Date of Publication:
April 2019

Cunninghamia

A journal of plant ecology for eastern Australia

The Royal Botanic Garden Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Macrozamia flexuosa C. Moore (Zamiaceae): a review of distribution, habitat and conservation status of an endemic cycad from the Hunter Region of New South Wales

Stephen A. J. Bell

School of Environmental and Life Sciences, University of Newcastle, University Drive, Callaghan, NSW 2308, AUSTRALIA. stephen.bell@newcastle.edu.au

***Abstract*:** A review has been undertaken of herbarium records, point location and full floristic data to assess the distribution, habitat and conservation status of *Macrozamia flexuosa* (Zamiaceae), a rare cycad endemic to the Hunter Region of New South Wales. Spatial analysis of all records (n=588) showed that the species is most prevalent on Permian-aged sediments but also occurs on older Carboniferous sediments and younger Triassic Narrabeen and Quaternary substrates. Point records intersect with a wide range of annual average rainfall bands (<700 to 1400 mm/yr), suggesting either that the species is tolerant of a variety of soil moisture gradients, or that current distribution may be representative of a differing climatic environment. Interpolation of database records (n=397) across 175,000 hectares of high-resolution vegetation mapping showed *Macrozamia flexuosa* to most frequently occur within the Lower Hunter Spotted Gum-Ironbark Forest (41%), followed by Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). Numerical analysis of full floristic plot data (n=86) largely supported these results, with the addition of Hunter Valley Moist Forest to these four regional communities.

A revised assessment of the conservation significance of *Macrozamia flexuosa* suggests that the existing conservation risk code of 2K be amended to 3RCa (distributional range >100km; rare but not immediately threatened; adequately conserved in at least 14 conservation reserves). An extent of occurrence of 6,319 km^2 and an area of occupancy of 696 km^2 have been determined for the species, and an estimated population size of between 1,740,000 and 43,500,000 individuals has been calculated. Under IUCN threat criteria, a code of NT (Near Threatened) is here considered appropriate for *Macrozamia flexuosa*, recognising uncertainties applicable to the assessment of Criteria A and B. It is noted, however, that *Macrozamia flexuosa* may currently be in slow decline due to as yet unknown limitations in flowering, pollination and/or dispersal mechanisms over a long period of time (many decades), with the longevity of individual specimens confounding any observable trends. A lack of demographic data relevant to these life traits limits comprehensive assessment, and further research to address these data gaps is recommended.

Key words: *Macrozamia flexuosa*, Hunter Valley, cycad, distribution, habitat, conservation status

Cunninghamia **(2019) 19: 007–027**
doi: 10.7751/cunninghamia.2019.19.002

Introduction

The endemic Australian genus *Macrozamia* Miq. (Zamiaceae, Cycadales) currently supports 41 named species (https://cycadlist.org), the majority of which occur only in the eastern states. All species are long-lived and resilient plants, often occupying restricted or specialised habitats (Hill & Osborne 2004). In fire-prone environments, this resilience is commonly aided by a subterranean stem which shields the plant from hot temperatures while above-ground leaves are consumed. Pollination in *Macrozamia* and other cycads is effected either by obligate specialist weevils in the *Tranes* genus (Curculionidae) or thrips in the *Cycadothrips* genus (Aeolothripidae). Evidence suggests that both insects and cycads derive a mutual benefit from this association, and that specific weevils or thrips have a sole cycad host (Terry et al 2005). Several studies have examined seed dispersal and spread in *Macrozamia* (e.g. Ballardie & Whelan 1986; Burbidge & Whelan 1982; Snow & Walter 2007; Hall & Walter 2013); in the absence of vertebrate vectors the relatively heavy seed-bearing cones rely on gravity for the dispersal of seed. In one quantitative study in *Macrozamia miquelii* (F.Muell.) A.DC., Hall and Walter (2013), found that between 70-100% of 812 seeds remained within 1 m of parent plants, and the only predator observed to disperse seeds was the brushtail possum *Trichosurus vulpecula*. This mammal also predates and disperses the seed of *Macrozamia communis* L.A.S.Johnson (Ballardie & Whelan 1986) and *Macrozamia lucida* L.A.S.Johnson (Snow & Walter 2007), while Bush Rats (*Rattus fuscipes*) have also been implicated. The poor dispersal mechanism operating in many species of *Macrozamia* has led to development of a 'grove-forming' habit, where dense stands of plants progressively populate and dominate an area primarily through gravity (Hall & Walter 2013).

Macrozamia flexuosa C. Moore (Figure 1) lies within the *Parazamia* section of the genus, characterised by a generally small habit with 1-15 leaves in the crown, thick prominent veins on the lower surface of pinnae, mucilage canals being absent from pinnae, and the lower pinnae not reducing to spines (Hill & Osborne 2004). Within *Parazamia*, *Macrozamia flexuosa* is diagnosed by the erect, strongly spirally twisted leaves with long +/- terete petioles, and lax mid-green pinnae exhibiting involute margins (Hill 1998). The type specimen of *Macrozamia flexuosa* was collected by Ernst Betche in January 1883 from Limeburners Creek, near Karuah (Moore 1883). Endemic to the Hunter Valley region of New South Wales (Bulahdelah to Wyong, inland to Belford), *Macrozamia flexuosa* was originally considered a variety of *Macrozamia spiralis* (Salisb.) Miq. before transferal to *Macrozamia pauli-guilielmi* subsp. *flexuosa* (C.Moore) L.A.S. Johnson, and then raised to specific rank as *Macrozamia flexuosa* (Hill 1998).

Macrozamia flexuosa is considered rare but not threatened in New South Wales or Commonwealth threatened species legislation, and carries a conservation risk code of 2K (a poorly known plant species with a geographical distribution of less than 100km: Briggs & Leigh 1996). Taxa carrying the 'K' label such as this potentially remain at risk from habitat loss and clearing while ever their status remains formally unassessed and unknown. Studies over the last fifteen years have revealed a number of populations of *Macrozamia flexuosa* within secure conservation reserves (e.g. Werakata & Columbey National Parks: Bell 2004, 2009), yet there has been no quantification or conservation assessment of the species as a whole. Currently, and in contrast to current threatened species legislation in Australia, *Macrozamia flexuosa* is listed on the IUCN Red List as Endangered under Criterion A4c (Hill 2010; IUCN 2019), based on suspected population decline resulting from reductions in area of occupancy, extent of occurrence and/or habitat quality. At the time of that assessment, *Macrozamia flexuosa* was thought to number between 2,500 and 10,000 mature individuals, and to be threatened by over-collecting and land clearance. Only six years earlier, previous assessments (e.g. Hill & Osborne 2004) considered this species to be of Least Concern (LC).

In light of these differing conservations assessments of *Macrozamia flexuosa*, this paper reviews the distribution and habitat of this poorly known taxon, and formally assesses conservation significance. It addresses both the legacy conservation risk code applied by Briggs & Leigh (1996) and implements the IUCN threat criteria to determine a new threat status for this species.

Fig 1. *Macrozamia flexuosa*, showing a male cone, growing in Werakata National Park.

Study Area

With the exception of a few presumed extinct individuals or unconfirmed records elsewhere, *Macrozamia flexuosa* occurs exclusively in the broader Hunter region (taken here as including the northern parts of the Central Coast) of central eastern New South Wales. This region includes the catchments of three major rivers; the Hunter and the Goulburn which converge near Muswellbrook in the west and flow east to the coast at Newcastle, and the Manning which flows to the coast near Taree (Figure 2). Although no formal boundary exists, the lower Hunter is generally considered to occur east from the Singleton district, and includes all or part of the local government areas (LGAs) of Central Coast,

Cessnock, Dungog, Lake Macquarie, Maitland, Mid Coast, Newcastle, Port Stephens and Singleton. The Hunter region lies at the northern end of the Sydney geological basin, which extends south to Batemans Bay. The Sydney Basin is bounded to the north-east, south-east, west and north by geological unconformities and thrust lines, with development thought to have occurred over a long period of time, the final definitive movements of which occurred within the Late Triassic period (Bembrick et al 1973).

The Hunter Valley falls within a warm temperate climatic zone, with a maritime influence near the coast, and experiences warm wet summers and cool dry winters. Rainfall generally peaks in late Summer and early Autumn, although local variations due to topography are evident. Annual average rainfall ranges from 677 mm at Singleton, through 986 mm at Dungog, 1,122 mm at Newcastle and 1,350 mm at Gosford. Temperatures range from a monthly average low of 4.2° C in July to a high of 31.9° C in January, with both extremes recorded at Singleton (Bureau of Meteorology 2018).

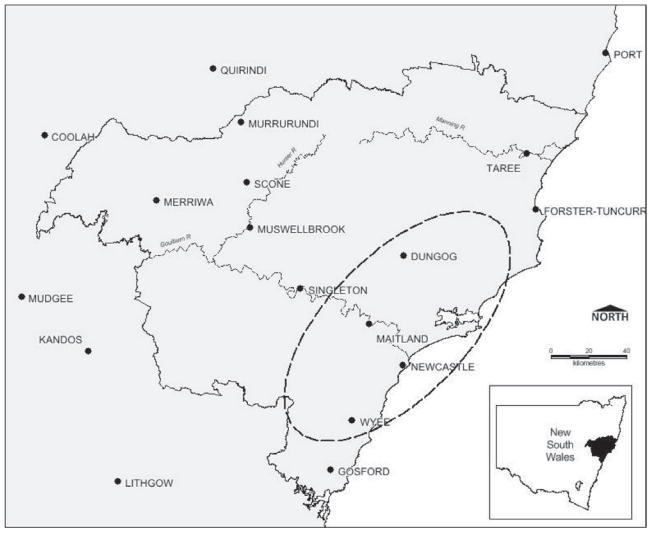

Fig 2. The study area, showing towns within the lower Hunter (ellipse) and broader Hunter region.

Methods

Existing and new populations

Existing records of *Macrozamia flexuosa* were extracted from personal databases and online records and collections within the New South Wales Office of Environment and Heritage *Bionet* database (http://www.bionet.nsw.gov.au/) and the Australian Virtual Herbarium (http://avh.chah.org.au/) (extracted November 2018). Duplicate records were removed from this combined dataset, after careful review of positional co-ordinates, associated written descriptions, collection accession numbers, and dates of observation.

A review was also made of the rapid point data generated as part of high-resolution sub-regional and special purpose vegetation mapping projects (e.g. DECC 2008; Bell 2009; Bell & Driscoll 2008, 2016; Bell & Carty 2012) to glean additional records of *Macrozamia flexuosa*. This dataset comprises 57,293 point locations from across the known distribution of *Macrozamia flexuosa* where dominant plant species and rare and significant taxa have been recorded. Although this data is not comprehensive across the full distribution of *Macrozamia flexuosa* (the bulk fall within Cessnock, Lake Macquarie and the Central Coast LGAs), it does act as a useful proxy in the absence of any other targeted survey data.

Habitat Assessment

Spatial Analysis

Occupied habitat for *Macrozamia flexuosa* was spatially assessed using Geographical Information System (GIS) analysis of point location data with broad environmental attributes, and against high resolution vegetation mapping where this was available (Table 1). For the former, point location data was overlain on available GIS layers for geology (Geoscience Australia) and a regional annual rainfall model developed from Bureau of Meteorology data (C. Driscoll, unpubl.), and univariate statistics applied to determine the most frequent combination of abiotic conditions supporting *Macrozamia flexuosa*. Recently completed high resolution vegetation mapping encompassing over 175,000 hectares of potential *Macrozamia flexuosa* habitat was used to determine the most frequent vegetation communities supporting the species. These mapping projects (Table 1, a subset of the total regional mapping effort) are built upon more than 42,000 ground control data points, and are consequently considered superior to other available vegetation maps which rely on modelling (e.g. NPWS 2000; Sivertsen et al 2012). Nicholls et al (2002) and Hunter (2015) provide reviews of such models, highlighting limitations in their use for conservation assessments.

Table 1. Available spatial data sources of high resolution mapping, used in GIS analysis of *Macrozamia flexuosa* point data.

Project	Source	Area (ha)
eastern Cessnock LGA	DECC 2008	65,690
Central Coast LGA (former Wyong LGA, west of M1 motorway)	Bell & Driscoll 2008	48,530
Lake Macquarie LGA	Bell & Driscoll 2016	38,557
Singleton Army Training Area	Bell & Carty 2012	14,470
Beresfield area (Stony Pinch)	Driscoll & Bell 2014	3,516
Salt Ash Weapons Range	Bell & Driscoll 2006	2,823
Columbey NP & SCA	Bell 2009, 2016	1,562
Total		175,148

Numerical Floristic Classification

Standard full floristic survey plots from areas supporting *Macrozamia flexuosa* were extracted from a regional database maintained by the author. Each plot of 0.04ha (nominally 20 x 20m) recorded all vascular plant species, and attributed each with a modified Braun-Blanquet (1928) cover abundance code (1 = <5% cover, few individuals; 2 = <5% cover, many individuals; 3 = 6-25% cover; 4 = 26-50% cover; 5 = 51-75% cover; 6 = 76-100% cover). Data

from these plots were analysed using the Primer multivariate statistical program (v6, Clarke & Gorley 2006) to assist identification of occupied habitat for the species. The CLUSTER and MDS analysis modules were used to examine patterns within the dataset, while the SIMPER routine was used to identify diagnostic species groups. Where possible, defined habitats were then aligned to regional (NPWS 2000) vegetation communities. Plant nomenclature follows the New South Wales online flora PlantNET (http://plantnet.rbgsyd.nsw.gov.au/floraonline.htm).

Results

Extant populations

Regionally, 588 separate records of *Macrozamia flexuosa* were retrieved from database auditing, spread across nine local government areas of the lower Hunter (Figure 3). The oldest record was in 1881 from near Limeburners Creek (Port Stephens LGA), while the most recent was in 2018. Most records occurred within the Cessnock LGA (300), followed by Lake Macquarie (73), Port Stephens (57), Dungog (52), Singleton (34), Mid Coast (32), Maitland (9), Newcastle (8) and Central Coast (1) LGAs. One of these records lies north of Taree in Coorabakh National Park and may be in error or represent a highly disjunct population; field survey undertaken in that location by the author has recorded only *Macrozamia communis*. There is also an additional single record from Shoalhaven LGA, and four in Sydney (1 each in Cumberland and Woollahra LGAs, and 2 in Hornsby LGA), but these too may be in error and require further confirmation.

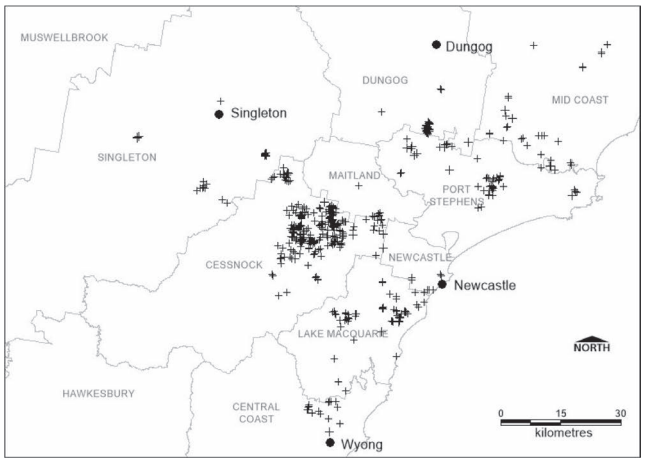

Fig 3. Distribution of *Macrozamia flexuosa* observations, from AVH and Bionet databases and personal records (n=588). Map excludes six outlying records in Mid Coast, Shoalhaven and three Sydney LGAs, which may be extinct, in error or represent disjunct and outlying populations.

Assessment of Abiotic Habitat

Spatial analysis showed that most records (89%) of *Macrozamia flexuosa* occur on a variety of sediments of Permian (73%) and Carboniferous (16%) age (Figure 4). Permian-aged sediments are typically comprised of highly erodible fine-grained sedimentary strata and some conglomerates and sandstones. The Newcastle Coal Measures (Pon; 13% of regional records) comprise coal seams, claystones, siltstones, sandstones and conglomerate. Similarly, fine-grained material comprising the Branxton Formation (Psab; 19%), the Farley Formation (Psdf; 12%) and the Rutherford Formation (Psdr; 10%), collectively support 41% of *Macrozamia flexuosa* records in the region. The Wallaringa Formation (Cswa) within the Carboniferous sediments, which shows as the most important unit within these older sediments (8% regional records), comprises thickly bedded lithic sandstone, conglomerate and some granitoids. These records nearly all emanate from a survey of Columbey National Park (Bell 2009), and consequently may be prominent in the spatial analysis due to sampling bias.

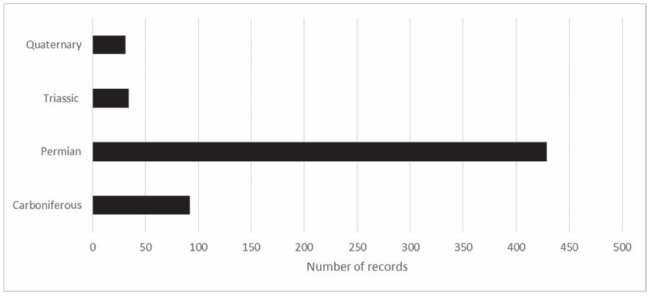

Fig 4. Distribution of *Macrozamia flexuosa* records across major geological strata from the species' full distributional range (n=588).

Analysis of annual rainfall (Figure 5) shows that the bulk of regional *Macrozamia flexuosa* records (93%) fall within the 700-1200mm rainfall band, with a small number of records also present at the extremes (<700mm & >1300mm). This wide range of annual rainfall suggests that the distribution of this species may not be determined or limited by soil moisture availability. Note that the apparent bimodal result shown in the regional rainfall distribution may be attributable to the absence of a comprehensive database of records across the full range of *Macrozamia flexuosa*.

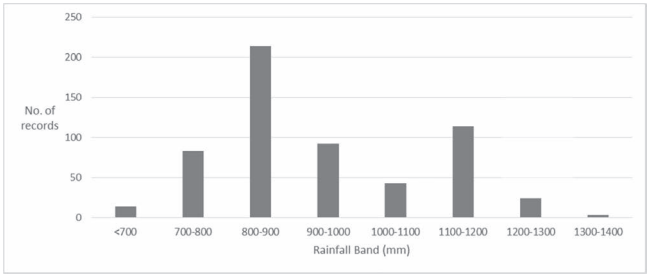

Fig 5. Distribution of *Macrozamia flexuosa* records across annual rainfall bands (n=588).

Assessment of Floristic Communities

Spatial Analysis

Spatial analysis of 397 *Macrozamia flexuosa* records was possible across seven areas of high resolution mapping, totalling c. 175,000 hectares (Table 2). This represents nearly 70% of the total 588 records of *Macrozamia flexuosa* across its entire range, and consequently can be considered

a reasonably good representation of occupied habitat for this species. All high-resolution mapping has employed a consistent community nomenclature, and one that can be readily grouped back to the widely-used regional NPWS (2000) classification. For discussion purposes, occupied habitat of *Macrozamia flexuosa* is cased within this NPWS (2000) regional classification. Four high-resolution communities (Cockle Creek Dune Forest, Ellalong Grey Gum-Stringybark-Apple Forest, Quorrobolong Scribbly Gum Forest, Sandstone Hills Bloodwood Woodland) have no NPWS (2000) equivalent, so have been retained in the analysis (Figure 6).

The most frequent regional vegetation type supporting *Macrozamia flexuosa* was found to be the Lower Hunter Spotted Gum-Ironbark Forest (41% of 397 records). Three other regional units follow this with between 13 and 16% of all records; Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). A further 13 regional communities also support the species, but only between 0.3 and 4% of records, and four communities not defined in NPWS (2000) support between 0.5 and 1.3% of records.

Table 2. Available spatial data sources of high resolution mapping, used in spatial analysis of *Macrozamia flexuosa* point data.

Project	Source	No. *Macrozamia* records
eastern Cessnock LGA	DECC 2008	237
Lake Macquarie LGA	Bell & Driscoll 2016	66
Columbey NP	Bell 2009	38
Salt Ash Weapons Range	Bell & Driscoll 2006	26
Beresfield area (Stony Pinch)	Driscoll & Bell 2014	13
Singleton Army Training Area	Bell & Carty 2012	10
Central Coast LGA (west of M1 motorway)	Bell & Driscoll 2008	7
Total		397

Floristic Analysis

Eighty six sample plots were found to support *Macrozamia flexuosa* during the auditing process, spread across the range of the species (Figure 7). Numerical analysis of these 86 sites revealed eight regional (NPWS 2000) and one transitional (DECC 2008) vegetation community where *Macrozamia flexuosa* is present (Figure 8). For six of the nine defined regional communities, *Macrozamia flexuosa* contributed between 3 and 5% of the total floristic diversity for each community, and was within the top 11 important species for those communities (Table 3). For the Seaham Spotted Gum-Ironbark Forest, *Macrozamia flexuosa* contributed only 2.16% and was less important, while Coastal Plains Scribbly Gum Woodland and Sandstone Grey Myrtle Sheltered Forest showed negligible (<0.1%) contribution. Based on the available dataset of full floristic plot data, important regional habitat for *Macrozamia flexuosa* include those broadly defined as Spotted Gum-Ironbark associations (unit 12, 15, 16 & 17), and those where *Angophora* species on sandy clays or clay loams occur (units 30 & 35). Other habitats where *Macrozamia flexuosa* may be present evidently support few populations of limited size. Floristic compositions of habitat for these nine communities, as determined through SIMPER analysis, are contained in Appendix 1.

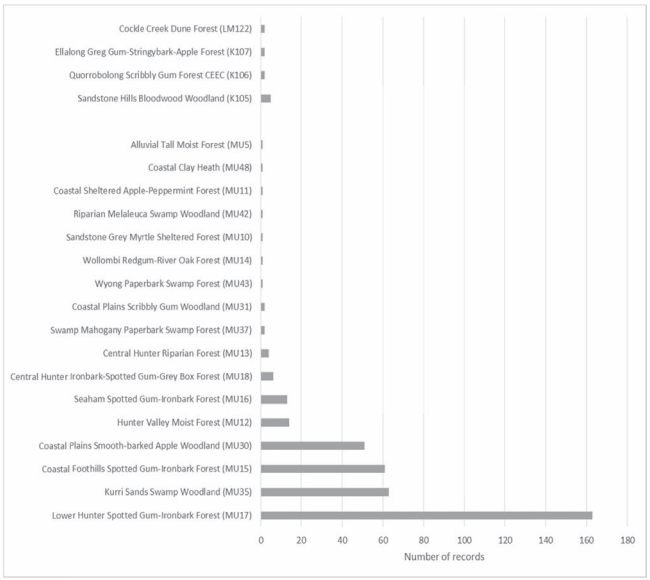

Fig 6. Distribution of *Macrozamia flexuosa* records across available high-resolution vegetation mapping (n=397). Community nomenclature follows NPWS (2000) for all but the upper four communities, which are as reported in sub-regional studies (see Table 1). MU = Map Unit (NPWS 2000); K = Cessnock-Kurri subregional study (DECC 2008); LM = Lake Macquarie subregional study (Bell & Driscoll 2016).

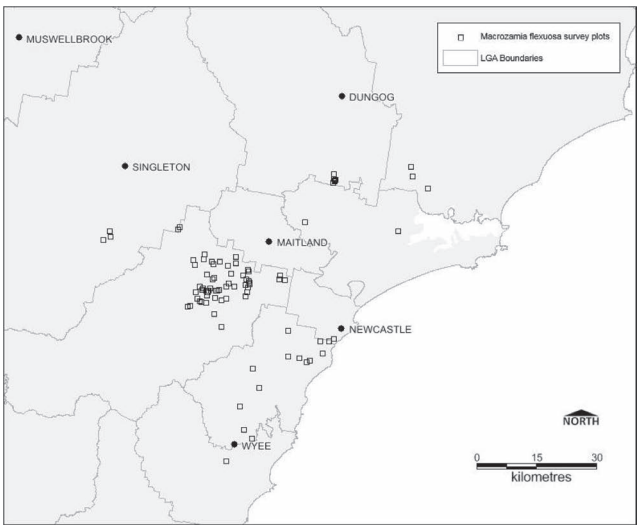

Fig 7. Distribution of sample plots supporting *Macrozamia flexuosa*, as used in the regional numerical analysis for habitat profiling (n=86).

Table 3. Percentage contribution and importance rank of *Macrozamia flexuosa* within nine defined regional communities (habitats), in decreasing order of % contribution.

Regional Community (NPWS 2000)	% Contribution	Importance Rank
Lower Hunter Spotted Gum-Ironbark Forest (Unit 17)	4.53	7
Hunter Valley Moist Forest (Unit 12)	4.44	6
Kurri Sands Swamp Woodland (Unit 35)	3.56	6
Coastal Plains Smooth-barked Apple Woodland (Unit 30)	3.45	6
Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15)	3.42	9
Lower Hunter Spotted Gum-Ironbark Forest (Transition) (Unit 17)	3.24	11
Seaham Spotted Gum-Ironbark Forest (Unit 16)	2.16	23
Coastal Plains Scribbly Gum Woodland (Unit 31)	-	-
Sandstone Grey Myrtle Sheltered Forest (Unit 10)	-	-

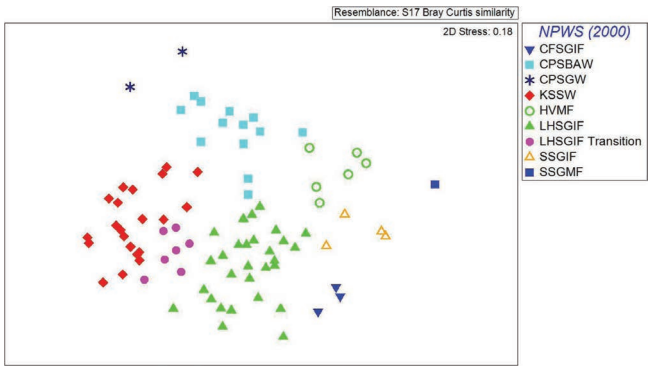

Fig 8. MDS ordination of 86 floristic sites supporting *Macrozamia flexuosa*, generated through the Primer analysis, and classified to the NPWS (2000) regional classification. Key: CFSGIF = Coastal Foothills Spotted Gum-Ironbark Forest; CPSBAW = Coastal Plains Smooth-barked Apple Woodland; CPSGW = Coastal Plains Scribbly Gum Woodland; KSSW = Kurri Sands Swamp Woodland; HVMF = Hunter Valley Moist Forest; LHSGIF = Lower Hunter Spotted Gum-Ironbark Forest; SSGIF = Seaham Spotted Gum-Ironbark Forest; SSGMF = Sandstone Grey Myrtle Sheltered Forest.

Each community can be briefly summarised as:

1. **Lower Hunter Spotted Gum-Ironbark Forest (Unit 17)** – Commensurate with the Endangered Ecological Community of the same name, typified by a canopy of *Corymbia maculata* and *Eucalyptus fibrosa*, over an understorey of prickly shrubs such as *Daviesia ulicifolia, Bursaria spinosa* and *Melaleuca nodosa*. Ground layer vegetation includes the grasses *Entolasia stricta, Aristida vagans* and *Themeda triandra*. *Macrozamia flexuosa* is locally common and widespread in this habitat, and in some areas co-occurs with *Macrozamia reducta*.

2. **Hunter Valley Moist Forest (Unit 12)** – Hunter Valley Moist Forest is a more sheltered form of the wider ranging Spotted Gum-Ironbark associations, and is typified in the canopy by *Corymbia maculata, Eucalyptus punctata, Eucalyptus acmenioides* and *Eucalyptus paniculata* or *Eucalyptus siderophloia*. Common understorey components include *Myrsine variabilis, Notelaea longifolia, Pittosporum undulatum, Polyscias sambuccifolia, Breynia oblongifolia* and *Persoonia linearis*. *Macrozamia flexuosa* can be locally common in this community type, but more often it is present as scattered individuals only.

3. **Kurri Sands Swamp Woodland (Unit 35)** - Broadly encompassed by the Endangered Ecological Community of the same name, this community occupies broad sandy plains, low ridgelines and clay-loam basins in the Cessnock to Kurri Kurri area of the lower Hunter. It supports a variable composition of open or scrubby forests of *Angophora bakeri, Eucalyptus parramattensis* subsp. *decadens, Corymbia gummifera, Eucalyptus racemosa, Eucalyptus fibrosa* and *Eucalyptus* sp aff *agglomerata* with a shrubby or grassy understorey. DECC (2008) have described five variants of Kurri Sands Swamp Woodland, and *Macrozamia flexuosa* can occur in any of these as widely spaced individuals.

4. **Coastal Plains Smooth-barked Apple Woodland (Unit 31)** – An open forest or woodland typified by the presence of *Angophora costata* in the canopy, but with co-occurring species also including *Corymbia gummifera, Eucalyptus umbra* and in some areas *Eucalyptus piperita* and/or *Eucalyptus haemastoma.* Understorey vegetation is generally shrubby and comprises various *Acacia* spp. and peas (*Pultenaea, Daviesia*), *Banksia collina* and *Leptospermum trinervium*. Within this habitat, *Macrozamia flexuosa* occurs as scattered individuals or small groups of plants, but never dominates the ground layer vegetation.

5. **Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15)** – An open forest occurring on the foothills adjacent to the coastal plains. Dominant canopy species include *Corymbia maculata, Eucalyptus paniculata, Eucalyptus punctata, Eucalyptus fergusonii, Eucalyptus umbra* and/or *Eucalyptus siderophloia*, over an understorey of species such as *Bursaria spinosa, Podolobium ilicifolium, Daviesia squarrosa, Notelaea longifolia* and *Persoonia linearis*. *Macrozamia flexuosa* is present in this habitat as scattered individuals or small groups of plants.

6. **Lower Hunter Spotted Gum-Ironbark Forest - Transitional (included in Unit 17)** - The Lower Hunter Spotted Gum-Ironbark Forest Transition group shown on Figure 8 is representative of the Sandstone Hills Transition Forest (MU105b) from the Cessnock area (DECC 2008). Although not defined in NPWS (2000), this type occurs on resistant sandstones of Permian age, and can be considered a form of Lower Hunter

Spotted Gum-Ironbark Forest. Common canopy species in this group include *Corymbia maculata, Corymbia eximia, Eucalyptus fibrosa, Eucalyptus capitellata* and *Corymbia gummifera*. *Macrozamia flexuosa* can be reasonably common in this habitat, but is often localised.

7. **Seaham Spotted Gum-Ironbark Forest (Unit 16)** – An open forest occurring generally north of the Hunter River, and dominated in the canopy by a range of eucalypts but *Corymbia maculata, Eucalyptus siderophloia*, and *Eucalyptus acmenioides* are generally abundant. Grasses and herbs dominate the ground layer, particularly *Microlaena stipoides*, and *Macrozamia flexuosa* occurs occasionally as individuals or in very small groups.
8. **Coastal Plains Scribbly Gum Woodland (Unit 31)** – An open forest or woodland characterised by *Eucalyptus haemastoma, Corymbia gummifera, Eucalyptus capitellata* and *Angophora inopina* in the canopy, over a heathy understorey of species such as *Banksia collina, Lambertia formosa, Leptospermum trinervium, Isopogon anemonifolius* and *Pultenaea tuberculata*. *Macrozamia flexuosa* is very rare in this habitat, and weight of records relative to survey effort suggests that this is marginal habitat.
9. **Sandstone Grey Myrtle Sheltered Forest (Unit 10)** – A gully forest dominated by *Backhousia myrtifolia* in the mid-layer, under emergent eucalypts. Ground layer vegetation is typically sparse due to the shading effect of the *Backhousia* canopy, but commonly includes ferns such as *Doodia aspera* and *Pellaea falcata*. This habitat is relatively rare towards the coastal parts of the region, but becomes better developed in inland areas where rainfall is less. *Macrozamia flexuosa* is very rare in this community type, and occurs only where it adjoins more favourable habitat.

Discussion

Regional Habitat

Two complementary methods have been used in this study to provide an assessment of habitat for *Macrozamia flexuosa*: spatial GIS analysis of a cleaned dataset of herbarium collections and observation records against environmental and locally-accurate vegetation mapping, and numerical analysis of full floristic plot data. Both methods have captured an array of existing and new data to identify habitat and vegetation communities currently supporting *Macrozamia flexuosa*. Collectively, these two methods have identified key habitats and vegetation communities for the species, summarised in Table 4 and Table 5.

In the spatial analysis, it was shown that *Macrozamia flexuosa* occurs most prevalently on Permian-aged sediments (principally the Branxton, Farley and Rutherford Formations). Older Carboniferous sediments (particularly the Wallaringa Formation) are also well represented in the data, although this is likely the result of previous concentrated survey effort within Columbey National Park (Bell 2009). Smaller occurrences are also evident within the younger Triassic Narrabeen and Quaternary sediments. A wide spread in annual average rainfall received was evident for areas supporting *Macrozamia flexuosa*, ranging from <700mm/yr to ~1400mm/yr. This suggests either that the distribution of this species is not limited or determined by available soil moisture, and that it is tolerant of a wide range of moisture environments, or that current-day populations are representative of a former environment with a different climate. Other studies (e.g. Preece et al 2007; Binns & Meek 2008) have shown a link between *Macrozamia* distribution and high moisture availability, although in the present study the largest populations of *Macrozamia flexuosa* occur in the drier habitats. Working on *Macrozamia lucida*, Kaye et al (2016) found a correlation between plant distribution and elevated moisture (relative humidity at the ground surface), but conceded that current-day distribution may represent a contraction from a formerly wider range under differing climatic regimes, rather than reliance on available moisture.

Table 4. Summary of GIS analysis of environmental attributes supporting *Macrozamia flexuosa* (n=588).

Attribute	Key elements (% of dataset)
Geological Age	Permian (73%)
	Carboniferous (16%)
	Triassic (6%)
	Quaternary (5%)
Geological Formation	Branxton Formation (Psab) (19%)
	Newcastle Coal Measures (Pon) (13%)
	Farley Formation (Psdf) (12%)
	Rutherford Formation (Psdr) (10%)
	Wallaringa Formation (Cswa) (8%)
Annual Rainfall (mm/yr)	800-900 (37%)
	1100-1200 (19%)
	900-1000 (16%)
	700-800 (14%)
Vegetation Type (GIS analysis)	Lower Hunter Spotted Gum-Ironbark Forest (MU17) (41%)
	Kurri Sands Swamp Woodland (MU35) (16%)
	Coastal Foothills Spotted Gum-Ironbark Forest (MU15) (15%)
	Coastal Plains Smooth-barked Apple Woodland (MU30) (13%)
	Hunter Valley Moist Forest (MU12) (4%)
	Seaham Spotted Gum-Ironbark Forest (MU16) (3%)

Table 5. Summary of numerical analysis of habitats (floristic type) supporting *Macrozamia flexuosa* (n=86). Nomenclature follows NPWS (2000).

Primary Habitats	*Secondary Habitats*
Lower Hunter Spotted Gum-Ironbark Forest (MU17)	Seaham Spotted Gum-Ironbark Forest (MU16)
Hunter Valley Moist Forest (MU12)	Coastal Plains Scribbly Gum Woodland (MU31)
Kurri Sands Swamp Woodland (MU35)	Sandstone Grey Myrtle Sheltered Forest (MU10)
Coastal Plains Smooth-barked Apple Woodland (MU30)	
Coastal Foothills Spotted Gum-Ironbark Forest (MU15)	
Lower Hunter Spotted Gum-Ironbark Forest (Transition) (MU17)	

Interpolation of database records across 175,000 hectares of high-resolution vegetation mapping showed that *Macrozamia flexuosa* has been most frequently recorded within the Lower Hunter Spotted Gum-Ironbark Forest (41% of 397 records), followed by Kurri Sands Swamp Woodland (16%), Coastal Foothills Spotted Gum-Ironbark Forest (15%) and Coastal Plains Smooth-barked Apple Woodland (13%). The remaining 15% of records are spread across a further thirteen regional and four subregional communities, each supporting less than 4% of records. The first two of these (Lower Hunter Spotted Gum-Ironbark Forest and Kurri Sands Swamp Woodland), collectively support 57% of all records and equate to threatened ecological communities protected under the NSW *Biodiversity Conservation Act 2016*.

Numerical analysis of full floristic plot data highlighted the importance of five regionally-defined vegetation communities for *Macrozamia flexuosa*, which largely supported results obtained in the spatial analysis: the Lower Hunter Spotted Gum-Ironbark Forest (Unit 17, & including a transitional form from Cessnock LGA), Hunter Valley Moist Forest (Unit 12), Kurri Sands Swamp Woodland (Unit 35), Coastal Plains Smooth-barked Apple Woodland (Unit 30), and Coastal Foothills Spotted Gum-Ironbark Forest (Unit 15). For all five of these communities, *Macrozamia flexuosa* contributes 3-5% of the diversity of all species present, and ranked in the top ten most important taxa for each community. Other less important regional communities include Seaham Spotted Gum-Ironbark Forest (Unit 16), Coastal Plains Scribbly Gum Woodland (Unit 31) and Sandstone Grey Myrtle Sheltered Forest (Unit 10).

Conservation Assessment

Reserve Representation

Macrozamia flexuosa is currently represented in fourteen secure conservation reserves throughout its range, across nine local government areas (Table 6). The species is also present in several of the State Forests around the Cessnock and Port Stephens region, including Cessnock, Aberdare and Medowie State Forests, and is informally protected in the Salt Ash Weapons Range and Singleton Army Training Area, both managed by the Commonwealth Department of Defence. Based on weight of records, Werakata, Columbey and Belford National Parks provide important habitat for the species, representing 82% of all observations made within conservation estate; collectively all reserves protect only 28% of records across the region.

Table 6. Representation of *Macrozamia flexuosa* within conservation reserve and local government areas, based on GIS analysis of point data (n=588), shown in decreasing order of importance.

Reserve	LGA	No. records
Werakata National Park	Cessnock	69
Columbey National Park	Dungog / Port Stephens	48
Belford National Park	Singleton	16
Werakata State Conservation Area	Cessnock	6
Lake Macquarie State Conservation Area	Lake Macquarie / Central Coast	5
Glenrock State Conservation Area	Lake Macquarie / Newcastle	4
Karuah Nature Reserve	Mid Coast / Port Stephens	4
Sugarloaf State Conservation Area	Lake Macquarie / Cessnock	3
Wallaroo National Park	Dungog / Port Stephens	2
Coorabakh National Park	Mid Coast	1
Medowie State Conservation Area	Port Stephens	1
Pambalong Nature Reserve	Newcastle	1
Pulbah Island Nature Reserve	Lake Macquarie	1
Watagans National Park	Cessnock / Lake Macquarie	1
Total		**162**

Conservation Risk Code

Briggs and Leigh (1996), during the last revision to the conservation risk codes for Australian plant species, attributed *Macrozamia flexuosa* with a code of 2K, indicating a poorly known taxon with a distributional range of less than 100 km. In the light of new information on distribution and reserve presence, it is appropriate to now review this coding and threat criteria to the species. Excluding the six highly disjunct records of *Macrozamia flexuosa* present in the Mid Coast, Shoalhaven and Sydney districts, the species currently occupies a distributional range of 120 km (maximum distance between current records). Additionally, *Macrozamia flexuosa* is present within fourteen conservation reserves which collectively are likely to well exceed 1,000 individual plants (162 point locations). Threats within these reserves are few, but in other land tenures the potential for habitat clearing and development remains current. Following the Briggs and Leigh (1996) system, this suggests that a revised conservation risk code of 3RCa is most suitable (i.e. a rare species with a geographical distribution of >100 km,

and adequately represented by >1,000 mature individuals within secure conservation reserves).

IUCN Criteria Assessment

An IUCN code of Endangered (EN) is currently applied to *Macrozamia flexuosa* in the IUCN Red List (Hill 2010; IUCN 2019), yet the species is currently not listed in threatened species legislation within New South Wales or Australia. As has been found with some other Red List *Macrozamia* occurring across restricted ranges (e.g. *Macrozamia johnsonii* D.L.Jones & K.D.Hill, Binns & Meek 2008; *Macrozamia platyrhachis* F.M.Bailey, Terry et al 2008), there is little justification or explicit documentation as to why such a listing has been determined. Interestingly, previous assessments (e.g. Hill & Osborne 2004, using 1994 IUCN categories modified to accommodate long-lived perennial plants) considered *Macrozamia flexuosa, Macrozamia platyrhachis* and *Macrozamia johnsonii* to be of Least Concern (LC), and not at risk.

A revised conservation assessment following the guidelines of IUCN (2017) has now been undertaken for *Macrozamia flexuosa*, using the data and observations discussed in this paper (Appendix 2). Although a rare taxon, *Macrozamia flexuosa* fails to meet any of the five IUCN criteria for any threatened category. For Criterion A, estimates exceeding the thresholds of the past or expected reduction in population sizes over 60 years (three generations) have been made, but these are subjective in nature and may change should a more quantitative assessment of habitat loss over this time period be undertaken. For Criterion B, data on population attributes could not meet two out of three sub-criteria to trigger a listing as Endangered or Vulnerable on distribution grounds, despite the primary criterion of extent of occurrence and area of occupancy being met. Best estimates for population size clearly exceed the thresholds for both Criteria C and D, and a quantitative analysis required under Criterion E is not possible due to data limitations.

Under IUCN (2017) criteria, and following the conclusions noted above, a code of NT (Near Threatened) is here considered appropriate for *Macrozamia flexuosa*, recognising some of the uncertainties applicable to the assessment of Criteria A and B. This finding is in contrast to the current Red List determination of Endangered for this taxon (IUCN 2019), but is consistent with other studies on *Macrozamia* that have questioned listings of Endangered on the IUCN Red List (Binns & Meek 2008; Terry et al 2008). Depending on the extent of land clearing and development in existing habitat that may continue in coming decades, detailed population estimates and a review of the NT coding for *Macrozamia flexuosa* may be necessary.

Further Research

Macrozamia flexuosa is clearly a species that is widespread within its relatively restricted geographical distribution (c. 6,300 km^2), yet appears to exist predominantly as scattered individuals or small groups in most habitats. The grove-forming habit of other *Macrozamia*, as outlined in Hall and Walter (2013), does not seem to be typical for *Macrozamia flexuosa* at many of the known sites. This, together with anecdotal observations of limited cone production and seedling presence in many populations, suggest that there may be some reproductive and dispersal limitations acting on this species, effects of which are masked by the longevity of mature individuals. A demographic and reproductive study of this species would be beneficial in this regard, and the methods devised by Borsboom et al (2015) for assessing population structure through leaf traits may apply well to *Macrozamia flexuosa*.

No research has yet been undertaken on pollination in *Macrozamia flexuosa* although Forster et al 1994 have identified obligate specialist weevils *Tranes* spp. for *Macrozamia pauli-guilielmi* (the species in which *Macrozamia flexuosa* was formerly considered a subsp.); this is an avenue for further research. An absence of appropriate insect pollinators may help to explain the apparent lack of fruiting and dispersal in *Macrozamia flexuosa*, and management to retain this pollinator in the environment may be required.

Additionally, as with all *Macrozamia* species the dispersal of seed is highly localised due to their large size and the scarcity of dispersal mechanisms. Some studies (Ballardie & Whelan 1986; Snow & Walter 2007; Hall & Walter 2013) have found that Common Brushtail Possum (*Trichosurus vulpecula*) and Bush Rats (*Rattus fuscipes*) consumed or carried *Macrozamia* seed away from mature plants, but dispersal rarely exceeded one metre. Burbidge and Whelen (1982) recorded dispersal distances of up to 40 cm for *Macrozamia riedlei* (Gaudich.) C.A.Gardner (very rarely up to 24 m), Hall and Walter (2013) reported one metre for *Macrozamia miquelii* (rarely up to 5 m), and Terry et al (2008) found no evidence of dispersal in *Macrozamia platyrhachis*. For *Macrozamia communis*, Ballardie and Whelan (1986) recorded dispersal distances of up to 2 m for the vast majority of studied seeds, but also noted that dispersal was lower in masting (i.e. synchronous cone or seed production) populations than non-masting populations. Evidently, in the absence of a sufficient predatory mammalian population gravity remains a prime dispersal agent for *Macrozamia flexuosa*. This, coupled with the apparent low rate of seed production, suggests that the spread of this species into currently unoccupied yet apparently suitable habitat is unlikely. Incidental observations at Columbey National Park show partially consumed seeds of *Macrozamia flexuosa* (Figure 9) within 1 m of adult plants, although the identity of the predator in this case is unknown.

Although current knowledge on population size and the extent of occurrence of *Macrozamia flexuosa* suggest an IUCN status of Near Threatened, it is plausible that this species may currently be in slow decline due to limitations in phenology, pollination, or dispersal mechanisms over a long time period (many decades), with the longevity of individual specimens confounding any observable trends (cf. Terry et al 2008 for *Macrozamia platyrhachis*). Research on the topics noted above will go some way towards clarifying the situation for *Macrozamia flexuosa*, particularly in regard to quantifying recruitment and how that may impact on IUCN assessments of observable continuing decline, as

captured within Criterion A. Re-assessment of this taxon following any new information gained on pollination and dispersal is recommended, particularly if clearing and fragmentation within prime habitats accelerates beyond current expectations.

Fig 9. Seed of *Macrozamia flexuosa* following partial consumption, presumably by a mammalian predator (Columbey National Park).

Acknowledgments

This research was partly supported by a Lake Macquarie Research Grant (No. 99/00-2), funded by Lake Macquarie City Council and various industry sponsors. The 1999/2000 sponsors included Pasminco Cockle Creek Smelter, Oceanic Coal Australia Limited, Delta Electricity and Powercoal. Thanks to Robbie Economos (Lake Macquarie City Council) for review of an earlier version of this paper, and Colin Driscoll (Hunter Eco) for field assistance and data collection across the lower Hunter Valley over many years. Comments from referees were gratefully received, and improved certain aspects of the paper.

References

Ballardie, R.T. & Whelan, R.J. (1986) Masting, Seed Dispersal and Seed Predation in the Cycad *Macrozamia communis*. *Oecologia* 70(1): 100-105.

Bell, S.A.J. (2004) Vegetation of Werakata National Park, Hunter Valley, New South Wales. *Cunninghamia* 8(3): 331-347.

Bell, S.A.J. (2009) Vegetation and floristics of Columbey National Park, lower Hunter Valley, New South Wales. *Cunninghamia* 11(2): 241-275.

Bell, S.A.J. (2016) *Vegetation and floristics of the Columbey Conservation Lands (NP & SCA), lower Hunter Valley, New South Wales*. Unpublished Report to Office of Environment & Heritage (Gloucester). January 2016. Eastcoast Flora Survey.

Bell, S.A.J. & Carty, A. (2012) *Vegetation mapping of the Singleton Military Area*. Unpublished report to Commonwealth Department of Defence. Eastcoast Flora Survey & SKM, June 2012.

Bell, S.A.J. & Driscoll, C. (2006) *Vegetation of the Salt Ash Air Weapons Range, Medowie, New South Wales*. Unpublished Report to Department of Defence. Eastcoast Flora Survey. May 2006.

Bell, S.A.J. & Driscoll, C. (2008) *Revised Vegetation Mapping of Wyong LGA: Stage 1 - West of F3 Freeway*. Unpublished Report to Wyong Shire Council. Eastcoast Flora Survey.

Bell, S.A.J. & Driscoll, C. (2016) *Vegetation Mapping Report, Lake Macquarie Local Government Area. Stages 1 - 6. Volume 1*. Unpublished Report to Lake Macquarie City Council. March 2016. Eastcoast Flora Survey.

Benson, D. & McDougall, L. (1993) Ecology of Sydney Plant Species. Part 1: Ferns, fern-allies, cycads, conifers and dicotyledon families Acanthaceae to Asclepiadaceae. *Cunninghamia* 3(2) 257-422.

Bembrick, C.S., Herbert, C., Scheibner, E., & Stuntz, J. (1973) Structural subdivision of the New South Wales portion of the Sydney-Bowen Basin. *New South Wales Geological Survey – Quarterly Notes* 7: 11 – 18.

Binns, D.L. & Meek, P. (2008) Population size, habitat and conservation status of an Endangered species, *Macrozamia johnsonii* (Zamiaceae). *Cunninghamia* 10(3): 373-380.

Borsboom A.C., Wang J., Forster P.I. (2015) Determining maturity and population structure in *Macrozamia parcifolia* (Zamiaceae), a threatened Australian cycad. *Australian Journal of Botany* 63: 392–402.

Braun-Blanquet, J. (1928) *Plant Sociology: The Study of Plant Communities*. McGraw Hill: New York.

Briggs, J.D. & Leigh, J.H. (1996) *Rare or Threatened Australian Plants*. CSIRO, Canberra.

Burbidge, A.H. & Whelan, R.J. (1982) Seed dispersal in a cycad, *Macrozamia riedlei*. *Australian Journal of Ecology* 7: 63-67.

Bureau of Meteorology (2018) Bureau of Meteorology Web site. (www.bom.gov.au/climate/averages).

Clarke, K.R. & Gorley, R.N. (2006) *PRIMER v6: User Manual/ Tutorial*. PRIMER-E: Plymouth.

Department of Environment & Climate Change (2008) *Vegetation of the Cessnock-Kurri Region, Cessnock LGA, New South Wales: Survey, Classification & Mapping*. Department of Environment & Climate Change.

Driscoll, C. & Bell, S. (2014) *Vegetation assessment of Stony Pinch and surrounds, Maitland & Cessnock LGAs*. Unpublished Report. Hunter Eco.

Forster, P.I., Machin, P.J., Mound, L., & Wilson, G.W. (1994) Insects associated with reproductive structures of cycads in Queensland and northeast New South Wales, Australia. *Biotropica* 26: 217-222.

Hall, J.A. & Walter, G.H. (2013) Seed dispersal of the Australian cycad *Macrozamia miquelii* (Zamiaceae): Are cycads megafauna-dispersed "grove forming" plants? *American Journal of Botany* 100(6): 1127–1136.

Hill, K.D. (1998) Cycadophyta. *Flora of Australia* 48: 597-661.

Hill, K.D. (2010) Macrozamia flexuosa. *The IUCN Red List of Threatened Species*. Version 2015.1. www.iucnredlist.org.

Hill, K. & Osborne, R. (2004) *Cycads of Australia*. Kangaroo Press, Sydney.

Hunter, J.T. (2015) *Assessment of the GHM mapping within the Upper Hunter*. Unpublished report to the Environmental Division, Hunter Councils. January 2015.

IUCN (2019) *The IUCN Red List of Threatened Species. Version 2018-2*. http://www.iucnredlist.org. Downloaded on 25 February 2019.

IUCN Standards and Petition Subcommittee (2017) *Guidelines for using the IUCN Red List Categories and Criteria: Version 13*. Prepared by the Standards and Petitions Subcommittee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf

Kaye L. A., Walter G. H., Raghu S. (2016) Patchy distribution and varied habitats of *Macrozamia lucida* cycads explained by constancy in a key environmental variable. *Australian Journal of Botany* 64: 285–294.

Moore, C. (1883) Notes on the Genus *Macrozamia*. *Journal and Proceedings of the Royal Society of New South Wales* 17: 115-122.

National Parks and Wildlife Service (2000) *Vegetation survey, classification and mapping: Lower Hunter and Central Coast region*. A project undertaken for the Lower Hunter and Central Coast Regional Environmental Management Strategy by CRA Unit, Sydney Zone, NPWS. April 2000.

Nicholls, A.O., Doherty, M.D., & Newsome, A.E. (2002) *Evaluation of data, modelling techniques and conservation assessment tools for the Lower Hunter Central Coast Regional Biodiversity Conservation Strategy*. CSIRO Sustainable Ecosystems.

Preece, L.D., Duguid, A.W., & Albrecht, D.E. (2007) Environmental determinants of a restricted cycad in central Australia, *Macrozamia macdonnellii*. *Australian Journal of Botany* 55(6): 601-607.

Sivertsen, D., Roff, A., Somerville, M., Thonell, J., & Denholme, B. (2012) *Hunter Native Vegetation Mapping. Geodatabase Guide (Version 4)*. Internal Report for the Office of Environment and Heritage, Department of Premier and Cabinet, Sydney, Australia.

Snow, E.L. & Walter, G.H. (2007) Large seeds, extinct vectors and contemporary ecology: testing dispersal in a locally distributed cycad, *Macrozamia lucida* (Cycadales). *Australian Journal of Botany* 55(6): 592-600.

Terry, I., Walter, G.H., Donaldson, J.S., Snow, E., Forster, P.I., & Machin, P.J. (2005) Pollination of Australian *Macrozamia* cycads (Zamiaceae): effectiveness and behavior of specialist vectors in a dependent mutualism. *American Journal of Botany* 92(6): 931-940.

Terry, I., Forster, P.I., Moore, C.J., Roemer, R.B., & Machin, P.J. (2008) Demographics, pollination syndrome and conservation status of *Macrozamia platyrhachis* (Zamiaceae), a geographically restricted cycad. *Australian Journal of Botany* 56(4): 321-332.

Manuscript accepted 1 March 2019

Appendix 1 Floristic Group Simper Analysis

The derivation of diagnostic species for each floristic group has been determined using the SIMPER routine in Primer (Clarke & Gorley 2006). SIMPER analysis provides the relative contributions of each taxon to the Bray-Curtis similarity within each of the defined floristic groups. Only those taxa contributing to a total cumulative contribution of 90% of the average similarity (ie: the value shown at the top of each table) for each community are listed. These taxa can be described of as typical of that group, and have a consistently large presence within the data as reflected in the ratio of their contribution to the standard deviation (the Sim/SD field in each table) across the within-group similarities (the average similarity). Groups with less than two samples (i.e. Sandstone Grey Myrtle Sheltered Forest) cannot be analysed in this way, and are therefore not presented.

In the diagnostic species tables:

- **Average similarity** is the within-group similarity for all pairs of sample plots comprising the group. Higher average similarity indicates a better defined group.
- **Av.Abund** is the average cover abundance of that species within sample plots comprising the group
- **Av.Sim** is the average similarity (contribution) made by each species to the within-group similarity (the overall average similarity).
- **Sim/SD** is the ratio of average similarity to standard deviation for each species across all pairs of samples. A high ratio represents a good discriminating species. At least three samples are required for this ratio to be calculated.
- **Contrib%** is the percentage contribution of each species to the overall average similarity for the group.
- **Cum.%** is the cumulative percentage contribution to the overall average similarity for the group.

Lower Hunter Spotted Gum-Ironbark Forest **(LHSGIF)**

Average similarity: 35.60

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Corymbia maculata	2.59	2.78	1.35	7.8	7.8
Aristida vagans	2.1	2.44	2.02	6.84	14.64
Eucalyptus fibrosa	2.38	2.25	0.94	6.32	20.96
Entolasia stricta	2.1	2.08	1.31	5.85	26.81
Lepidosperma laterale	1.79	2.05	1.82	5.75	32.56
Cheilanthes sieberi subsp. *sieberi*	1.55	1.7	1.45	4.76	37.32
Macrozamia flexuosa	**1.38**	**1.61**	**3.13**	**4.53**	**41.85**
Phyllanthus hirtellus	1.41	1.43	1.13	4.02	45.87
Lomandra multiflora subsp. *multiflora*	1.28	1.18	1.04	3.31	49.17
Eragrostis brownii	1.31	1.17	1.01	3.28	52.46
Pomax umbellata	1.24	1.07	0.85	2.99	55.45
Grevillea montana	1.17	1.02	0.83	2.86	58.31
Panicum simile	1.28	0.97	0.78	2.73	61.04
Melaleuca nodosa	1.86	0.9	0.43	2.54	63.58
Bursaria spinosa	1.34	0.79	0.57	2.21	65.79
Dianella revoluta var. *revoluta*	0.93	0.72	0.78	2.03	67.81
Microlaena stipoides var. *stipoides*	1.07	0.7	0.67	1.96	69.77
Lomandra filiformis subsp. *coriacea*	0.97	0.69	0.64	1.95	71.72
Glycine clandestina	0.97	0.62	0.6	1.73	73.45
Persoonia linearis	0.86	0.58	0.74	1.64	75.09
Daviesia ulicifolia subsp. *ulicifolia*	1.03	0.52	0.51	1.47	76.56
Lissanthe strigosa subsp. *subulata*	0.86	0.48	0.48	1.35	77.91
Themeda triandra	1.24	0.46	0.4	1.28	79.19
Denhamia silvestris	0.66	0.42	0.57	1.18	80.37
Aristida ramosa	1	0.39	0.37	1.08	81.45
Pratia purpurascens	0.76	0.35	0.46	0.98	82.43
Imperata cylindrica	0.79	0.34	0.4	0.95	83.39
Cymbopogon refractus	0.79	0.34	0.41	0.95	84.34
Paspalidium distans	0.72	0.27	0.34	0.75	85.09
Acacia ulicifolia	0.66	0.25	0.41	0.7	85.79
Vernonia cinerea var. *cinerea*	0.59	0.24	0.43	0.69	86.48

Lower Hunter Spotted Gum-Ironbark Forest					**(LHSGIF)**
Average similarity: 35.60					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Cassytha glabella f. glabella	0.52	0.22	0.38	0.62	87.1
Lomandra longifolia	0.55	0.21	0.37	0.58	87.68
Billardiera scandens	0.52	0.2	0.38	0.56	88.24
Pultenaea spinosa	0.48	0.19	0.28	0.53	88.77
Lomandra confertifolia subsp. *pallida*	0.59	0.19	0.26	0.52	89.29
Dendrophthoe vitellina	0.38	0.18	0.39	0.51	89.8
Eucalyptus umbra	0.59	0.16	0.26	0.45	90.25

Coastal Foothills Spotted Gum-Ironbark Forest					**(CFSGIF)**
Average similarity: 33.88					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Bursaria spinosa	2	2.32	112.72	6.84	6.84
Cheilanthes sieberi subsp. *sieberi*	2	2.32	112.72	6.84	13.67
Cymbopogon refractus	2	2.32	112.72	6.84	20.51
Gahnia aspera	2	2.32	112.72	6.84	27.35
Microlaena stipoides var. *stipoides*	2.67	2.32	112.72	6.84	34.19
Themeda triandra	2	2.32	112.72	6.84	41.02
Oxalis perennans	1.67	1.54	2.32	4.56	45.58
Lepidosperma laterale	1.33	1.16	112.72	3.42	49
Macrozamia flexuosa	**1**	**1.16**	**112.72**	**3.42**	**52.42**
Corymbia maculata	2	1.15	0.58	3.39	55.81
Echinopogon ovatus	1.33	0.77	0.58	2.27	58.08
Eucalyptus punctata	1.67	0.77	0.58	2.27	60.36
Plantago debilis	1.33	0.77	0.58	2.27	62.63
Pratia purpurascens	1.33	0.77	0.58	2.27	64.91
Aristida ramosa	1.33	0.77	0.58	2.26	67.17
Brunoniella australis	1.33	0.77	0.58	2.26	69.43
Dichondra repens	1.33	0.77	0.58	2.26	71.69
Eucalyptus moluccana	1.67	0.77	0.58	2.26	73.95
Lepidosperma gunnii	1.67	0.77	0.58	2.26	76.21
Melichrus urceolatus	1.33	0.77	0.58	2.26	78.48
Notodanthonia longifolia	1.67	0.77	0.58	2.26	80.74
Olearia elliptica subsp. *elliptica*	1.33	0.77	0.58	2.26	83
Opercularia diphylla	0.67	0.39	0.58	1.15	84.15
Digitaria ramularis	1	0.39	0.58	1.14	85.29
Grevillea montana	0.67	0.39	0.58	1.14	86.42
Notelaea longifolia f. longifolia	1	0.39	0.58	1.14	87.56
Acacia parvipinnula	0.67	0.38	0.58	1.13	88.69
Aristida vagans	1	0.38	0.58	1.13	89.82
Breynia oblongifolia	0.67	0.38	0.58	1.13	90.95

Coastal Plains Smooth-barked Apple Woodland					**(CPSAW)**
Average similarity: 35.19					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Themeda triandra	2.77	2.69	2.86	7.64	7.64
Entolasia stricta	2.69	2.37	1.87	6.75	14.39
Angophora costata	2.23	2.09	1.95	5.93	20.32
Corymbia gummifera	2.23	1.81	1.34	5.14	25.46
Panicum simile	1.85	1.71	1.5	4.85	30.31
Macrozamia flexuosa	**1.15**	**1.21**	**8.75**	**3.45**	**33.76**
Aristida vagans	1.62	1.16	0.89	3.3	37.06

Coastal Plains Smooth-barked Apple Woodland					**(CPSAW)**
Average similarity: 35.19					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Billardiera scandens	1.31	1.14	1.85	3.25	40.3
Xanthorrhoea latifolia subsp. *latifolia*	1.62	1	0.72	2.85	43.15
Pteridium esculentum	1.62	0.99	0.85	2.82	45.97
Allocasuarina littoralis	1.77	0.97	0.62	2.76	48.73
Phyllanthus hirtellus	1.31	0.94	0.88	2.68	51.4
Lomandra obliqua	1.23	0.87	0.74	2.48	53.88
Glycine clandestina	1.15	0.81	1.04	2.3	56.18
Banksia collina	1.38	0.79	0.82	2.24	58.42
Imperata cylindrica	1.31	0.77	0.82	2.18	60.61
Gompholobium latifolium	1.08	0.68	0.83	1.93	62.54
Dianella caerulea var. *assera*	1	0.64	0.82	1.81	64.35
Persoonia linearis	0.92	0.59	0.89	1.69	66.03
Acacia myrtifolia	0.92	0.58	0.87	1.65	67.69
Lepidosperma laterale	1	0.57	0.58	1.62	69.31
Leptospermum trinervium	1.08	0.54	0.58	1.54	70.85
Ptilothrix deusta	1.08	0.51	0.55	1.44	72.29
Lambertia formosa	1.23	0.5	0.54	1.43	73.72
Eucalyptus piperita	1.38	0.49	0.42	1.39	75.11
Hardenbergia violacea	0.77	0.42	0.73	1.21	76.32
Gonocarpus tetragynus	0.85	0.42	0.56	1.19	77.5
Pimelea linifolia subsp. *linifolia*	0.85	0.4	0.56	1.13	78.63
Persoonia levis	0.69	0.34	0.58	0.95	79.59
Lomandra multiflora subsp. *multiflora*	0.77	0.33	0.46	0.95	80.54
Epacris pulchella	0.77	0.33	0.45	0.94	81.48
Eragrostis brownii	0.77	0.31	0.38	0.89	82.37
Leptospermum polygalifolium subsp. *cismontanum*	0.77	0.31	0.45	0.87	83.24
Eucalyptus capitellata	1	0.3	0.34	0.87	84.1
Anisopogon avenaceus	0.85	0.3	0.45	0.85	84.95
Patersonia glabrata	0.77	0.3	0.38	0.85	85.8
Pratia purpurascens	0.69	0.26	0.45	0.75	86.55
Dillwynia retorta	0.77	0.26	0.45	0.75	87.29
Microlaena stipoides var. *stipoides*	0.69	0.19	0.36	0.55	87.84
Eucalyptus umbra	0.85	0.19	0.25	0.55	88.39
Dodonaea triquetra	0.77	0.19	0.29	0.54	88.92
Rytidosperma pallidum	0.62	0.18	0.36	0.52	89.44
Brunoniella australis	0.62	0.18	0.29	0.51	89.95
Goodenia heterophylla subsp. *heterophylla*	0.54	0.16	0.36	0.46	90.41

Kurri Sands Swamp Woodland					**(KSSW)**
Average similarity: 41.57					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Melaleuca nodosa	2.95	2.41	0.85	5.79	5.79
Lomandra cylindrica	1.81	2.35	2.05	5.64	11.44
Anisopogon avenaceus	1.9	2.2	2.25	5.3	16.74
Entolasia stricta	1.76	1.92	1.53	4.61	21.35
Dillwynia retorta	1.95	1.8	1.38	4.32	25.67
Macrozamia flexuosa	**1.24**	**1.48**	**4.88**	**3.56**	**29.24**
Astrotricha sp. Quorrobolong (S. Lewer 40)	1.52	1.47	1.36	3.55	32.78
Xanthorrhoea glauca subsp. *glauca*	1.52	1.41	1.3	3.4	36.18
Leptospermum parvifolium	1.81	1.28	0.74	3.09	39.27
Hakea sericea	1.52	1.17	0.86	2.81	42.08
Grevillea parviflora subsp. *parviflora*	1.38	1.12	0.91	2.68	44.76

Kurri Sands Swamp Woodland					**(KSSW)**
Average similarity: 41.57					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Dianella revoluta var. *revoluta*	1.19	1.06	1.01	2.56	47.32
Eucalyptus parramattensis subsp. *decadens*	1.48	1.04	0.81	2.5	49.82
Aristida warburgii	1.33	1.04	0.76	2.5	52.32
Melaleuca thymifolia	1.33	1.02	0.79	2.47	54.78
Leucopogon virgatus	1.1	0.99	1.01	2.39	57.17
Platysace ericoides	1	0.82	0.91	1.97	59.14
Angophora bakeri	1.57	0.8	0.51	1.92	61.06
Pimelea linifolia subsp. *linifolia*	0.9	0.76	0.94	1.83	62.89
Isopogon anemonifolius	1.05	0.76	0.7	1.82	64.71
Eragrostis brownii	1.05	0.74	0.7	1.77	66.48
Hibbertia pedunculata	1	0.73	0.69	1.76	68.24
Leptospermum trinervium	1.1	0.66	0.67	1.58	69.82
Aristida ramosa	1.14	0.63	0.6	1.51	71.33
Themeda triandra	1.24	0.59	0.48	1.42	72.75
Lomandra glauca	1.05	0.55	0.49	1.32	74.07
Cassytha glabella f. glabella	0.86	0.55	0.62	1.32	75.39
Phyllanthus hirtellus	0.9	0.55	0.5	1.31	76.71
Cheilanthes sieberi subsp. *sieberi*	0.86	0.54	0.62	1.3	78.01
Monotoca scoparia	0.9	0.53	0.55	1.29	79.29
Callistemon linearis	0.9	0.53	0.45	1.27	80.56
Persoonia linearis	0.76	0.52	0.75	1.25	81.81
Banksia collina	1.05	0.51	0.48	1.23	83.04
Lepidosperma laterale	0.81	0.5	0.64	1.21	84.25
Grevillea montana	0.76	0.47	0.65	1.13	85.38
Bossiaea rhombifolia	1.14	0.41	0.39	0.99	86.37
Lambertia formosa	1	0.39	0.41	0.94	87.32
Eucalyptus fibrosa	0.62	0.37	0.59	0.89	88.21
Gonocarpus tetragynus	0.71	0.32	0.43	0.77	88.97
Acacia elongata	0.67	0.29	0.42	0.71	89.68
Acacia brownii	0.71	0.29	0.43	0.7	90.38

Lower Hunter Spotted Gum-Ironbark Forest Transition					**(LHSGIF Transition)**
Average similarity: 43.97					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Entolasia stricta	2.71	3.05	5.28	6.94	6.94
Rytidosperma pallidum	2.43	2.93	3.46	6.66	13.6
Lomandra cylindrica	2	2.7	8.06	6.13	19.73
Pomax umbellata	2	2.7	8.06	6.13	25.86
Phyllanthus hirtellus	1.71	2.02	1.52	4.6	30.46
Corymbia maculata	1.86	1.98	2.84	4.49	34.96
Persoonia linearis	1.57	1.77	2.25	4.02	38.97
Eragrostis brownii	1.57	1.68	3.69	3.83	42.8
Grevillea parviflora subsp. *parviflora*	1.57	1.62	1.33	3.69	46.49
Leptospermum parvifolium	1.86	1.44	0.92	3.28	49.76
Macrozamia flexuosa	**1.29**	**1.43**	**3.19**	**3.24**	**53.01**
Lepidosperma laterale	1.43	1.38	1.3	3.14	56.15
Eucalyptus agglomerata	1.71	1.3	0.62	2.96	59.1
Hakea sericea	1.43	1.15	1.2	2.61	61.71
Platysace ericoides	1.29	1.13	0.86	2.56	64.27
Eucalyptus fibrosa	1.57	1.09	0.79	2.49	66.75
Melaleuca nodosa	1.57	0.88	0.79	1.99	68.75
Corymbia eximia	1.57	0.87	0.59	1.99	70.74

Lower Hunter Spotted Gum-Ironbark Forest Transition					**(LHSGIF Transition)**
Average similarity: 43.97					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Astrotricha sp. Quorrobolong (S. Lewer 40)	1.14	0.79	0.85	1.79	72.52
Aristida ramosa	1.71	0.73	0.59	1.67	74.19
Monotoca scoparia	1	0.72	0.87	1.64	75.83
Anisopogon avenaceus	1.14	0.72	0.61	1.63	77.46
Cheilanthes sieberi subsp. *sieberi*	1.14	0.69	0.61	1.58	79.04
Grevillea montana	1	0.67	0.87	1.53	80.57
Cassytha glabella f. glabella	1	0.67	0.58	1.51	82.09
Gompholobium uncinatum	1	0.61	0.58	1.38	83.46
Daviesia ulicifolia	1.29	0.45	0.39	1.02	84.48
Goodenia rotundifolia	0.86	0.42	0.58	0.95	85.43
Acacia brownii	0.57	0.42	0.62	0.95	86.38
Podolobium ilicifolium	0.86	0.41	0.55	0.94	87.32
Melichrus urceolatus	0.71	0.39	0.61	0.9	88.22
Lomandra multiflora subsp. *multiflora*	0.71	0.38	0.61	0.87	89.09
Dillwynia retorta	1.14	0.37	0.4	0.85	89.93
Hardenbergia violacea	0.57	0.35	0.61	0.79	90.72

Hunter Valley Moist Forest					**(HVMF)**
Average similarity: 33.57					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Corymbia maculata	3.33	2.63	1.27	7.83	7.83
Poa affinis	2.67	2.42	2.13	7.2	15.02
Entolasia stricta	2.17	1.9	1.26	5.65	20.67
Pteridium esculentum	2.33	1.74	2.86	5.18	25.85
Lomandra longifolia	1.83	1.62	1.36	4.83	30.69
Macrozamia flexuosa	**1.5**	**1.49**	**3.11**	**4.44**	**35.12**
Hardenbergia violacea	1	1.25	15.34	3.72	38.85
Themeda triandra	2	1.19	0.74	3.53	42.38
Dianella caerulea var. *assera*	1.33	1.06	1.17	3.16	45.54
Polyscias sambucifolia	1.33	1.05	1.19	3.14	48.68
Eustrephus latifolius	1.33	0.95	0.79	2.82	51.5
Breynia oblongifolia	1	0.82	1.36	2.44	53.94
Imperata cylindrica	1.67	0.81	0.69	2.43	56.36
Microlaena stipoides var. *stipoides*	1.17	0.74	0.72	2.19	58.55
Desmodium rhytidophyllum	1.17	0.73	0.74	2.17	60.73
Eucalyptus punctata	1.5	0.72	0.48	2.14	62.87
Dioscorea transversa	1.17	0.72	0.71	2.14	65.01
Eucalyptus acmenoides	1.67	0.71	0.48	2.11	67.12
Billardiera scandens	1	0.62	0.73	1.84	68.95
Pittosporum undulatum	1.17	0.58	0.73	1.72	70.67
Cassytha glabella f. glabella	1	0.57	0.71	1.7	72.37
Podolobium ilicifolium	1	0.5	0.48	1.49	73.86
Persoonia linearis	0.83	0.49	0.79	1.46	75.32
Eucalyptus umbra	1	0.49	0.48	1.45	76.76
Parsonsia straminea	0.83	0.47	0.79	1.41	78.17
Pandorea pandorana	1	0.46	0.48	1.37	79.54
Allocasuarina torulosa	1	0.32	0.45	0.97	80.5
Clematis glycinoides var. *glycinoides*	0.83	0.32	0.45	0.97	81.47
Notelaea longifolia f. longifolia	0.83	0.31	0.46	0.93	82.4
Oplismenus imbecillis	1	0.31	0.46	0.93	83.32
Pseuderanthemum variabile	0.83	0.31	0.46	0.93	84.25
Leucopogon lanceolatus var. *lanceolatus*	0.67	0.26	0.48	0.77	85.02

Hunter Valley Moist Forest					**(HVMF)**
Average similarity: 33.57					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Myrsine variabilis	0.67	0.26	0.48	0.76	85.79
Angophora floribunda	1.17	0.25	0.26	0.76	86.55
Glochidion ferdinandi var. *ferdinandi*	0.67	0.25	0.48	0.75	87.3
Zieria smithii	0.5	0.25	0.48	0.75	88.05
Denhamia silvestris	0.5	0.25	0.48	0.74	88.79
Glycine clandestina	0.67	0.25	0.48	0.73	89.53
Geitonoplesium cymosum	0.5	0.23	0.48	0.68	90.21

Coastal Plains Scribbly Gum Woodland					**(CPSGW)**
Average similarity: 35.90					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Dillwynia retorta	3	3.85	-	10.71	10.71
Drosera auriculata	2	2.56	-	7.14	17.86
Entolasia stricta	2.5	2.56	-	7.14	25
Epacris pulchella	2	2.56	-	7.14	32.14
Eucalyptus haemastoma	3	2.56	-	7.14	39.29
Lindsaea linearis	2	2.56	-	7.14	46.43
Platysace linearifolia	2	2.56	-	7.14	53.57
Tetratheca juncea	2.5	2.56	-	7.14	60.71
Acacia suaveolens	1.5	1.28	-	3.57	64.29
Acacia ulicifolia	1.5	1.28	-	3.57	67.86
Banksia oblongifolia	1.5	1.28	-	3.57	71.43
Cassytha glabella f. glabella	1.5	1.28	-	3.57	75
Corymbia gummifera	2	1.28	-	3.57	78.57
Dampiera stricta	1.5	1.28	-	3.57	82.14
Dianella caerulea var. *assera*	1.5	1.28	-	3.57	85.71
Mirbelia rubiifolia	1.5	1.28	-	3.57	89.29
Persoonia levis	1	1.28	-	3.57	92.86

Seaham Spotted Gum-Ironbark Forest					**(SSGIF)**
Average similarity: 43.83					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Microlaena stipoides var. *stipoides*	2.5	2.06	4.73	4.69	4.69
Dichondra repens	2	1.89	44.34	4.32	9.01
Pratia purpurascens	2	1.89	44.34	4.32	13.32
Corymbia maculata	2.5	1.88	1.86	4.29	17.61
Eucalyptus acmenoides	2.5	1.43	0.91	3.27	20.88
Brunoniella australis	1.75	1.43	2.64	3.25	24.14
Galium binifolium	1.75	1.41	2.82	3.22	27.36
Notelaea longifolia f. longifolia	1.75	1.11	2.66	2.53	29.89
Acacia implexa	1.5	1.1	2.84	2.52	32.41
Oxalis perennans	1.5	1.1	2.84	2.52	34.93
Cheilanthes sieberi subsp. *sieberi*	1.5	1.1	3.08	2.51	37.43
Desmodium gunnii	1.5	0.96	0.91	2.19	39.62
Dianella caerulea var. *assera*	1.5	0.96	0.91	2.19	41.81
Glycine clandestina	1.5	0.96	0.91	2.19	44
Panicum simile	1.5	0.96	0.91	2.19	46.18
Poa labillardierei var. *labillardierei*	1.5	0.96	0.91	2.19	48.37
Allocasuarina torulosa	1.75	0.96	0.91	2.18	50.55
Oplismenus imbecillis	1.75	0.96	0.91	2.18	52.73
Breynia oblongifolia	1.25	0.95	44.34	2.16	54.89

Seaham Spotted Gum-Ironbark Forest					**(SSGIF)**
Average similarity: 43.83					
Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Desmodium rhytidophyllum	1.25	0.95	44.34	2.16	57.05
Eustrephus latifolius	1	0.95	44.34	2.16	59.21
Lomandra longifolia	1.25	0.95	44.34	2.16	61.36
Macrozamia flexuosa	**1.25**	**0.95**	**44.34**	**2.16**	**63.52**
Denhamia silvestris	1.25	0.95	44.34	2.16	65.68
Myrsine variabilis	1.25	0.95	44.34	2.16	67.84
Dichelachne micrantha	1.5	0.93	0.91	2.13	69.97
Plantago debilis	1.5	0.93	0.91	2.13	72.1
Leucopogon juniperinus	1.5	0.64	0.81	1.47	73.57
Lagenophora stipitata	1.25	0.64	0.81	1.46	75.03
Lomandra multiflora subsp. *multiflora*	1.25	0.64	0.82	1.45	76.49
Echinopogon ovatus	1.25	0.64	0.82	1.45	77.94
Imperata cylindrica	1.5	0.64	0.82	1.45	79.39
Veronica plebeia	1.25	0.64	0.82	1.45	80.83
Plectranthus parviflorus	1.25	0.62	0.81	1.43	82.26
Eucalyptus siderophloia	1.75	0.49	0.41	1.12	83.38
Clematicissus opaca	0.75	0.48	0.91	1.09	84.47
Pomax umbellata	0.75	0.48	0.91	1.09	85.57
Clerodendrum tomentosum	0.75	0.48	0.91	1.09	86.66
Geitonoplesium cymosum	1	0.47	0.91	1.07	87.72
Lepidosperma laterale	1	0.47	0.91	1.07	88.79
Sigesbeckia orientalis subsp. *orientalis*	0.75	0.47	0.91	1.07	89.85
Vernonia cinerea var. *cinerea*	1	0.47	0.91	1.07	90.92

Appendix 2 IUCN Conservation Risk Assessment for *Macrozamia flexuosa*

A conservation risk assessment for *Macrozamia flexuosa*, using IUCN (2017) criteria, has been undertaken with the best available information. Key factors in the application of the five IUCN assessment categories are the extent of occurrence, occupancy area, population size and dynamics, and generational time. Data on all of these factors are not essential for an assessment to proceed, as a listing for Critically Endangered, Endangered or Vulnerable can be triggered through multiple paths.

Extent of Occurrence (Criteria A & B) - Based on all available and valid point locations for *Macrozamia flexuosa* (n=582), the extent of occurrence (EOO) has been calculated as 6,319 km^2 (631,900 ha) using the online Geospatial Conservation Assessment Tool (GeoCAT: https://www.kew.org/science/projects/geocat-%E2%80%93-geospatial-conservation-assessment-tool). Six records were excluded from this analysis, as detailed earlier in this paper. Of these, five are observation records only with no voucher specimens in support, which lessens their reliability. Juvenile individuals of *Macrozamia reducta* K.D.Hill & D.L.Jones and *Macrozamia communis* do occasionally exhibit a flexuous habitat, and it is possible that these have been misidentified as *Macrozamia flexuosa*. Alternatively, these individuals may instead refer to *Macrozamia spiralis*, a predominantly Sydney-based species that also supports a twisted leaf rachis. The sixth excluded record is an AVH collection from 1881 '*near Port Jackson*', which within the context of European colonisation at that time may refer to any location between Sydney and the Hunter region. If all 588 records are accepted as valid, the EOO increases significantly to 20,736 km^2. Hill (2010) had earlier estimated EOO as 3,500 km^2, nearly half of that determined from point data records (excluding outliers) here.

Area of Occupancy (Criteria A, B & D) – the IUCN Guidelines suggest that a scale of 1-4 km^2 is generally appropriate for assessing occupancy area for most species. Consequently, using a cell size of 4 km^2, again using GeoCAT, an area of occupancy (AOO) of 696 km^2 (69,600 ha) was determined for the 582 valid point locations (excluding the 6 outliers). With all records retained, the AOO is marginally greater at 720 km^2.

Population Size (Criteria A, C & D) - To date, no comprehensive detailed studies on population size of *Macrozamia flexuosa* have yet been undertaken, although Hill (2010) estimated a range of between 2,500 to 10,000 mature individuals. As a surrogate, it is possible to extrapolate this number based on field and herbarium specimen notes, and the application of cover abundance values when sampled during vegetation classification exercises. For the 86 full floristic 0.04 ha sample plots analysed in this study, estimates of cover abundance values used the modified Braun-Blanquet (1928) scale (1 = <5% cover, few individuals; 2 = <5% cover, many individuals; 3 = 6-25% cover; 4 = 26-50% cover; 5 = 51-75% cover; 6 = 76-100% cover). For practical applications when applying cover values of 1 or 2 in the field, the word 'few' generally translates as 5 individuals or less, and 'many' as greater than 5 individuals (but covering only up to 5% or 20 m^2 of the plot). Within a 20m^2 area and based on field observations, it may be expected that a maximum of 20-25 mature individuals of *Macrozamia flexuosa* can be present. For a cover value of 3 (6-25% cover under the Braun-Blanquet scale), perhaps 25-150 mature individuals may be present. Of the 86 sample plots available, 72% recorded *Macrozamia flexuosa* with a cover value of 1 (1-5 individuals/0.04 ha, or 25-125 individuals/ha), 27% with a cover value of 2 (6-25 individuals/0.04 ha, or 150-625 individuals/ha), and 1% with a cover value of 3 (26-150 individuals/0.04 ha, or 650-3,750 individuals/ha). As none of the 86 floristic plots were positioned to specifically target *Macrozamia flexuosa*, they can be considered to represent a random sample of occupied habitat. Overwhelmingly, this species occurs only sparingly within sampled habitat, with 99% of plots recording 1 to 25 mature individuals in a 0.04 ha plot, or 25 to 625 mature individuals per hectare. By comparison, quantitative assessments by Preece et al (2007) for *Macrozamia macdonnellii*, Binns and Meek (2008) for *Macrozamia johnsonii*, Terry et al (2008) for *Macrozamia platyrhachis* and Hall and Walter (2013) for *Macrozamia miquelii* resulted in densities of 50-100, 158, 700-4,575 and 1,000-4,600 mature individuals per hectare respectively.

Extrapolating these figures for *Macrozamia flexuosa* density across the regional extent of occurrence (i.e. 25-625 individuals/ha over 631,900 ha), the maximum expected population size (assuming that all habitat within this area is suitable and supports the species) is likely to lie somewhere between 15,797,500 and 394,937,500 individuals. This estimate is comparable to recent work undertaken on *Macrozamia johnsonii* by Binns & Meek (2008), who calculated approximately 3,500,000 plants over an extent of occurrence of only 22,200 ha (an area c. 3.5% of the extent of occurrence of *Macrozamia flexuosa*). However, based on the current as-known area of occupancy for *Macrozamia flexuosa* (69,600 ha) a total population of between 1,740,000 and 43,500,000 individuals is more realistic. This estimate is comparable to that calculated in other studies: Terry et al (2008) estimated over 611,000 adult plants of *Macrozamia platyrhachis* in central Queensland, but within a total occupancy area of only 365 ha (c. 0.5% of the occupancy area of *Macrozamia flexuosa*).

Plant Generation (Criteria A, C & E) – the issue of generational time is important in some assessment criteria, and the IUCN Guidelines define this as '*the average age of parents of the current cohort (i.e. newborn individuals in the population)*', and '*generation length is greater than the age at first breeding and less than the age of the oldest breeding individual*'. As with most *Macrozamia*, the life span of *Macrozamia flexuosa* can extend for several decades, and potentially over one hundred years. Benson and McDougall (1993) and Hill (2010) suggested longevity in this species to be 60 years or more, and for the related *Macrozamia communis* and *Macrozamia spiralis* they specify a primary juvenile period (time to first reproduction) of 10-20 years. Binns and Meek (2008) consider *Macrozamia johnsonii* to have very low natural mortality and an unspecified

yet long generation time, with a primary juvenile period of 20-40 years. Preece et al (2007) suggested that some individuals of *Macrozamia macdonnellii* may be several centuries old, and for *Macrozamia platyrhachis* Terry et al (2008) estimated a generation time of 20-25 years (60-80 years for three generations). In the absence of suitable quantitative data, figures such as these are also plausible for *Macrozamia flexuosa*, and for IUCN assessments a 20 year generation period has been selected.

Reduction in Population (Criterion A) – the IUCN Guidelines specify a reducing population as one which shows '*a decline in the number of mature individuals of at least the amount (%) stated under the criterion over the time period (years) specified, although the decline need not be continuing*'. The causes of decline are separated into those that are reversible (e.g. changing land management practices), those that are irreversible (e.g. land clearing), those that are fully understood (e.g. fire regime) and those that have now ceased (e.g. collecting). For *Macrozamia flexuosa*, the greatest threat known to result in declining populations is land clearing, which is irreversible and continuing.

Using available data, and incorporating the qualifying statements made above, the following IUCN assessment has been made for *Macrozamia flexuosa*.

- **Criterion A: Reduction in population size**: Under Red List definitions, population is the total number of individuals of a taxon, which for functional reasons is measured as the number of mature individuals only. A reduction in population size is assessed over a 10-year period or three generations of the target taxon (whichever is greater): in the case of *Macrozamia flexuosa*, three generations is estimated to be at least 60 years. Based on current knowledge, an estimated extant population size of 1,740,000 and 43,500,000 mature individuals has been calculated for *Macrozamia flexuosa*. There is no comprehensive data on historical population sizes, and consequently it is difficult to quantify the reduction that may have occurred over the preceding 60 years. With the amount of land clearing that has been undertaken in the lower Hunter over the past 100 years, a reduction in population size is certainly likely. However, it is doubtful that this reduction would be greater than 30% over the last 60 years (since 1955). Ongoing clearing will potentially further reduce the number of extant plants, but it is not expected that this will exceed 30% over the next 60 years. Potential limitations in pollination and dispersal for this species (see Discussion above) may influence the triggering of a reduction in population size over three generations, however there is insufficient data at present to quantify this trend. Populations may very well be static and therefore not show any decreasing trends over a 60-year period.

  Macrozamia flexuosa does not meet the various sub-criteria for Critically Endangered (inferred, non-reversible population reduction ≥ 80%, past or future), Endangered (inferred, non-reversible population reduction ≥ 50%, past or future) or Vulnerable (inferred, non-reversible population reduction ≥ 30%, past or future) under Criterion A.

- **Criterion B: Geographical Range (B1, extent of occurrence and/or B2, area of occupancy):** The extent of occurrence (Criterion B1) for *Macrozamia flexuosa* has been estimated at 6,319 km^2. This figure exceeds the thresholds for Critically Endangered (<100 km^2) and Endangered (<5,000 km^2), but meets the threshold for Vulnerable (<20,000 km^2). However, for Criterion B1 to be enacted two of three sub-criteria must also be met. The first of these (severely fragmented population or known to exist at <10 locations) does not apply given the 588 point records of this species dispersed over a wide area. IUCN guidelines define location as a '*geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present*'. The 588 point locations occupy a wide range of habitats subject to many potentially threatening events, and it is estimated that at least 25 'locations' are definable under this definition. In addition, 'severely fragmented' refers to a situation where most individuals are found in small and relatively isolated subpopulations, with a reduced probability of gene flow and recolonization if they become locally extinct. While the distribution of *Macrozamia flexuosa* may be sparse at most locations, subpopulations are not small or isolated in this sense. The second sub-criteria relates to an observed, inferred or projected and continuing decline, which for *Macrozamia flexuosa* is likely to be met with continuing habitat loss. The final sub-criterion considers extreme fluctuations in extent of occurrence, area of occupancy, number of locations of subpopulations or number of mature individuals. Apart from declines in some of these attributes, there are unlikely to be any extreme fluctuations in *Macrozamia flexuosa* populations, as this species is a stable and long-lived taxon.

  The area of occupancy (Criterion B2) for *Macrozamia flexuosa* has been estimated at 696 km^2. This is outside of the threshold for Critically Endangered (<10 km^2) and Endangered (<500 km^2) but meets the threshold for Vulnerable (<2,000 km^2). However, as with extent of occurrence, for Criterion B2 to be enacted two of the same three sub-criteria outlined above must also be met. As discussed above, these sub-criteria are not fulfilled, and hence neither Criteria B1 nor Criteria B2 apply to *Macrozamia flexuosa*.

- **Criterion C: Population Size:** Best estimates for the total (regional) population size of *Macrozamia flexuosa* are between 1,740,000 and 43,500,000 individuals. In the absence of quantitative data within replicated sample areas, this is based on an extrapolation of plot-based cover abundance data across the calculated area of occupancy for this species. Recognising the limitations of this method, the lower bounds of this estimate clearly exceed the thresholds for Critically Endangered (<250 mature individuals), Endangered (<2,500 mature individuals) and Vulnerable (<10,000

mature individuals), and Criterion C (or any of the sub-criteria within) does not apply to *Macrozamia flexuosa*.

- **Criterion D: Very Small Population Size:** As for Criterion C, the lower estimate of over 1,740,000 mature individuals of *Macrozamia flexuosa* clearly exceeds the threshold for Critically Endangered (<50 mature individuals), Endangered (<250 mature individuals) and Vulnerable (D1: <1,000 mature individuals; or D2: area of occupancy <20 km^2, <5 locations), and Criterion D does not apply.
- **Criterion E: Quantitative Analysis:** The IUCN guidelines specify quantitative analysis as being any form of analysis (such as population viability analysis) which estimates the extinction probability of a taxon based on known life history, habitat requirements, threats and any specified management options. At present, insufficient data is available on life history and threats to *Macrozamia flexuosa* to enable a quantitative analysis to be undertaken, and hence Criterion E is not applicable.