to comply with Conditions of Approval under the EPBC Act for dispersing the flying-fox roost at the Royal Botanic Gardens Sydney (J. Martin RBG and J. Welbergen UWS, unpublished data). Over the five years of the telemetry study, tagged animals were documented throughout the Eby and Law (2008) study area. Jessica Meade and Justin Welbergen of the University of Western Sydney assessed this extensive dataset (>70,000 foraging fixes from 110 study animals) with the aim of providing external validation of the habitat rankings presented in Eby and Law (2008; see Appendix 2 for details). They concluded that their analysis, albeit necessarily based on fairly simple assumptions, provides good support for the preference of GHFFs for foraging habitats identified as higher quality (ranks 1 & 2) in Eby and Law (2008). These results support the conclusion that the habitat scores on which the rankings are based reflect the real-world feeding preferences of the animals. They also support the application of the methods of Eby and Law (2008) to the 2019 project.

Study area and limitations in underlying data

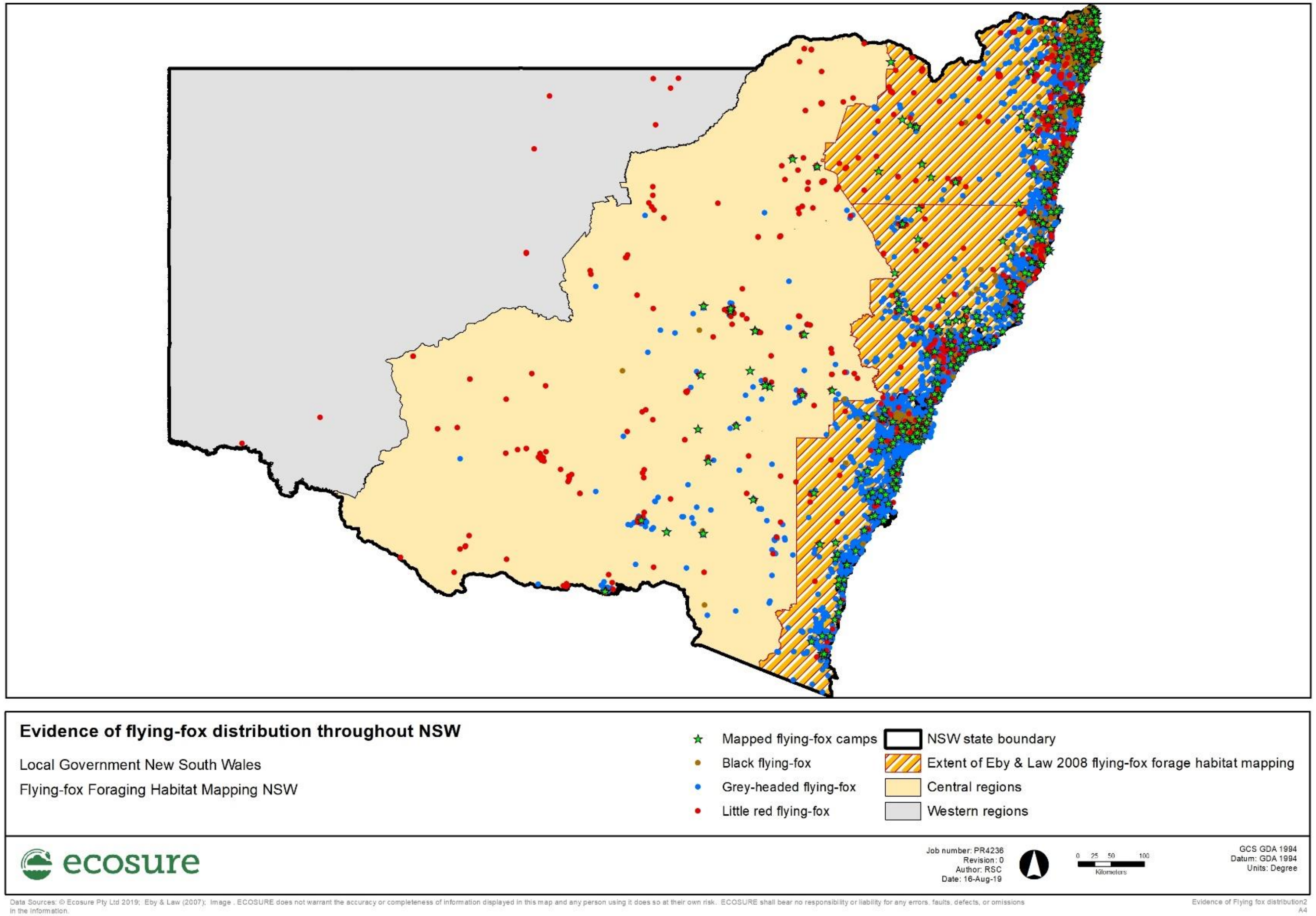
The vegetation of NSW has been broadly characterised by Keith (2004). Species rich, diverse forests and woodlands occur in coastal lowlands and eastern ranges. These vegetation systems are associated with dense and frequent sightings of flying-foxes (Figure 1).

West of the escarpment, records of LRFFs and GHFFs are scattered and become progressively sparse. The vegetation formations of the central zone are predominantly dry sclerophyll forests and grassy woodlands that grade to semi-arid woodlands in the west. Species richness of canopy trees declines westward and the canopy layer opens to <20% cover. Native vegetation in this zone has been heavily cleared for agriculture. The progressive reduction and simplification of tree cover continues through the western zone. Semi-arid woodlands containing scattered trees grade to treeless arid shrublands and forested wetlands are associated with inland river systems. Records of LRFFs are rare in the western zone and restricted to the eastern half.

The Eby and Law (2008) study was conducted in the data-rich eastern portion of the state. It was supported by a substantial body of data on flying-fox diet and flower characteristics that had been compiled over several decades of ecological observation and research. The work benefited from the input of numerous people with experience of flying-foxes and/or experience of the flowering and fruiting characteristics of canopy trees in eastern NSW. The paucity of records of flying-foxes and data on flying-fox diet and flowering characteristics available in the western portions of the state introduce an increased, and unmeasured level of uncertainty to habitat assessments, particularly in the far west.

End users of this project should be aware of the spatial variations that exist in the amount and quality of the underlying data that supports assessments and the associated variation in uncertainty in the outputs, particularly in the western zone.

Figure 1. The distribution of records of flying-foxes in NSW lodged with the Atlas of Living Australia database.
data accessed 24 March 2019.



2. Diet list

The native diet list for GHFFs in Eby and Law (2008) was scrutinised and updated and diet lists were compiled for BFFs and LRFFs. Information on native plants used by flying-foxes was gathered from a variety of sources, including published and unpublished accounts, surveys of experts including wildlife ecologists and field naturalists, web searches, records in Government databases and the records of wildlife rehabilitation groups. Only those species confirmed by direct field observations were included in the final diet list. Lists of flowering and fruiting diet plants were compiled separately and taxonomy followed the classification of flowering plants by the National Herbarium of New South Wales http://plantnet.rbgsyd.nsw.gov.au

There is evidence that flying-foxes sometimes eat leaves (Parry-Jones and Augee 1991) and exudates from leaf-mining insects, such as psyllids (Law and Lean 1992). Insect remains are also occasionally found in faecal material (Parry-Jones and Augee 1991). Nonetheless, this assessment was restricted to the primary dietary items, fruit and blossom. Subsidiary items were not considered.

The state-wide native diet list for flying-foxes comprises 60 species in the blossom diet and 54 species in the fruit diet (Tables 1 and 2). One new flower diet species was added within the Eby and Law (2008) study area: *Banksia aemula*. Use of this species by LRFFs was confirmed. Four species with distributions to the west of the Eby and Law (2008) study area were also identified and validated by direct observation: *Corymbia terminalis, E. coolabah, E. ochrophloia and E. populnea*.

There are distinct seasonal patterns to the flowering phenologies of NSW diet plants. The majority flower in warmer months, >60% flower in the December-January bi-month. By contrast, 20% flower in cooler months from April to September (Table 1).

No new species were added to the fruit diet list and Table 2 is taken from Eby and Law (2008).

Table 1. Species in the combined nectar diet of grey-headed, black and little red flying-foxes in NSW, and their seasonal flowering phenologies scored at bi-monthly intervals.

Species	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
Angophora costata	X					X
A. floribunda	X					
Banksia aemula		X	X	X		
B. integrifolia			X	X	X	
B. serrata	X	X	X			
Callistemon salignus	X					X
Callistemon viminalis	X					X
Castanospermum australe	X					X
Corymbia eximia						X
C. gummifera	X	X	X			
C. henryi	X					X
C. intermedia	X	X				
C. maculata		X	X	X	X	
C. tesselaris	X					
C. trachyphloia	X	X				
C. variegata	X	X				
Eucalyptus acmenoides	X					X
E. albens				X	X	
E. amplifolia	X					X
E. andrewsii	X	X				
E. bancroftii						X
E. botryoides	X	X				
E. camaldulensis, subsp camaldulensis	X					X
E. campanulata		X				
E. conica					X	X
E. coolabah	X					
E. deanei	X	X				
E. fibrosa	X	X				X
E. fusiformis				X	X	
E. grandis		X	X			
E. maidenii		X				
E. melanophloia	X					
E melliodora	X					X
E. moluccana		X				
E. muelleriana	X	X				
E. nubila	X	X				
E. ochrophloia			X	X	X	
E. paniculata	X				X	X
E. parramatensis	X					
E. pilularis	X	X	X	X		

Species	Dec-Jan	Feb-Mar	Apr-May	Jun-Jul	Aug-Sep	Oct-Nov
E. piperita	**X**	**X**				
E. planchoniana	**X**					**X**
E. populnea	**X**					
E. propinqua	**X**	**X**				
E. punctata	**X**	**X**				
E. pyrocarpa		**X**				
E. resinifera	**X**					
E. robusta			**X**	**X**		
E. rummeryi	**X**					**X**
E. saligna	**X**	**X**	**X**			
E. saligna x botryoides	**X**					
E. seeana					**X**	**X**
E. siderophloia	**X**				**X**	**X**
E. sideroxylon				**X**	**X**	**X**
E. tereticornis	**X**				**X**	**X**
E. tetrapleura				**X**	**X**	
E. tricarpa			**X**	**X**		
Grevillea robusta						**X**
Melaleuca quinquenervia		**X**	**X**	**X**		
Syncarpia glomulifera					**X**	**X**
Count	**38**	**24**	**12**	**12**	**13**	**22**

Table 2. Species in the fruit diet of flying-foxes in NSW with an estimate of the southern limit to their range. Species on this list have been confirmed by direct observation of feeding animals or by identification from faecal or spat material. From Eby and Law (2008).

Family	**Species**	**Common name**	**Latitude of southern limit**
GYMNOSPERMAE			
Podocarpaceae	*Podocarpus elatus*	Plum Pine	35.7
ANGIOSPERMAE			
Anonaceae	*Rauwenhoffia leichardtii*	Zig Zag Vine	30.3
Apocynaceae	*Melodinus australis*	Southern Melodinus	34.5
Arecaceae	*Livistona australis*	Cabbage Palm	37.8
	Archontophoenix cunninghamiana	Bangalow Palm	35.7
Avicenniaceae	*Avicennia marina*	Grey Mangrove	39
Caprifoliaceae	*Sambucus australasica*	Yellow Elderberry	37.8
Chenopodiaceae	*Rhagodia candolleana*	Seaberry Saltbush	Tasmania
Cunoniaceae	*Schizomeria ovata*	Crabapple	36.2
Davidsoniaceae	*Davidsonia* spp.	Davidson's Plum	28.8
Ebenaceae	*Diospyros pentamera*	Myrtle Ebony	35.5
Ehretiaceae	*Ehretia acuminata*	Koda	36.7
Elaeocarpaceae	*Elaeocarpus obovatus*	Hard Quandong	33.3
	E. reticulatus	Blueberry Ash	Tasmania
	E. grandis	Blue Fig	30.7
Escalloniacae	*Polyosma cunninghamii*	Featherwood	35.5
Euphorbiaceae	*Mallotus discolor*	White Kamala	29.7
Icacinaceae	*Pennantia cunninghamii*	Brown Beech	35.7
Meliaceae	*Melia azedarach*	White Cedar	34.9
Monimiaceae	*Hedycarya angustifolia*	Native Mulberry	Tasmania
Moraceae	*Ficus coronata*	Creek Sandpaper Fig	37.8
	F. fraseri	Sandpaper Fig	33.3
	F. macrophylla	Moreton Bay Fig	34.9
	F. obliqua	Small-leaved Fig	36.2

Family	Species	Common name	Latitude of southern limit
	F. rubiginosa	Rusty Fig	37
	F. superba	Deciduous Fig	35.3
	F. virens	White Fig	29.7
	F. watkinsiana	Strangler Fig	32.4
	Maclura cochinchinensis	Cockspur Thorn	35.3
Myrtaceae	*Acmena hemilampra*	Broad-leaved Lilly Pilly	29.4
	A. ingens	Red Apple	28.9
	A. smithii	Lilly Pilly	39
	Rhodamnia argentea	Malletwood	31.4
	Syzygium australe	Brush Cherry	35.7
	S. corynanthum	Sour Cherry	31.6
	S. crebrinerve	Purple Cherry	31.6
	S. luehmanii	Riberry	31
	S. oleosum	Blue Lilly Pilly	34.4
Passifloraceae	*Passiflora herbertiana*	Native Passionfruit sp.	36.2
Pittosporaceae	*Pittosporum undulatum*	Sweet Pittosporum	38.3
Rhamnaceae	*Alphitonia excelsa*	Red Ash	36.2
Rosaceae	*Rubus rosifolius*	Native Raspberry	38.1
Rubiaceae	*Morinda jasminoides*	Morinda	38.3
Sapindaceae	*Diploglottis australis*	Native Tamarind	34.6
Sapotaceae	*Planchonella australis*	Black Apple	34.4
Solanaceae	*Solanum aviculare*	Kangaroo Apple	Tasmania
Urticaceae	*Dendrocnide excelsa*	Giant Stinging Tree	36.7
	D. photinophylla	Shining-leaved Stinging Tree	33.5
Viscaceae	*Notothixos cornifolius*	Kurrajong Mistletoe	33.5
Vitidaceae	*Cissus hypoglauca*	Five-leaf Water Vine	38.2

3. Characterisation of flowering attributes

Temporal and spatial flowering patterns and productivity of diet species are significant components of the assessment of foraging habitat. A high-quality diet species is considered one that has the potential to be highly productive in nectar secretion and pollen provision, is annually reliable in its productivity, and is productive for lengthy periods. Species in the flower diet of flying-foxes were characterised using the productivity and reliability of flowering patterns and seasonal flowering phenology scored at bi-monthly intervals. See Appendix 1 for details of the methods. Non-diet plants were assigned scores of zero.

Productivity and reliability

The measure of productivity is a function of the maximum abundance of resource available to flying-foxes from an individual tree, and the spatial synchrony of flowering of the species in a local area. The reliability of a plant moderates its productivity through time (over many years). Reliability is a measure of the frequency of substantial flowering events. It is a function of annual frequency and the proportion of flowering events that produce significant resources for flying-foxes. Diet species that flower reliably are likely to be of particular importance to flying-foxes at times when many other species fail to flower for environmental reasons.

Weighted productivity x reliability (wt p*r)

Productivity and reliability describe different elements of resource provision. The two scores were combined to create a single value which was used to score the overall characteristics of individual species within vegetation types. Productivity was weighted more highly than reliability in the calculation because flying-foxes are highly mobile over large areas and are known to access rich, but unreliable resources.

Wt p*r = $(\text{productivity})^{0.7} * (\text{reliability})^{0.3}$

Bi-monthly flowering schedules

While most plants in the diet of flying-foxes do not flower or fruit every year, the majority have clear seasonal phenologies. Long-term studies of flowering patterns have found that some eucalypts are able to produce flowers in most months of the year, but that discernible monthly peaks occur in the probability of flowering (Law *et al.* 2000, Hudson *et al.* 2010). The annual flowering schedules of diet plants were collated as presence/absence data at bi-monthly intervals. Periods of sparse (<10% canopy cover) flowering were excluded from assessments.

Information on the flowering attributes of diet plants was compiled from the sources listed above, from the records of apiarists, from published studies, from information that support the apiary industry (e.g. Blake and Roff 1985, Clemson 1986, Somerville 1999) and from preliminary results of a study of the foraging habitats of LRFFs in Queensland (Eyre *et al*. 2018). Where possible, data on flowering schedules and attributes of widespread species were acquired in different regions to test for and accommodate spatial variations. However, the paucity of data available in the central and western zones prohibited repeat assessments in newly mapped areas of the state. It may be that some diet plants are not used throughout their range in these zones. However, there were insufficient field records for this to be confirmed. In the absence of data, diet species were considered to be potentially attractive to flying-foxes throughout these areas.

Table 3. The flowering traits of tree species in the diet of flying-foxes in NSW characterised using scored productivity, reliability and a combined score weighted for productivity. Flowering traits may vary under different conditions. Where more than one score was assigned to a species, the range is given. Decreasing species richness in diet plants in the Central and Western zones is consistent with sparse records of flying-foxes in these areas.

Species	Prod	Relia	Wt P*R	Eby & Law	Central	Western
Angophora costata	0.37	0.3	0.35	X	X	
A. floribunda	0.54	0.3	0.45	X	X	
Banksia aemula	0.54	0.3	0.45	X		
B. integrifolia v. integrifolia	0.77	1	0.83	X		
B. serrata	0.54	0.3	0.45	X		
Callistemon salignus	0.37	1	0.5	X		
Callistemon viminalis	0.37	1	0.5		X	
Castanospermum australe	0.77	1	0.83	X		
Corymbia eximia	0.7	0.3	0.54	X	X	
C. gummifera	0.91	0.3	0.65	X		
C. henryi	0.7	0.3	0.54	X		
C. intermedia	1	0.6	0.86	X		
C. maculata	0.91	0.3	0.65	X	X	
C. tessellaris	0.61	0.15	0.4		X	X
C. trachyphloia	0.54	0.3	0.45	X	X	X
C. variegata	0.91	0.3	0.65	X		
Eucalyptus acmenoides	0.37	0.6	0.43	X		
E. albens	0.7	0.3	0.54	X	X	X
E. amplifolia	0.7	0.15	0.44	X		
E. andrewsii	0.59	0.8	0.65	X	X	
E. bancroftii	0.7	0.3	0.54	X		
E. botryoides	0.54	0.45	0.51	X		
E. camaldulensis	0.7	0.6	0.67	X	X	X
E. campanulata	0.37-0.54	0.30-0.45	0.39-0.45	X	X	
E. conica	0.54	0.8	0.61		X	
E. coolabah	0.54	0.2	0.4		X	X
E. deanei	0.7	0.8	0.73	X	X	
E. fibrosa	0.7	0.3	0.54	X	X	
E. grandis	0.54	0.6	0.56	X		
E. maidenii	0.54	0.3	0.45	X		
E. melanophloia	0.32	0.6	0.39	X	X	X
E. melliodora	0.54-0.70	0.3	0.45-0.54	X	X	
E. moluccana	0.37-0.59	0.30-0.80	0.35-0.65	X	X	
E. muelleriana	0.47	0.3	0.41	X		
E. nubila	0.54	0.7	0.3		X	

Species	Prod	Relia	Wt P*R	Eby & Law	Central	Western
E. ochrophloia	0.7	0.3	0.54			**X**
E. paniculata	0.61	0.3	0.49	**X**		
E. parramattensis	0.54	0.3	0.45	**X**	**X**	
E. pilularis	0.54-0.80	0.45	0.51-0.67	**X**		
E. piperita	0.59	0.45	0.55	**X**	**X**	
E. planchoniana	0.7	0.3	0.54	**X**		
E. populnea	0.31	0.32	0.3		**X**	**X**
E. propinqua	0.47	0.15	0.34	**X**		
E. punctata	0.54	0.6	0.56	**X**	**X**	
E. pyrocarpa	0.7	0.3	0.54	**X**		
E. resinifera	0.54	0.15	0.37	**X**		
E. robusta	1	1	1	**X**		
E. rummeryi	0.7	0.3	0.54	**X**		
E. saligna	0.7	0.8	0.73	**X**		
E. saligna x botryoides	0.54	0.45	0.51	**X**		
E. seeana	0.77	0.8	0.78	**X**		
E. siderophloia	0.91	0.6	0.81	**X**		
E. sideroxylon	0.7	0.3	0.54	**X**	**X**	
E. tereticornis	0.54-0.91	0.15-0.60	0.37-0.88	**X**	**X**	
E. tricarpa	0.47	0.15	0.34	**X**		
Grevillea robusta	1	1	1	**X**		
M. quinquenervia	0.91	0.8	0.88	**X**		
Syncarpia glomulifera	0.54-0.59	0.60-0.80	0.56-0.65	**X**	**X**	
			COUNT	**51**	**26**	**8**

4. Selection of vegetation maps and acquisition of spatial data

Digital vegetation maps from across NSW were compiled and merged to create a single, seamless habitat map for flying-foxes. The accuracy and reliability of the foraging habitat map is directly linked to the spatial accuracy and quality of floristic information and line work contained in the vegetation maps and classifications available to the project. Every effort was made to ensure the best available data was utilised.

The NSW Department of Planning, Industry and Environment is currently in the process of creating a unified State Vegetation Type Map (SVTM) of Plant Community Types (PCT) (NSW Office of Environment and Heritage 2018). Where possible, SVTM data formed the base map layer. At the time of this project, the SVTM had been completed for the western 80% of NSW (Figure 2), with the remaining eastern coastal section yet to be finalised (A. Roff *pers. comm*.). It was therefore necessary to source alternative vegetation maps to serve as the base layer in areas not yet covered by the SVTM.

The Eby and Law (2008) map was taken as the base map layer in that study area. Gaps that arose between the SVTM and Eby and Law (2008) mapping extents were filled based on data identified through an in-depth review of all vegetation mapping available both within public data catalogue sources (i.e. NSW Bionet http://www.bionet.nsw.gov.au/, NSW SEED https://www.seed.nsw.gov.au/) and non-public sources. Mapping completed after the 2008 project was assessed for use in updating the Eby and Law (2008) map.

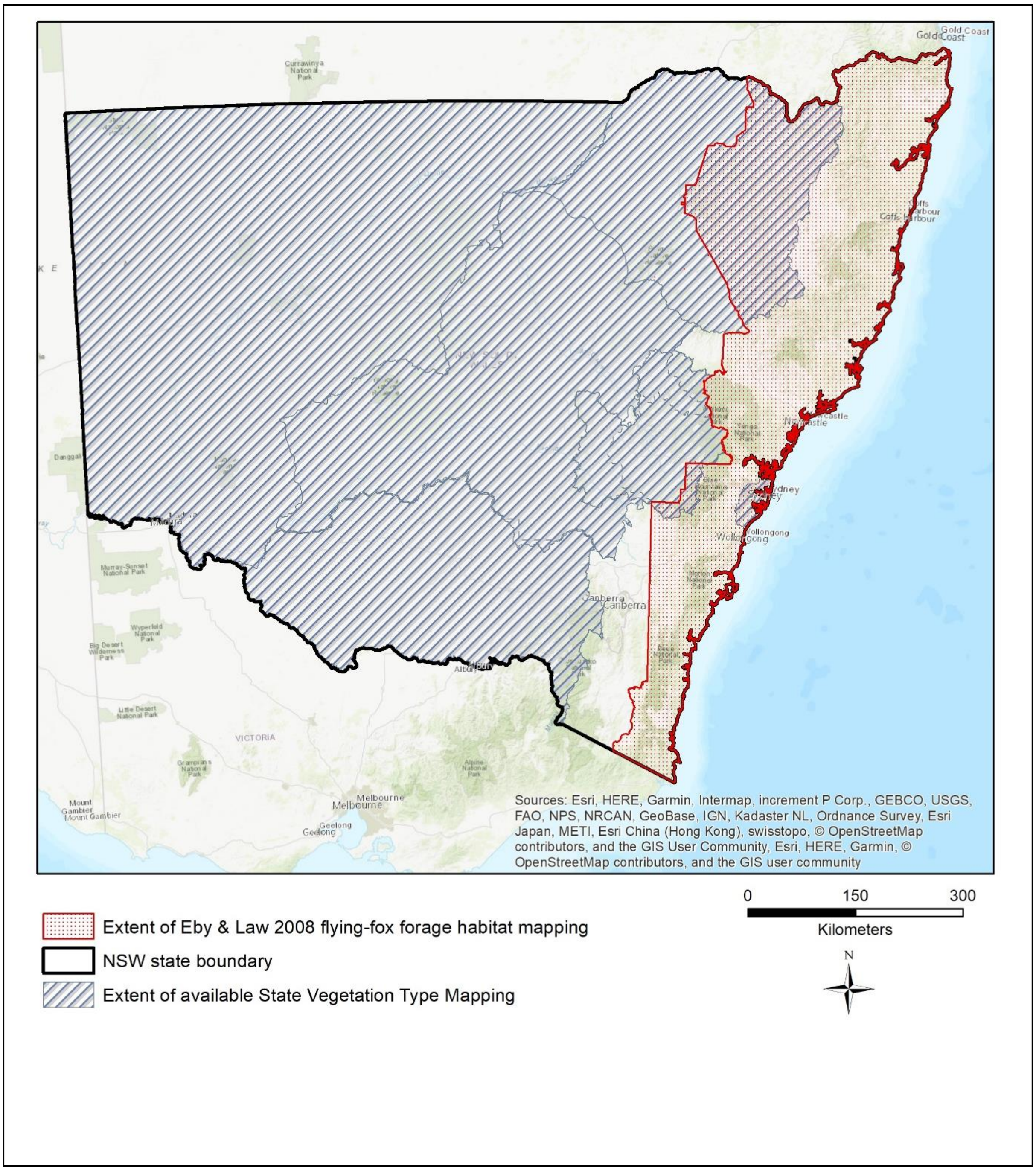
Initially, a combined map footprint layer (NSW Office of Environment and Heritage 2019) which overlays the outer boundaries of native vegetation type maps within a single shapefile was interrogated to gain an understanding of mapped vegetation coverage in target areas and assist with visualising the data available to the project at different scales and locations. The majority of datasets, including all SVTM layers, were downloaded from the SEED data portal. Data searches extended the list of candidate vegetation maps beyond those listed in the state data portal (e.g. Central Coast Regional Council). The technical reports associated with selected vegetation mapping layers were acquired and reviewed.

As there were more than 1,000 overlapping vegetation maps available to the project, a rule-based selection process was required to select and prioritise the most suitable datasets for inclusion in the final state-wide map. To achieve this, the technical reports associated with vegetation mapping layers were acquired and reviewed in terms of:

- suitability of vegetation descriptions for identifying flying-fox diet plants and estimating their relative abundance within vegetation types
- temporal currency, scale and accuracy of line work
- model accuracy (assessed based on number and distribution of field data plots and model results).

Note that technical reports for the majority of SVTM map tiles are not currently available via NSW Bionet. Model accuracy for PCTs can vary widely between vegetation types in the same area due to variations in the quality of data available to the model. PCTs with low model accuracy were highlighted in the data.

Figure 2. A map of New South Wales showing the extent of the existing Eby and Law (2008) flying-fox foraging habitat map against the extent of State Vegetation Type Mapping SVTM available to the project – interpreted as PCT=*** in map descriptors.



In areas covered by multiple map layers, a process of prioritisation was used to select data to be included in the development of the final map. In order of descending priority:

1. attribute relevance (i.e. vegetation descriptions)
2. spatial scale and line work accuracy
3. model accuracy
4. temporal currency.

All spatial data was subject to a Creative Commons Attribution 3.0 Australia Licence or was available for a sharing agreement. The priority rankings of map layers are given in Table 4. A complete list of the 39 datasets used to compile the final state-wide flying-fox foraging habitat map and references for the source data is provided in Appendix 3.

Variations in the scale and accuracy of linework between successive local vegetation mapping projects precluded assessments of change in flying-fox habitat within the Eby and Law (2008) study area. Exceptions occurred in Tweed LGA and Gosford LGA where projects explicitly aimed to describe patterns of loss of native vegetation associated with high rates of development (Kingston and Hall 2011, Bell 2013). This notably incomplete dataset is not examined here.

Table 4. Criteria used for dataset selection in the creation of the 2019 NSW flying-fox foraging habitat mapping.

Dataset	Vis ID	Priority Rank	Vegetation descriptions	Scale	Year published	Other
une nsw	-	2	Various	Various	2008	See Eby & Law report (2008)
lne nsw	-	3	Various	Various	2008	See Eby & Law report (2008)
Tweed LGA	3912	1	Vegetation types	1:5,000	2011	No accuracy assessment provided
Wyong	3904	1	Vegetation types	1:15,000	2016	Accuracy assessment provided
Gosford	3908	1	Vegetation types	1:5,000	2013	No accuracy assessment provided
Wollemi National Park Southeast	4184	1	Vegetation types & descriptions	1:15,000	2012	Qualitative accuracy assessment provided in report
Baulkham 2236	2236	2	Vegetation types	?	2007	
Marra Muog 2322	2322	2	Vegetation types	?	2002	
Hornsby	4471	2	Vegetation types	?	2008	
SENSW SCIVI	2230	1	Vegetation types & descriptions	1:25,000	2010	
Wollemi National Park Northwest	3863	1	Vegetation types & descriptions	1:15,000	2012	Qualitative accuracy assessment provided in report
Wollemi National Park Southeast	4184	1	Vegetation types & descriptions	1:15,000	2012	Qualitative accuracy assessment provided in report
Western Blue Mountains	2231	1	Vegetation types & descriptions	1:15,000	2006	Qualitative accuracy assessment provided in report
SVTM Border Rivers Gwydir Nam	4467	2	PCT	1:25,000	2015	User accuracy per PCT accessed
SVTM Central West Lachlan	4468	2	PCT	1:25,000	2015	User accuracy per PCT accessed
SVTM Central Tablelands	4778	3	PCT	1:25,000	2017	User accuracy per PCT accessed
SVTM Upper Hunter Valley	4184	4	PCT	1:25,000	2018	User accuracy per PCT accessed
SVTM Riverina Murray River	4469	1	PCT	1:25,000	2017	User accuracy per PCT accessed
FE STHN	3858	3	CRAFTI	1:50,000	1999	

5. State-wide map and definition of regions

The selected vegetation maps were spatially merged or ‘stitched’ together to form a seamless state-wide vegetation map. Where selected spatial layers overlapped at the perimeter, selection rules as described above were used to prioritise and select the dominant layer.

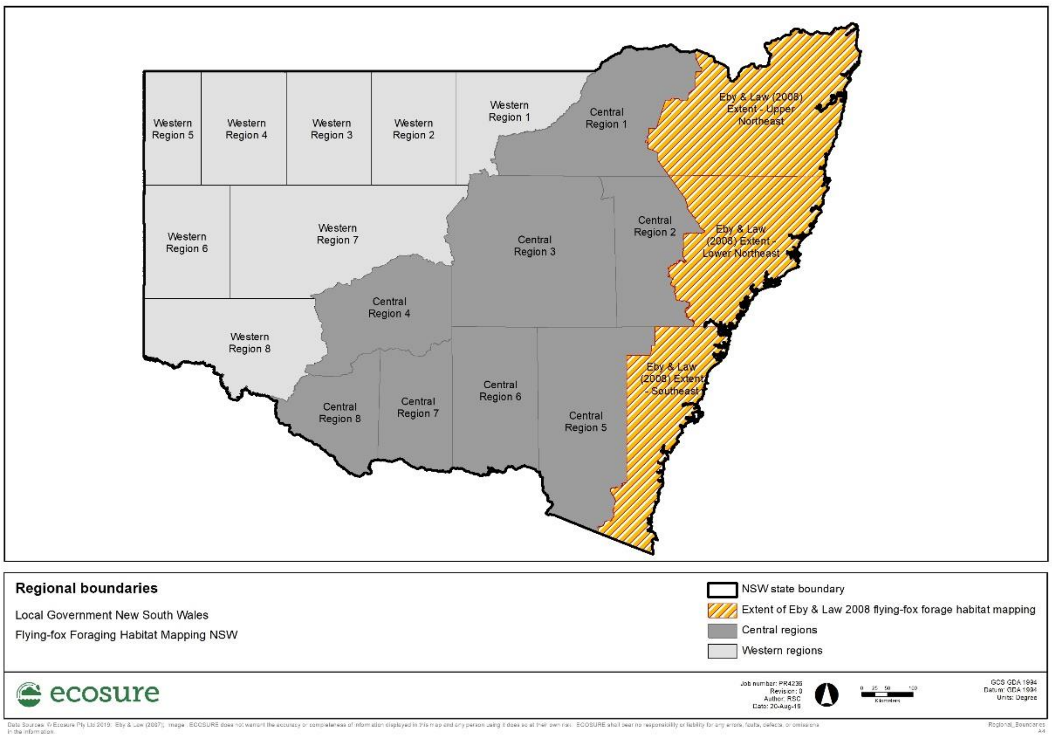
The state-wide map is a compilation of vegetation classifications and mapping projects throughout NSW. The task was approached separately in each of three broad zones from east to west (i.e. eastern (Eby & Law 2008 extent), central and western).

Definitions of regions

Once merged, the combined spatial datasets for the whole of NSW produced a digital layer too data-heavy for ease of viewing or analysis. Therefore, to facilitate creation of the database and to create a final mapping product that is practical to work with on a computer setup for basic GIS operation, the state map was divided to produce 19 regional datasets (Figure 3). Regional boundaries were determined by maximum file size (ideally <800 Mb with a maximum limit of 1 Gb when zipped).

Figure 3 shows the defined regional boundaries broadly grouped into the Eby & Law (2008) extent in the east (its 3 regions unaltered from their original 2008 extents); the central zone (divided into 8 regions); and the western zone (divided into 8 regions). Appendix 3 provides a list of the constituent vegetation mapping layers which were used in each region.

Figure 3. The boundaries of 19 regions defined in the study.



6. Habitat scores

Nectar habitat scores

Feeding habitats of flying-foxes in NSW were identified from descriptions of the plant assemblages (vegetation types) in the vegetation classifications and technical reports accompanying spatial layers. The quality of different habitats was defined by the species richness, relative abundance and flower scores of the diet species they contain.

The relative abundance of diet plants in each vegetation type was estimated from type descriptions provided in technical reports for the vegetation classifications. Habitat scores were calculated by summing the products of estimates of relative abundance and the nectar scores of each diet plant in the vegetation type. Habitat scores for productivity and weighted productivity x reliability were calculated separately for each vegetation type. Total habitat scores were derived by including all diet species in these calculations and six bi-monthly habitat scores of productivity and wt p*r were generated by including in calculations only those species that are productive in each bi-month.

Generating nectar habitat formulae

The procedures used to describe species composition and abundance vary between vegetation classifications and can be grouped as qualitative and quantitative accounts. Each approach uses standard methods: an averaging method was used to develop formulae for qualitative accounts and a frequency-cover abundance method was used for quantitative accounts.

The frequency-cover abundance method is the more objective and was applied preferentially over the averaging method where the data were available. The frequency-cover abundance method was used where the occurrence of species in vegetation types was described numerically in tables of standard data from field samples (e.g. SCIVI map units (Tozer *et al.* 2010) and Yengo-Parr map units (NSW Department of Environment and Climate Change 2008)). For each vegetation class, the frequencies (f) of canopy species were calculated as the proportion of field samples in which the species was recorded. Cover abundance scores (C/A) were taken as median scores from the field samples, scored on a 6 class modified Braun-Blanquet scale (Poore 1955). Tree species with frequencies <0.3 or C/A scores <2 were excluded from calculations of habitat scores due to their infrequent or sparse occurrence in the vegetation class.

The averaging method was used in vegetation classifications where the species composition of the canopy was described by lists of dominant and subdominant or associated species (eg. PCTs). Formulae for calculating habitat scores for these qualitative accounts average the scores of canopy trees, weighted for dominance or sub-dominance. The openness of the canopy layer was estimated from data provided in vegetation descriptions in the central and western zones (e.g. Upper 1 Cover Data in PCT descriptor table, Office of Environment and Heritage 2019). An average percentage canopy cover value was used as an unweighted multiplier. Values ranged from 0.80 in closed forest types to 0.05 in semi-arid woodlands with scattered trees.

Bi-monthly nectar habitat scores

Bi-monthly habitat scores were generated by including in calculations only those species that are productive in each bi-month. Diet species that were not productive in a given bi-month were treated as non-diet plants and assigned scores of zero. For each habitat in each region, bi-monthly habitat scores were produced for wt p*r and productivity.

Tables of all unique vegetation types included in each regional map and the habitat attributes of the types appear in Appendix 4. These summary tables were joined with the spatial data in each region to produce attribute tables for each polygon in the habitat maps. The fields contained in the attribute tables are described in Table 5. In general, the attribute fields include: codes and descriptive names of each vegetation type in the region; a reference for the primary source of the vegetation classification and map associated with the type; a list of diet plants in the type; habitat scores for the type: both total scores and scores calculated at bi-monthly intervals to describe seasonal variation.

7. Habitat maps

A series of maps of the study area illustrate the distribution of vegetation types that contain plants contributing nectar and pollen to the diet of flying-foxes and the relative quality of the types as foraging habitat. Habitat quality in these maps was assessed using the weighted productivity * reliability scores of diet plants. Figure 4 illustrates the distribution of all potential foraging habitat and includes all diet plants. Seasonal variations are not taken into account. Polygons containing the highest-scoring vegetation (wt p*r = 0.8 – 1.0) are small, rare, restricted to areas east of the escarpment and generally not discernible at the scale of this map. Habitat quality as assessed in this project decreases substantially to the west of the Eby and Law (2008) study. Vast areas containing no flowering habitat occur at high altitudes in southern regions of the central zone and in arid areas in the western zone.

Bi-monthly patterns of distribution of nectar-producing habitat shown in Figures 5a-f illustrate the near absence of productive habitat in the western zone in several bi-months and the relative productivity of remnant woodlands in the central zone, particularly in colder bi-months. These patterns are consistent with the habitat requirements of various nectar-feeding birds, including species listed as threatened in NSW and emphasise the potential utility of the maps for assessing habitats of other canopy-feeding nectarivores (see references in Eby 2016).

Table 5. A list of the attributes assigned to each polygon in the spatial layers, describing characteristics of the vegetation types and the diet plants they contain.

Attribute field	Description
REGION	The name of the region in which the polygon occurs. Nineteen regions have been defined in this project. See Figure 3 for regional boundaries
SOURCE	The primary source of the line work and vegetation classification referred to in polygons. See Appendix 3 for references.
VEGCODE	The (generally numeric) identification codes assigned to vegetation types within the source classification.
VEG TYPE	The descriptive names assigned to vegetation types within the source classification.
DIET SPECIES	List of diet species found in vegetation types as identified in vegetation classifications. A five-letter code is used: 1-2 = genus, 3-5=species.
RAINFOREST	Rainforest vegetation categorised by the species diversity of flying-fox diet plants.
TOT WT P_R	weighted productivity * reliability scores for nectar habitat, calculated using all diet species assigned to vegetation types
TOT PROD	productivity scores for vegetation types calculated using all diet species assigned to vegetation types
D-J WT P_R	bi-monthly habitat scores: weighted productivity * reliability scores and productivity scores calculated using diet species that are productive in each bi-month
D-J PROD	
F-M WT P_R	
F-M PROD	
A-M WT P_R	
A-M PROD	
J-J WT P_R	
J-J PROD	
A-S WT P_R	
A-S PROD	
O-N WT P_R	
O-N PROD	
FINAL RANK	The overall conservation rank of habitat in the polygon (scale 1 to 4), based on wt p*r scores. Habitat ranks are assigned to vegetation in the Eby and Law (2008) regions only.
D-J RANK	The conservation rank of habitats in the Eby and Law (2008) regions assessed at bi-monthly intervals
F-M RANK	
A-M RANK	
J-J RANK	
A-S RANK	
O-N RANK	

Figure 4. The distribution of vegetation types that contain plants in the blossom diet list of flying-foxes in NSW. Total habitat scores calculated using wt p*r are grouped at equal intervals and depicted in graduated colours on a red ramp.

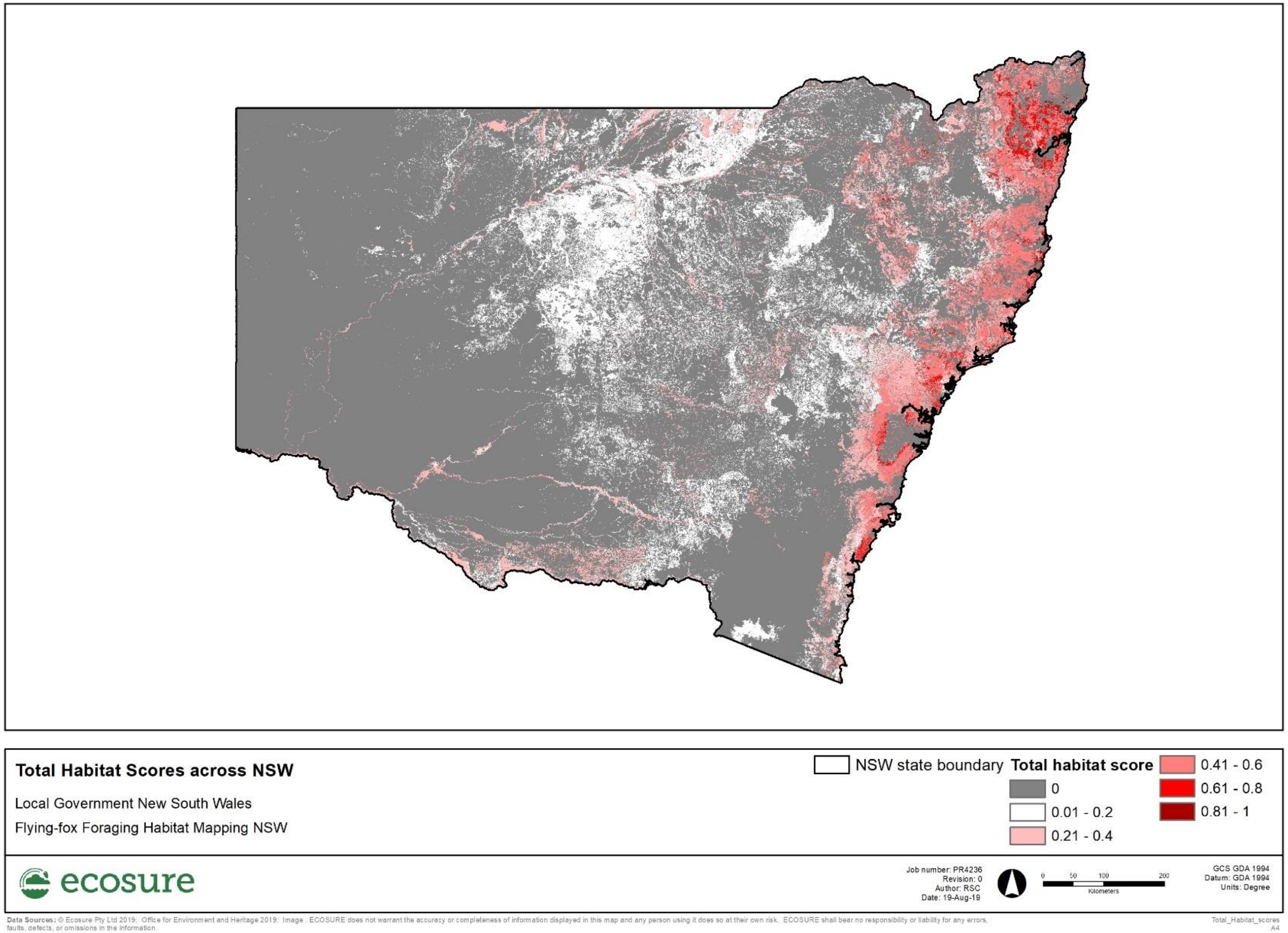


Figure 5a. The distribution of habitat productive in December-January.

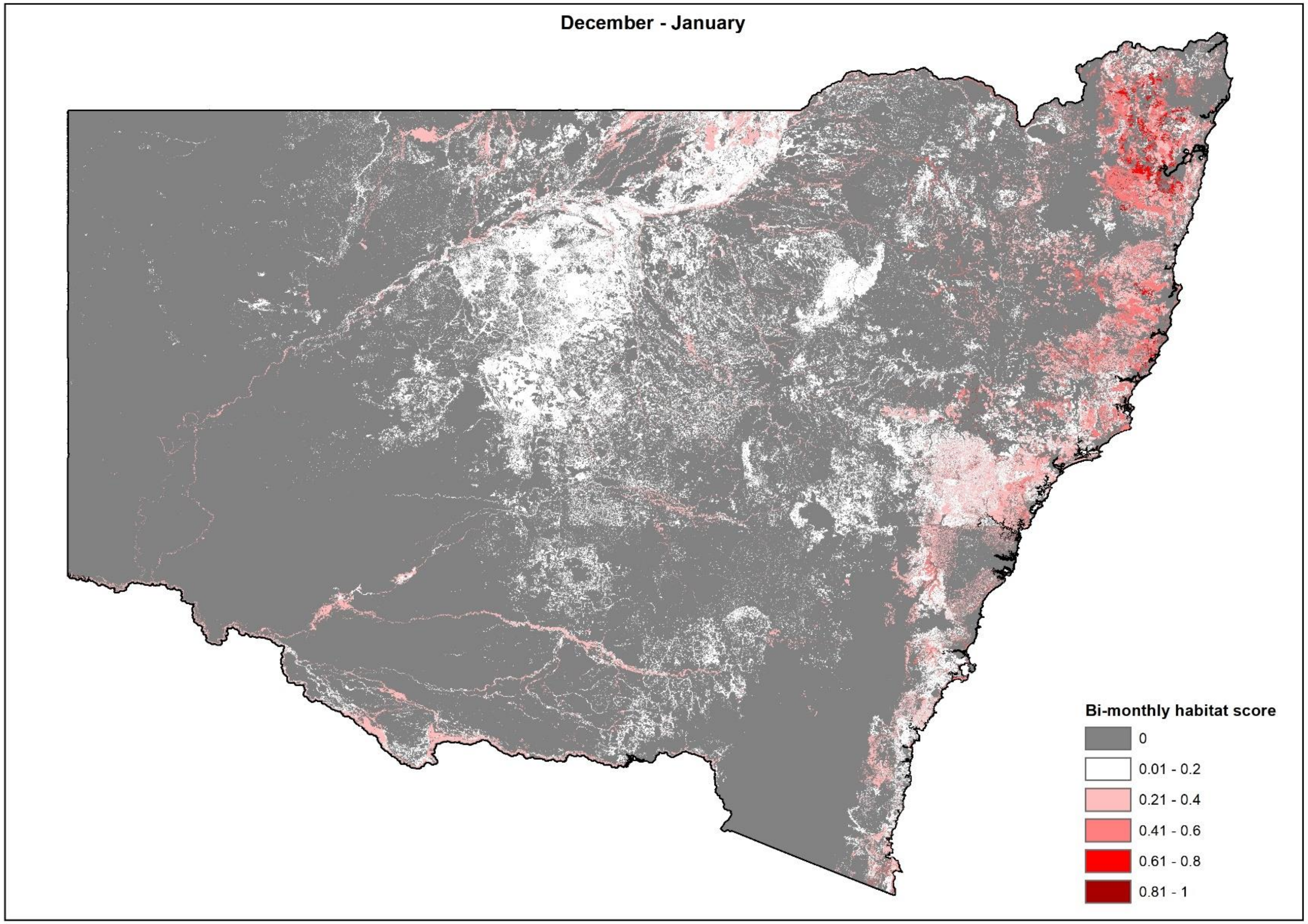


Figure 5b. The distribution of habitat productive in February-March.

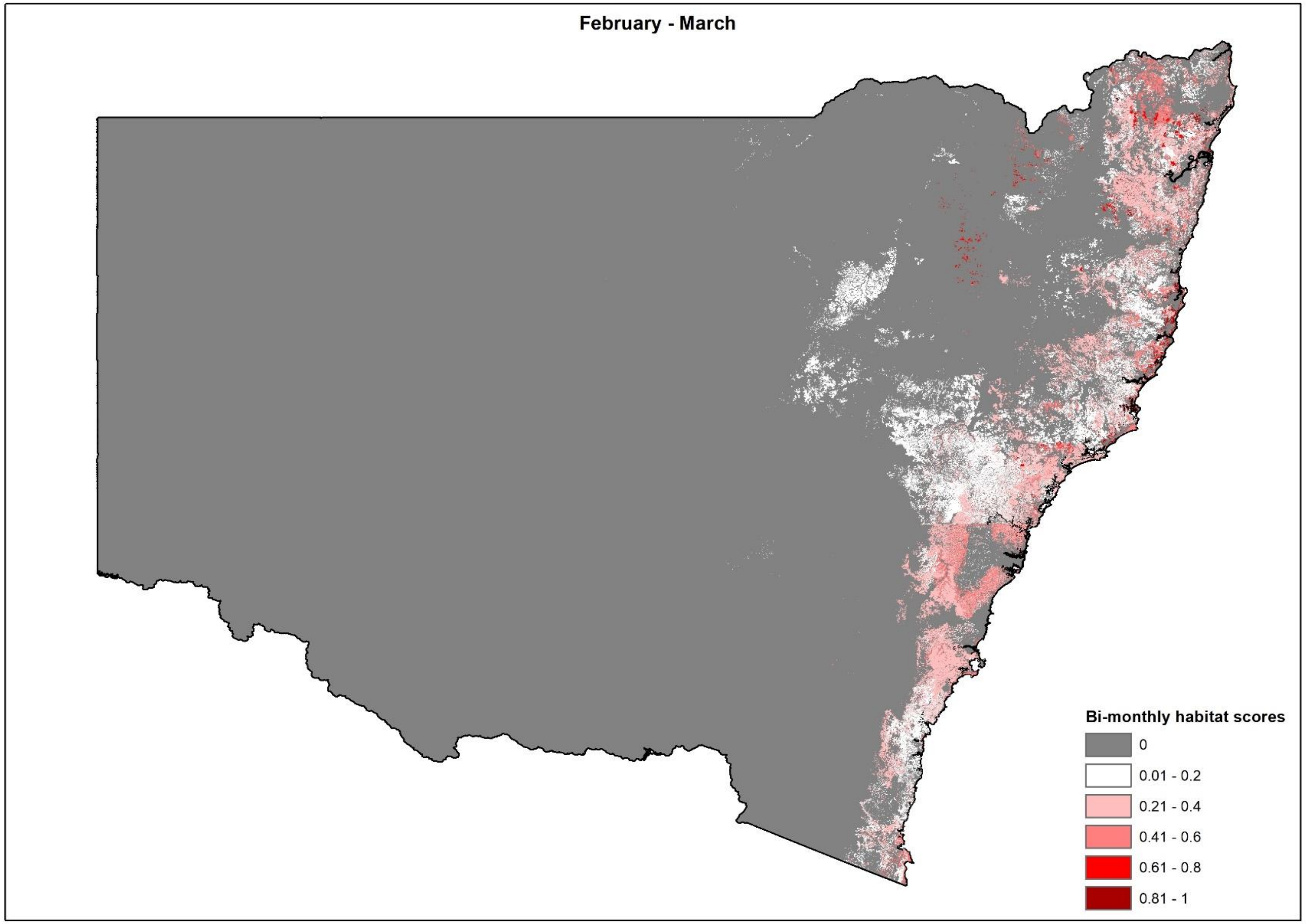


Figure 5c. The distribution of habitat productive in April-May.

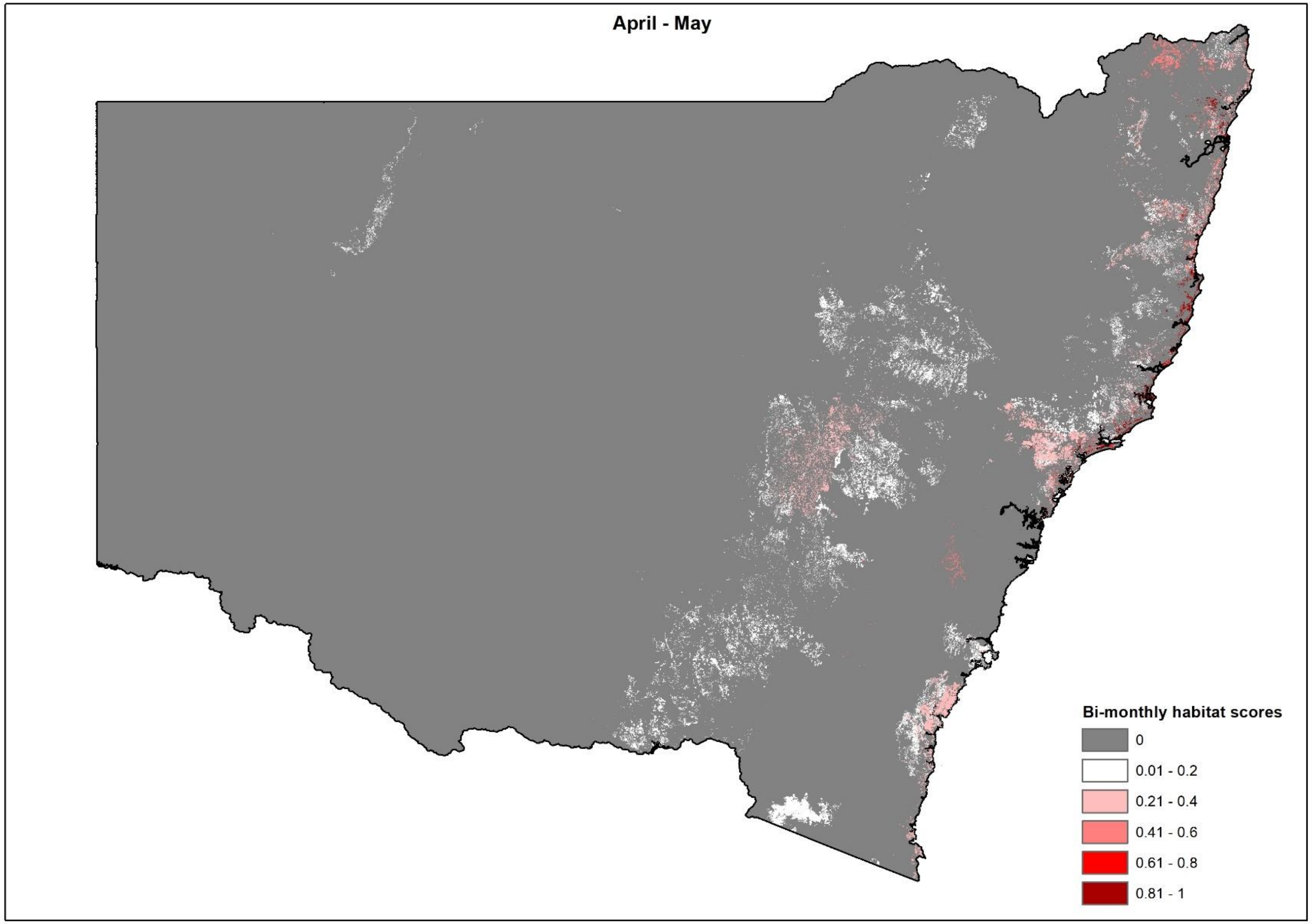


Figure 5d. The distribution of habitat productive in June-July.

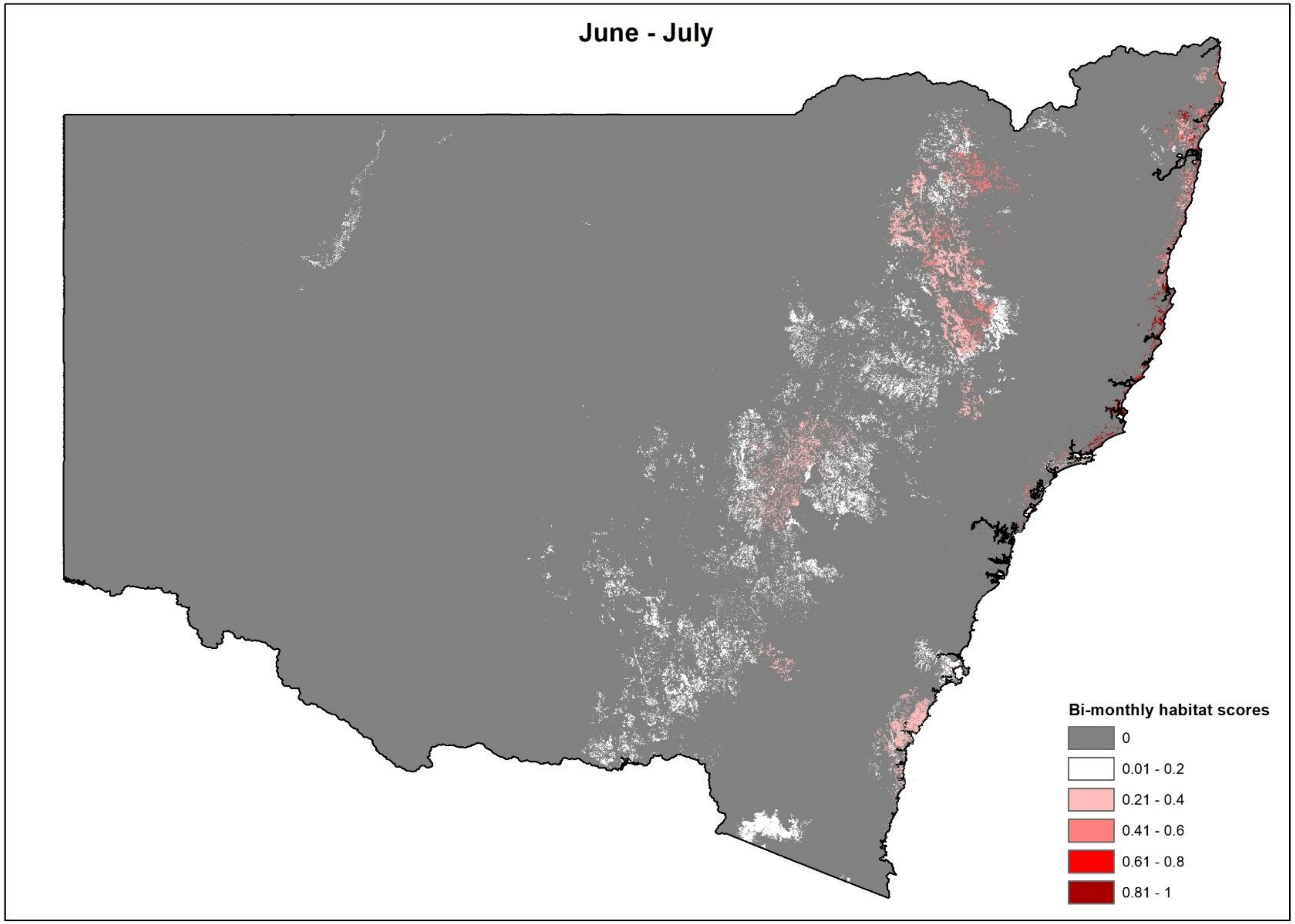


Figure 5e. The distribution of habitat productive in August-September.

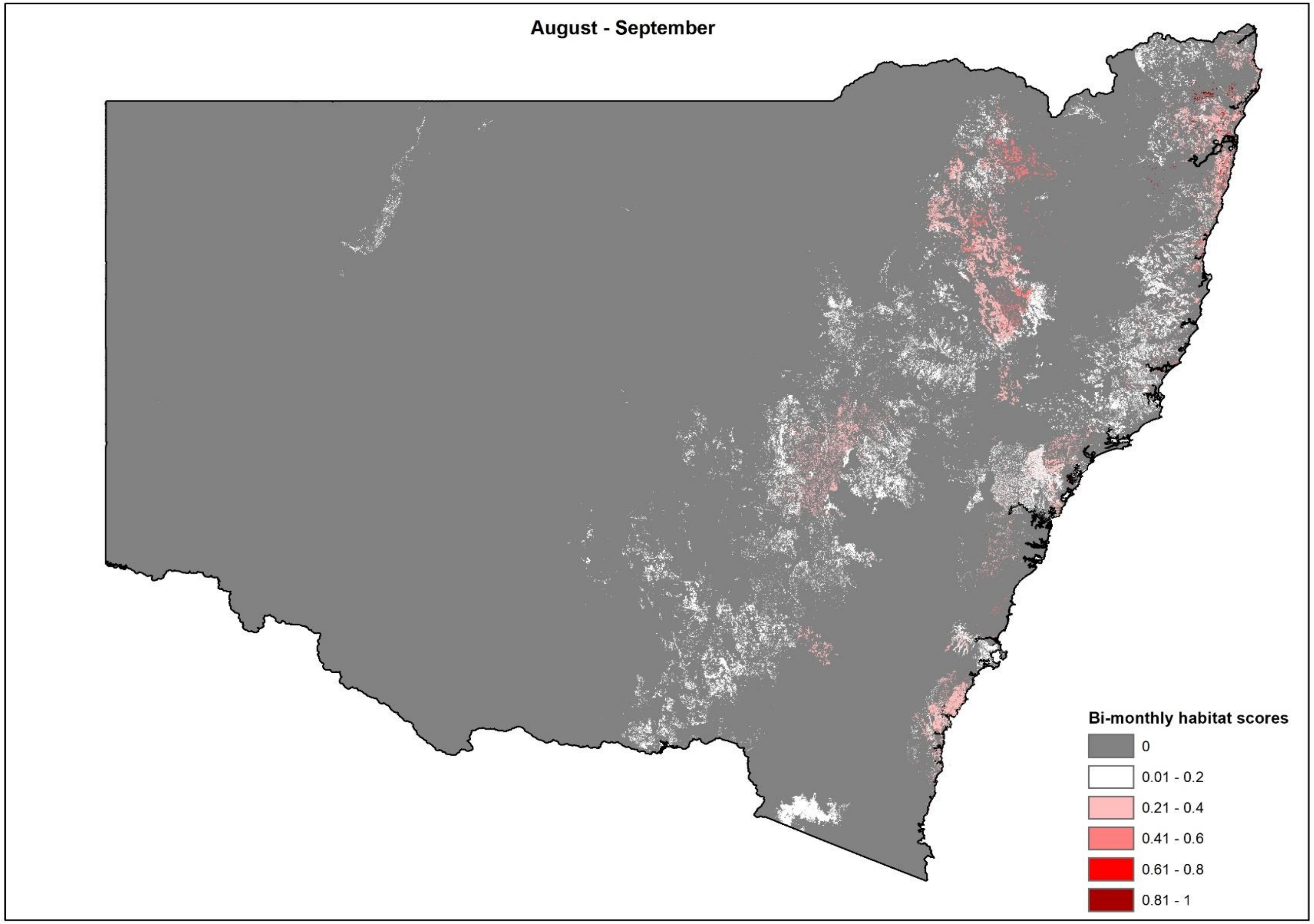
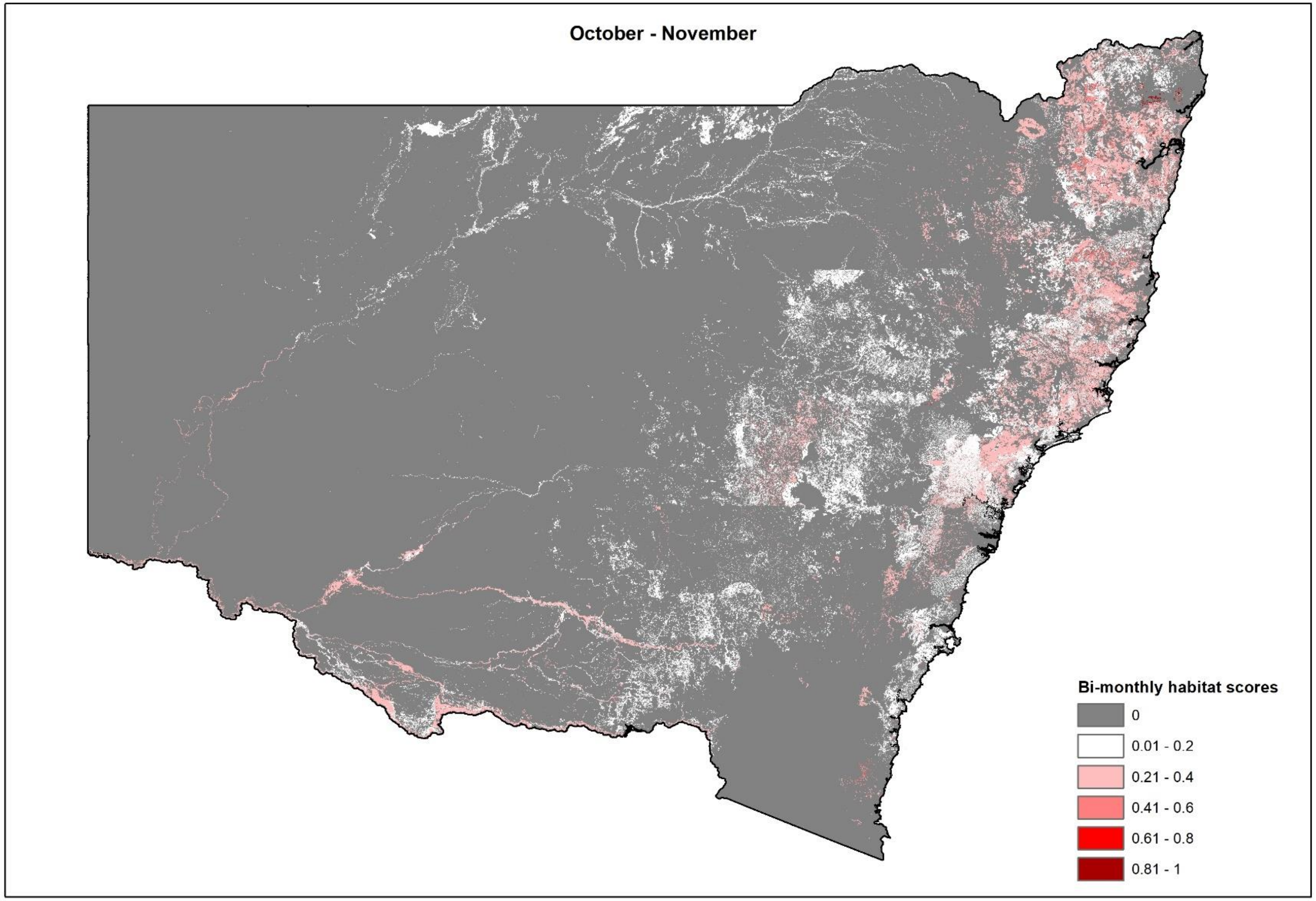


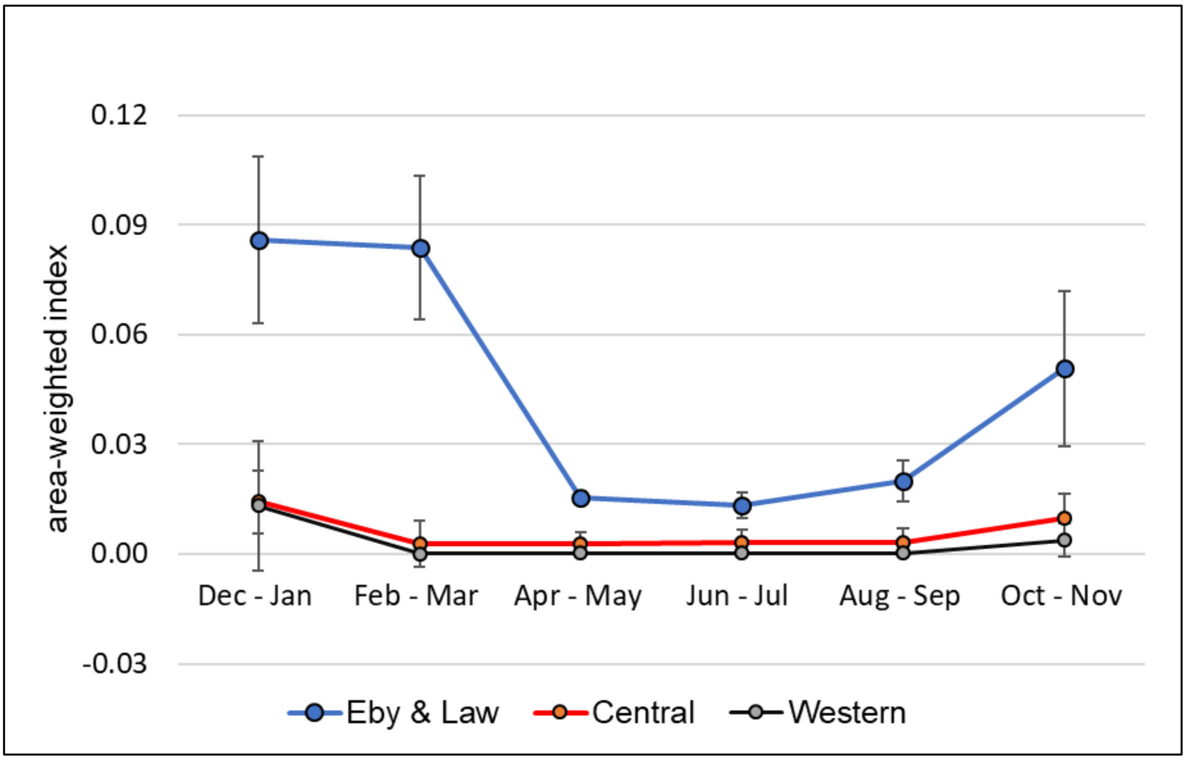
Figure 5f. The distribution of habitat productive in October-November.



Area-weighted indices

Area-weighted indices were calculated to summarise overall levels of nectar habitat quality across regions, and to allow comparisons to be drawn between regions of different land area. They are the sum of products of wt p*r for individual vegetation types and the area of types found within the region of interest, divided by the total land area of the region, ($\Sigma_{1\text{-}j}$(habitat score$_{(j)}$*area$_{(j)}$))/total land area. Area-weighted indices were calculated in each region, at each bi-monthly interval. The plot below is a visualisation of the distinct spatial and temporal patterns of foraging habitat potentially available to flying-foxes in the 3 broad zones of the study area.

Figure 6. Plot of mean $\pm$ SD area-weighted indices of the regions within each of three broad geographic zones in NSW, calculated at bi-monthly intervals.

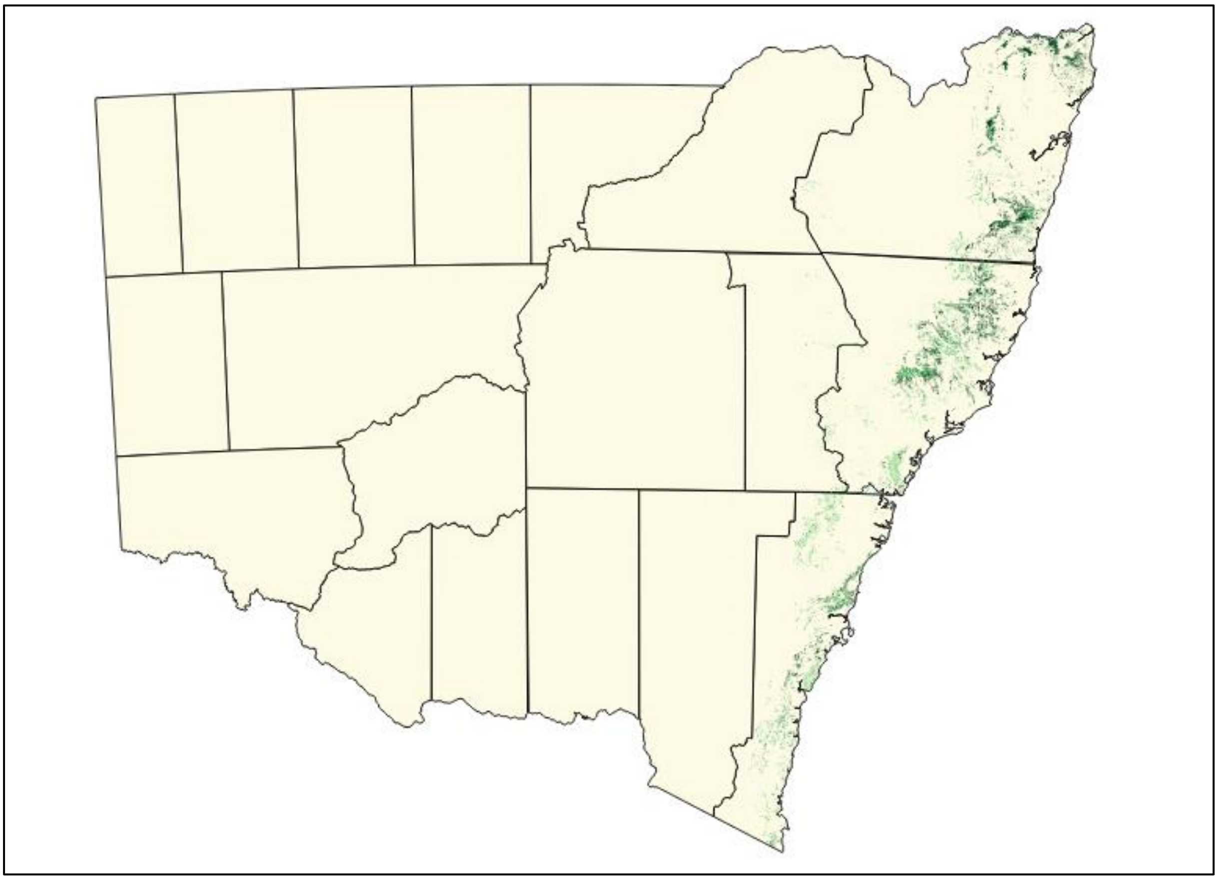


Fruit habitat scores

Insufficient data were available on the characteristics of fleshy fruits in the diet of flying-foxes to allow comparisons to be drawn between species. Rainforest vegetation types were therefore scored on the species richness of diet plants. Types that contained ≥10 species were assigned the highest score, habitats with 5-9 species were assigned an intermediate score, habitats with <5 species were assigned a low score.

The revision of vegetation classifications and spatial layers in the eastern Eby and Law (2008) zone did not substantially alter assessments of the distribution and species richness of fleshy fruit-producing rainforest habitats and the expansion of assessments to central and western zones confirmed the absence of fleshy fruits in all but two regions (Table 5, Figure 7).

Figure 7. The distribution of vegetation types in NSW containing canopy species in the fruit diet of flying-foxes.



Habitat ranks

A primary aim of the Eby and Law (2008) project was to rank the foraging habitat of GHFFs for conservation management. The weighted productivity * reliability scores of habitats were used to assign ranks to vegetation in each bi-monthly period. Each region was assessed separately. Scores were classified into four ranks of equal land area, with 1 being the highest rank. The final nectar rank of a vegetation type was taken as the highest bi-monthly rank assigned to it. This ensured that the maximum productive value of a vegetation type was ranked and mapped.

The reliable nature of fruiting phenologies in diet plants was of particular benefit to GHFFs, providing relatively predictable feeding habitat. A rank of one was subjectively assigned to rainforest habitats containing ≥5 diet plants, a rank of two was assigned to habitats with <5 diet plants.

The scope of this project did not include ranking habitats. Nonetheless, habitat ranks were reassigned to vegetation types in the Eby and Law (2008) study area and included in attribute tables for vegetation in that zone (see Appendix 4). However, the process used to assign habitat ranks was deemed not to be applicable to vegetation in the central and western zones due to the underlying assumption that potential nectar resource was the primary driver of habitat use (i.e. no substantial influence of ambient temperature and humidity, access to water, isolation distance from nearest neighbouring productive habitat, etc.), and uncertainty in the underlying data. Conservation ranks were not assigned to habitats in those zones.

8. References

A complete set of references for Eby and Law (2008) is in Appendix 1.

References for spatial data sources are in Appendix 3.

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