University of Southern Queensland

Faculty of Engineering and Surveying

Assessment of Habitat Factors and Development of a Species Distribution Model for the Long Nosed Potoroo (*Potorous tridactylus tridactylus*) in SEQ

A dissertation submitted by

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Abstract

A species distribution model for the long-nosed potoroo (*Potourous tridactylus tridactylus*) was developed for South East Queensland based upon known occurrence locations using Maxent software (3.3.3k). Nine environmental predictor datasets reflective of bioclimatic, biophysical and anthropogenic elements were initially compiled and developed for the purpose of comparison against known occurrences of the species. To minimise issues associated with high localised survey bias and spatial autocorrelation resulting in discrete clusters of record locations, occurrence records were initially spatially rarefied. Residual broad geographic survey bias was then addressed via development of a bias grid, based upon 1,106 surveyed sites from a target group species background sample consisting of 26 small native mammal species.

Model performance was based upon the threshold independent measure, the area under the curve (AUC) value, developed from the receiver-operator characteristic curves (ROC). Of the initial nine predictors, a subset of four which excluded strongly correlated variables was found to produce the highest level of discrimination between observed occurrence locations and random background locations. The four variables which were retained were, the “mean annual temperature”, “low undergrowth vegetation cover”, “potential vegetated habitat extent within 1km of each cell location” and “mean annual precipitation”. Whilst this combination of predictor variables was found to be highly significant when assessed against 1,000 bias corrected null models, a number of competing models were developed which also exhibited high levels of performance. Further work is required to validate the final suite of variables used to model the focal species distribution.

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Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Chapter 1. Introduction

The Long-nosed potoroo (*Potorous tridactylus*) is listed as vulnerable under both the Queensland *Nature Conservation Act 1992* and federally, under the *Environment Protection and Biodiversity Conservation Act 1999.* Since European settlement, the species is thought to have undergone a significant decline in its distribution primarily due to the introduction of non-native predators, habitat loss and disturbance (Seebeck 1981; Short 1998; Claridge, Seebeck & Rose 2007; DEPI 2013).

Disjunct coastal populations have been recorded from southern Queensland though to the south-eastern corner of South Australia (Amos 1982; Lindenmayer 1994; Johnston 2008). Populations in Tasmania are considered to be more widespread compared to their mainland counterparts (Johnston 2008). Within Queensland, sightings have occurred from the northern extent of the South East Queensland bioregion, through to the south-eastern corner of the Brigalow Belt bioregion (Amos 1982; Lindenmayer 1994; DSITI 2014).

Due to its small size and cryptic nature, the specific habitat requirements of *Potorous tridactylus* are not well known (Norton, French and Claridge 2010). Species distribution modelling is an approach used to examine the effect that macro biotic and abiotic elements and their interactions, may impose on a species distribution.

Species distribution modelling has a range of potential uses, including a means to focus future field survey effort, as well as aid in land planning and management decisions. For example, the Queensland Department of Environment and Heritage Protection undertakes habitat modelling as part of its biodiversity mapping framework, to identify areas likely to contain populations of threatened species. Similarly, the *Vegetation Management Act 1999*, identifies areas of 'Essential Habitat' which in part utilizes habitat models as a development trigger mechanism for vegetation clearing within Queensland.

The overarching aim of this project is to identify broad areas potentially suitable for habitation by *Potorous tridactylus* within its suspected Queensland distribution using Geographic Information System (GIS) and species distribution modelling software. Known and suggested factors which possibly impact the species greater distribution were compiled from existing published literature and are presented in Chapter 3. These preferences formed the basis for the subsequent selection of key environmental datasets to identify potential relationships against known occurrences of the species and to then interpolate the findings to the greater study area.

The following chapter provides an overview of species distribution modelling and considerations which should be addressed.

Chapter 2. Species Distribution Modelling

Species distribution models or habitat suitability index models are used to extrapolate environmental functions and niche interactions to a broader study area to estimate potential suitable habitat and/or as a reflection of the probability of occurrence. Such models have been used to: investigate spatial, temporal and biotic interactions between species and their environment; to identify dispersal barriers and limiting factors; to target field survey effort to identify new populations; locate suitable sites for translocation and; where validated, can be used to inform land management and planning decisions (Ottaviani et al. 2004; Hirzel & Lay 2008).

The predictive accuracy by which a model estimates a species distribution, is largely dependent upon the relevance, availability, scale, coverage, accuracy and resolution of the environmental, topographic and distributional data that is used as base inputs against which species responses are assessed. If these elements are unavailable, unknown or cannot be determined, then the accuracy of the model will be compromised. A common problem ecologist's face however, is that limited or insufficient information is known with respect to a species habitat preferences and niche interactions which affect how it responds to environmental, spatial and temporal changes. Detailed species distribution data can be used to investigate such relationships, however, is often not available (Odom et al. 2001; Ottaviani et al. 2004).

For example, the inclusion of 'true' absence records (i.e. where the species does not occur), in conjunction with presence records, can better inform species distribution models by identifying potential variables or ranges of variables which are less suitable for habitation (Elith et al. 2011; Royle et al. 2012; Hastie & Fithian 2013). However, results from targeted systematic surveys that provide consistent and comparative coverage over large geographic regions, and identify both presence and absences are generally not available due to time and resource constraints. Furthermore, the accurate determination of species absence at sites, especially for cryptic species such as *Potorous tridacylus*, is difficult to achieve.

Conversely, databases of presence records obtained by varying survey methods and which cover broad geographic regions are often collated and maintained by government bodies, land management and conservation groups, museums, herbariums and are more widely available (Tsoar et al. 2007; Elith et al. 2011). In recent years, a number of modelling approaches have been developed which make use of presence only data to explore potential relationships between environmental variables and species occurrence. This is largely in an attempt to fill the need for the rapid acquisition of information to inform conservation and natural resource management decisions for species with limited distributional data available and/or where little ecological information on niche requirements is known.

Early concepts focused on assessing the similarity between the ‘envelopes’ of environmental space where a species is known to occur such as the software packages BIOCLIM and HABITAT. More recently, models have been developed which assess presence records, with respect to the range of environmental variation present across a broader study area. Regression models, such as generalized linear models and generalised additive models, are two commonly used approaches. (Pearce & Boyce 2006)

However, whilst presence only records may be more available than their counterpart, a number of limitations are inherent with the use of such and must be realised when undertaking species distribution modelling.

2.1 Presence Only Data

Collation of presence data is often via multiple sources, and even within a single database, methods and accuracy of collection for individual records may differ substantially, dependent upon whether captured through systematic and effort intensive surveys, or through incidental sightings. The attribute information pertaining to the data, such as its spatial accuracy or the confidence of identification, may vary based upon the locational reference method used (i.e. GPS, versus referencing topographic or built environment features) as well as the experience of the individual making the observation.

Another issue, is that areas where ‘older’ occurrences of the species were observed may have been subject to substantial environmental change (e.g. vegetation clearing) since the date of observation. This can result in misleading interpretations if environmental predicator datasets reflect recent conditions (Phillips, Anderson & Schapire 2006). Vetting of presence records such as the removal of low accuracy records, and dated records at locations in which the species is assumed no longer present, is usually undertaken to mitigate these issues.

Lastly, when using presence only data for the purpose of species distribution modelling, the probability of occurrence cannot strictly be calculated (Elith et al. 2011), rather only a comparative index of potential habitat suitability can be generated (Pearce & Boyce 2006). This is essentially based on the premise that in order to calculate the probability of occurrence, true absence records are necessary as background samples, or ‘pseudo absences’, do not necessarily represent true absences as such, and will often include areas where the species is present (Pearce and Boyce 2006).

2.2 Spatial Bias and Spatial Autocorrelation

As a result of various species field survey methods employed and differing levels of effort, another issue ecological modellers face is that presence only data often contains an inherent level of geographic bias (Phillips et al. 2009; Elith et al. 2011). Specifically, geographically biased records may not reflect a random sample of the species greater distribution. Rather, they are biased towards accessible sites or locations around populated centres, or areas where greater effort and more intensive survey methods have been applied (e.g. National Parks).

Geographic, or spatial bias, can in turn translate to environmental bias (Phillips et al. 2009). For example, if sightings are biased around populated centres, this may result in a model falsely associating certain environmental variables within the local geographic area with occurrence of the species. Alternatively, the omission of presence records within certain environments which make observation of individuals difficult, may impact a models predicative capability by not incorporating the full suite of relevant variables.

A related issue, is the problem of spatial autocorrelation of records, records which are not independent of one another and which are often clustered at discrete locations. This may occur due to ecological reasons (i.e. organism-specific dispersal mechanisms); observer bias (e.g. inclusion of multiple records of a single individual derived from radio tracking); or differences in sampling strategies for example (Dorman et al. 2007). Occurrence records which exhibit spatial autocorrelation, provide little independent information, however inflate the sample size thereby incorrectly weighting model inference and increasing the chance of a type 1 error (i.e. rejecting the null hypothesis) (Dorman et al. 2007). Methods to assess and correct spatially autocorrelated presence only records appear to be largely limited (Dorman et al. 2007).

For species distribution models which examine presence records with respect to the range of background environmental variation across a study area, two common approaches have been adopted to reduce impacts of spatial bias (Kramer-Schadt et al. 2013). The first is by manipulation of the background sample against which presence records are assessed to infer relationships (e.g. increasing the proportion of the background sampled within heavily biased areas), and the second, is by manipulation of the presence records themselves (i.e. reducing records proportionately to increasing survey effort, or spatially rarefying records over a broad geographic area).

With respect to background sample manipulation, a novel approach suggested by Phillips et al. (2009), was to mimic bias present in a focal species occurrence records by adopting a background sample derived from records from multiple species assumed to be collected or surveyed in a similar manner (referred to as a target group background sample). This approach is based upon the premise, that if the background sample is biased similarly to the presence records, it should effectively cancel the bias out.

A potential issue with this approach, is that the target group background sample if heavily biased, may not capture the range of environmental variation present with a study area (Phillips et al. 2009). In turn, this may limit the accuracy of a model to extrapolate inferences to the broader area. Another issue, is that an underlying assumption is that target group background species abundance and richness are consistent across a study area. Presumably, relative species abundance and richness will influence capture or opportunistic observation success rates. For example, in areas of high species diversity and abundance, more records are likely to be observed given a similar amount of sampling effort in comparison with areas of lower species abundance and richness.

Other approaches have involved the development of bias grids to reflect survey effort which are then used to proportionately select background samples. Common methods used to estimate relative survey effort are via point density analysis of focal species records (or again, records from taxon groups which are considered likely to be subject to similar bias), using a moving cell window approach to generate neighbourhood statistics based upon sampled sites or counts of records within a predefined area around each grid cell and/or distance decay algorithms with respect to proximity to certain geographical locations (i.e. populated centres, roads etc.) (Phillips et al. 2009; Elith, Kearney & Phillips 2010; Kramer-Schadt et al. 2013; Fourcade et al. 2014).

Once defined, grids of relative survey effort can be rescaled to reflect the estimated range of survey effort present across a study area. Accurately estimating the range of survey effort however, is intrinsically difficult and generally requires detailed information on the methods of survey and their individual level of effort. As discussed, such information is generally not readily available in compiled record collections. A number of studies (Elith, Kearney & Phillips 2010; Peers, Thornton & Murray 2013) have thus adopted conservative rescaling ranges, such as rescaling bias grid values to between one and twenty to reduce extreme down weighting of environmental variables in low survey effort areas.

Another limitation for bias grids developed using a focal species presence records (or target group background sample), is that it cannot be explicitly stated that the relative output is purely a reflection of sample effort, rather than a result of the species (or target groups of species) preferred habitat preferences and selection against such areas (Elith, Kearney & Phillips 2010).

The second suite of approaches have focused on spatially filtering or rarefying presence records to reflect a more disperse sample of the target species geographic distribution. Benefits of these approaches is that they provide a simple method to reduce record density in broad geographic areas which exhibit high survey effort, whilst also reducing the chance of overweighting variable importance at clustered locations due to higher survey effort and/or spatial autocorrelation, rather than a reflection of population density.

A study by Kramer-Schadt et al. (2013) which compared methods of accounting for sampling bias, adopted what they termed a ‘balanced’ approach whereby they spatially filtered the focal species occurrence data based upon its known home range size so that only a single record could be retained within a 10 km radius ensuring independent records. However, they observed that the remaining records still exhibited significant bias and so further reduced record density via random selection in a geographic area subject to high survey effort. The final selection of records exhibited more comparative levels of record density across areas. They recommended that a ‘balanced approach’ in many instances will provide better predictability than simple bias grids, especially where limited information on sample effort is available, or can be confidently estimated.

Another study by Fourcade et al. (2014) investigated five common approaches to dealing with bias, systematic sampling; development of a bias grid; restricting background sampling areas to a specified neighbourhood/region around presence locations; cluster analysis (so that only a single record per cluster was retained) and splitting a study areas into multiple regions for which individual models were run. The study suggested that course systematic sampling consistently ranked as one of the better approaches.

Both of the above mentioned approaches of manipulating either the background or focal species records are not mutually exclusive and can be jointly used. For example, in a study by Peers, Thornton and Murray (2013) which investigated niche displacement in the Canadian lynx and bobcat, they initially spatially rarefied the occurrence data and then implemented a bias grid to account for residual survey effort.

The type of approach adopted to reduce survey bias also need to be considered with respect to the intent of the study and the available information at hand. For example, spatially rarefying records may not be appropriate if the intent is to produce an index of the relative probability of occurrence whereby the removal of independent clustered records may down weight the importance of highly suitable areas. Similarly, if too small a number of focal species records is available, or if the species has a restricted range, spatially filtering again may not be appropriate (Kramer-Schadt et al. 2013). Where detailed knowledge of survey effort is available or can be estimated and the intent to produce a relative estimate of the probability of occurrence, bias grids likely present a better approach.

2.3 Other Considerations

In addition to those matters associated with presence data discussed above, a number of other considerations need to be taken into account in species distribution modelling. A primary aim of such exercises is to identify the key environmental parameters which make up a species niche, thus the selection of environmental variables to be used in a model is a fundamental component (Hirzel & Lay 2008).

Hirzel and Lay (2008) provided a summary of commonly noted habitat variables with respect to a species niche. These included local variables such as vegetation, patch size, food, soil microclimate, breeding and refuge sites, proximity to water and broader climatic variables such as temperature, rainfall, and topographic variables (elevation, slope, aspect, and curvature), landscape diversity, configuration and connectivity, and causal variables such as grazing, hunting and predation.

The choice of environmental variables to be used is largely dependent upon a number of factors, including the grain and scale of a proposed study, which in turn is dependent on in its intended use, the availability of the data, and the relevance to a species niche requirements at the proposed scale of modelling (Phillips, Anderson & Schapire 2006). For example, at a local scale, broad climatic variables are unlikely to be relevant, conversely at the macro or meso scale, a knowledge of the specific micro-habitat preferences may not be applicable, except where they can be generalised to the broader landscape.

The omission of variables from a model which affect a species distribution will limit model quality (Phillips, Anderson & Schapire 2006). Conversely, the inclusion of too many environmental variables may overfit a model to meet constraints imposed by environmental variables, some of which may not be relevant. A sound knowledge of the available information relevant to a species preferred habitat reduces the risk of omitting relevant model inputs and/or incorrectly selecting or not reclassifying data to best reflect potential preferences. Thus, even when an inductive modelling approach is adopted, a review of existing literature or expert advice should be sought in regards to a species potential or known environmental niche to target core variables to be assessed.

Similarly, consideration must be given with respect to input variables which co-vary. For example, if a species distribution is optimal within a certain temperature range, there is the potential that a false relationship may also be identified with elevation (i.e. for which temperature decreases with increasing elevation). The adopted study area should also be confined to reasonable extents which encapsulate the focal species records and care taken when extrapolating model inferences to areas outside of the original area. Enlarging a study area or extrapolating to areas significantly outside of the distribution of species records, increases the potential for incorrect assumptions to be applied by which model inferences may not accurately account for new ranges of variables or species interactions encountered. (Hirzel & Lay 2008)

Lastly, any model which uses base spatial data, will inherently be subject to the same underlying spatial and attribute accuracy limitations and errors. The resolution of available data, when compared to the intended grain of a proposed study may inhibit the use of some, or reduce the predicative capacity of a model unless it can be suitably reclassified (Phillips, Anderson & Schapire 2006). Interpretation and validation of any model following completion, is essential (Hirzel & Lay 2008).

Chapter 3. Species Profile

Potorous tridactylus is part of the family Potoridae (potoroos, bettongs and rat-kangaroos) and one of the smaller members of the order Diprotodontia (kangaroos, wallabies, possums, wombats amongst others). Individuals have been known to live up to several years in the wild (Johnston 2008). Body length ranges between 259 – 410 mm, tail length of 198 – 262 mm and weight range between 660 – 1640 g (Johnston 2010, p. 95). Sexual dimorphism is often present with males being larger than females.

Fur coloration is generally dark brown to grey dorsally, tending to paler shades on the sides and a white-greyish coloration present on the underside of the body (Amos 1982; Johnston 2010). The tail is dark and may have a white tip, though this trait is rare in the northern extent of its geographic distribution (Amos 1982; Johnston 2008). As per the species name, the nose is long and tapered, though shorter in Queensland compared to southern populations (Johnston 2008), with a hairless patch covering the nose and encroaching onto the snout (Amos 1982; Johnston 2008).

Figure 1: Image of the Long-nosed potoroo (Long-nosed Potoroo (Potorous tridactylus) 2008)

Similar to Kangaroos, Potoroos have well developed hind limbs and long hind feet. *Potorous tridactylus*'s hind feet length is shorter than its head length, in contrast to its close relative the Long-footed potoroo (*Potorous longipes*) (Johnston 2010). Locomotion involves either a pentapedal walk (when using the tail as a prop), quadrupedal four legged crawl, or bipedal hopping motion (Claridge, Seebeck & Rose 2007).

The species is considered to be predominantly nocturnal emerging to forage at dusk (Seebeck & Rose 1989; Johnston 2008). During the day, individuals retire to a roughly constructed squat of vegetation over a scrape in the ground in dense ground and shrub cover (DEPI 2013). *Potorous tridactylus* is omnivorous, its diet incorporating fungi, roots, tubers, seeds, fleshy fruit, flowers and soil invertebrates (Seebeck & Rose 1989; Claridge, Tanton & Cunningham 1993; Tory et al. 1997; Johnston 2008). However, mycrophagy (fungal eating) is considered to make up a large to the majority component of its dietary intake (Claridge, Cunningham & Tanton 1993; Claridge, Tanton & Cunningham 1993; Tory et al. 1997). These studies suggest that hypogeal (underground fruiting) fungi's which form ectomycorrhizal associations (symbiotic associations on external roots of plant hosts) with native flora, make up the greater portion of its mycophagous behaviour. Water intake for Potoroids is believed to be met through their foraging requirements (Seebeck & Rose, 1989).

3.1 Greater Distribution and Status

Potorous tridactylus's greater distribution extends along the southeast mainland of coastal Australia and into Tasmania. Populations from southeast Queensland to western Victoria and into the southeastern corner of South Australia occur patchily as disjunct populations (Amos 1982; Lindenmayer & Viggers 1994; Johnston 2008). In contrast, the species is relatively widespread in Tasmania, and is not considered as being under significant threat.

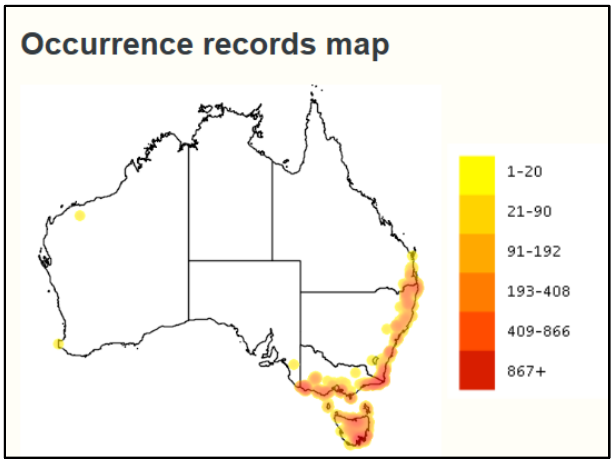


Figure 2: Distribution, based upon known occurrence records (Occurrence records map for the long-nosed potoroo 2014).

Similar to many small native Australian mammals, reductions in *Potorous tridacylus*'s distribution since European settlement is attributed largely to the introduction of non-native predators such as European Fox, (*Vulpes vulpes*), the feral cat (*Felis catus*) and the domestic dog (*Canis canis*), as well as habitat clearing for agriculture, grazing and urbanisation and resultant fragmentation impeding migration between populations and habitat patches (Seebeck 1981; Short 1998; Claridge, Seebeck & Rose 2007; DEPI 2013). In addition, land management practices such as thinning and grazing within areas of native vegetation, as well as altered fire regimes, have also been shown to reduce the chance of occurrence due to reduced habitat complexities.

As a result of population declines, the species is classed as Vulnerable in Queensland (*Nature Conservation Act 1992*), New South Wales (*Threatened Species Conservation Act 1995*) and federally, under the *Environment Protection and Biodiversity Conservation Act 1999.* In Victoria, the species is listed as threatened *(Flora and Fauna Guarantee Act 1988*) and in South Australia, as Endangered (*National Parks and Wildlife Act 1972*).

Recent phylogenetic studies in 2012, have segregated the mainland species into two subspecies, *Potorous tridactylus tridactylus* and *Potorous tridactylus trisulcatus*. The subspecies in Tasmania and the Bass Straight Islands is *Potorous tridactylus apicalis*. *Potorous tridactylus tridactylus* is considered to encapsulate the northern NSW populations (i.e. those occurring north of Sydney) and those in Queensland. (Frankham, Handasyde & Eldridge 2012)

3.2 Habitat Preferences

3.2.1 Vegetation

The species has been observed across a range of communities, including wet coastal heathland and wallum communities with a dominant stratum of small trees or large shrubs and further inland in dry to wet sclerophyll woodlands and forests, wet heaths and mesic scrub communities, temperate rainforests, as well as subtropical rainforests and notophyll vine forests in Queensland (Seebeck 1981; Amos 1982; Mason 1997; Holland & Bennet 2007; Johnston 2008; Johnston 2010; Menkhorst & Knight 2010;).

A commonality between studies, is the presence of dense groundcover. Groundcover have been observed to consist of grasses, grass trees (*Xanthorrea*), sedges, ferns, forbs and heath species and/or a low shrub layer (i.e. leptospermum, Melaleuca, Banksia) (Seebeck 1981; Amos 1982). It is postulated that *Potorous tridactylus* requires a range of habitat mosaics and ecotones to meet its specific niche requirements, specifically that a dense groundcover is necessary to avoid predation and to provide shelter during the day, interspersed or surrounded by more open mosaics suitable for foraging activities (Bennet 1993; Claridge, Cunningham & Tanton 1993; Tory et al 1997; Claridge & Barry 2000; Norton, French & Claridge 2010).

Frankham et al. 2011 on French Island Victoria, consistent with another study by Gloury (2008) (cited in Frankham et al. 2011, p78), observed that individuals did not appear to frequent areas of pasture or regrowth vegetation where little lower story vegetation cover was present, rather, preferred to remain within areas of mature intact vegetation. Trapping studies by Holland and Bennet (2007), failed to capture any individuals in areas subject to severe grazing, or in surrounding clearing agricultural land. Similarly, Claridge and Barry (2000) found that the probability of occurrence of individuals in areas subject to recent fires was significantly low in comparison to those which had not been exposed to fire for a period of 20 years or more. Reasons for absence are generally suggested to be associated with the resultant removal of understory vegetation and in the case of fire, potentially also as a result of envisaged impacts to shallow hypogeal fungi (Claridge & Barry 2000; McIntyre 1984 cited in Claridge, Tanton & Cunningham 1993, p. 332).

Whilst dense groundcover appears to be a limiting factor, Seebeck (1981), suggested that the long-nosed potoroo does not occur in areas of treeless heath, irrespective of the density of ground cover, and that a higher canopy, even where sparse, is necessary. Similarly, Norton, French & Claridge (2010) found that individuals exhibited preference for higher canopy and shrub covers where foraging, possibly to minimise the risk associated with aerial predation.

At the floristic level, no studies appear to have directly linked the probability of occurrence with respect to certain species of flora. Communities which house particular groups of vegetation, such as species of Eucalypts, Acacias, Allocasuarinas, Casuarinas, Leptospermum and Nothofagus known to host hypogenous ectomycorrhizal associations (Warcup 1980; Claridge 2002) however, may be favoured (Claridge, Tanton & Cunningham 1993).

3.2.2 Soils

Species occurrence is associated with light friable soils (Johnston 2008). In coastal areas, the species occur in areas of sandy, shallow and nutrient poor soils, whilst in inland areas, soils are typically characterised as poorly drained, but again of a light friable composition (Norton, French & Claridge 2010). This requirement may be a reflection of its foraging behaviour for fungi, soil dwelling invertebrates, roots and tubers.

Ariel et al. (2013) investigated the impacts of selected soil properties on two subgenera of American pocket gophers with different morphological adaptions for digging. They found that clay content, bulk density a soils shrink-swell capacity and depth to bedrock were explanatory variables in terms of distributional limits. Whilst it was shown that the subgenera with tooth digging adaptions could access harder soils, both still selected the least energetically costly soils given the range of soils types available, especially with respect to the soil properties clay content and bulk density.

Soils with increasing clay content have higher plasticity which makes manipulation of such soils difficult. Bulk density is used as an indication of soil compaction which can restrict plant root growth and is given as the ratio of the dry weight of a soil to its volume (USDA 2001). Soil bulk density may vary dependent upon the soil's organic, clay, silt, sand and gravel content, their packaging arrangement, soil depth, the shrink-sell capacity, the soil biota, vegetation, weathering and erosion processes, as well as land use (i.e. grazing, cultivation etc.) (USDA 2001).

Sandy soils, naturally have high bulk densities due to the heavy weight of their mineral particle size, however, due to low cohesion properties and large individual pore spaces, bulk density is not considered an effective indicator of soil hardness (Ariel at al. 2013). Conversely clays and loams have lower bulk densities, but can reflect more compact, 'harder' soil types. Thus, Ariel at al. (2013) recommend that the interplay between bulk density and clay content be considered when categorising soil hardness.

Potorous tridactylus locates hypogeal fungi by smell using claws on its forepaws to excavate producing small characteristic diggings (Andren et al. 2013). Observations of forage ''diggings'' have observed the species excavating to depths of approximately 150 mm (Claridge, Cunningham & Tanton 1993; Tory et al 1997). According to a study by Vernes and Jarman (2014), the time spent excavating at a site for hypogeal searching for fungi was relatively short, usually less than 5 seconds before moving where unsuccessful. For a species where a large component of their dietary intake requires excavation of soil invertebrates and hypogeal fungi, 'harder', shallower and gravelly soils which incur greater energy expenditure, or impede excavation, may potentially limit its distribution.

Another soil characteristic which has been correlated to species occurrence, is soil fertility. Claridge and Barry (2000) in a study covering 32, 800 km^2 and encompassing 136 sites in East Gippsland, Victoria, found that the probability of potoroo occurrence was negatively related to increasing soil nitrogen content. Studies by Catling and Burt (1994, 1995a, 1995b, cited in

Claridge & Barry 2000) have similarly found that the occurrence of small ground dwelling mammals is lower in nutrient high soils. One potential explanation for this, is that hypogenous fungi has been postulated to be at lower abundances in nutrient high soils (Claridge & May 1994). However, a second study encompassing the same 136 sites (Claridge et al. 2000) which investigated soil nitrogen content and the abundance of Hypogenous fungi, did not identify a relationship between the two.

3.2.3 Precipitation and Temperature

Areas containing populations of *Potorous tridactylus* generally coincide with mean annual rainfalls of greater than 760 mm per annum (Seebeck 1981; Johnston 2008). A few sites have been noted to receive less, such as in a site in Tasmania (Driessen et al. 2011) where the mean annual rainfall was observed as 670 mm.

Studies by Tandy (1975) and Fogel (1976) (cited in Claridge, Tanton and Cunningham 1993) observed an increase in the abundance of fruiting bodies of certain hypogeal fungi's with increasing rainfall and/or soil moisture content. Claridge, Tanton and Cunningham (1993) observed at one of two sites in East Gippsland (Victoria) seasonal variation in the intake of fungi at different times of the year, increasing during wetter periods, where the diversity of shallower hypogeal fungi types was observed to increase in certain topographic areas within the site. Similarly, in another study by Claridge et al. (2000), the probability of occurrence of the fungi genus, *Mesophellia* (known to form a component of the Potoroos fungal diet (Claridge, Tanton and Cunningham 1993)), increased with increasing annual mean moisture index. Conversely, whilst moist soils may in some instances support growth and diversity of certain species of fungi, Bennet (1993) noted that seasonally inundated areas which create waterlogged soils and anaerobic conditions are less likely to support hypogeal fungi.

Holland and Bennet (2007) also postulated that in addition to a potential increase in hypogeal diversity and abundance, other dietary components of the species such as seeds, fruits and invertebrates, may also be greater in wetter environments.

A study by Bateman, Abell-Davis and Johnson (2011) on the endangered northern bettong (*Bettongia tropica*) in the Australian Wet Tropics (a species which also feeds on fruiting bodies of hypogenous ectomycorrhizal fungi), suggested that the climatic variables maximum temperature of the warmest quarter, precipitation in the driest month and the mean annual temperature were explanatory elements with respect to truffle habitat. Suitable truffle habitat was suggested to decline with higher temperatures in the warmest month, reduced precipitation in the driest quarter and increasing annual temperature.

With respect to the focal species, Claridge and Barry's (2000) study in East Gippsland found a significant relationship between the chance of occurrence of *Potorous tridactylus* and temperature, with increasing probability associated with an increase in the mean minimum temperature in the coldest month of the year. In areas where minimum temperatures were less than -2 degrees, the probability of occurrence was modelled as being very low. It was uncertain whether this was due to internal thermoregulatory functions, or another factor, such as by directly limiting an important species resource (Claridge & Barry 2000).

3.2.4 Topographic Position

Often, changes in topographic parameters which affect a species distribution are more a reflection of variations in climatic variables such as temperature and precipitation (Hirzel & Lay 2008). Given temperature decreases generally at higher elevations, susceptibility to reduced temperatures may explain observed altitudinal differences with respect to increasing latitude (Claridge & Barry 2000). Observations suggest the species is generally found between 0 - 800 m above sea level (Claridge, Seebeck & Rose 2007). Records in southern mainland Australia suggest the species occurs up to altitudes of 650 m (DEPI 2013), however, in northern NSW the species has been observed at elevations of up to almost 1600 m.

At the macro scale, the species appears to occur across a range of landscape positions from lowland coastal areas, to slopes, hills and montane environments. At the local scale, studies by Claridge, Cunningham and Tanton (1993) and Tory et al. (1997) suggest that the species may exploit a range of topographic positions from gullies to mid-slopes and ridges in relation to seasonal changes and the distribution of food resource abundances.

3.3 Patch Size

Studies suggest that individuals are for the most part sedentary, with a relatively high percentage of adults commonly being recaptured within the same areas over concurrent sessions and with fewer 'transient' or new individuals recorded (Mason 1997; Norton et. al. 2010; Frankham et al. 2011). Juvenile capture and recapture rates are generally low, potentially resultant of low trap success rates, high mortality rates in young individuals and/or that they disperse distant to the maternal home range (Bennet 1987a cited in Bennet 1990, p 116; Norton et. al. 2010).

Whilst solitary, the species is not considered to be territorial (Amos 1982; Seebeck & Rose 1989; Johnston 2008; DEPI 2013). Other than a small core exclusive area (Seebeck & Rose 1989), home ranges of *Potorous tridactylus* appear to overlap, especially between males and females (Seebeck & Rose 1989; Long 2001; Norton et al. 2010). Estimates of mainland home range size vary from approximately 2 to 5 ha in size (DEHP 2013), with density estimates ranging between 0.19 individuals (Heinson 1968 - cited in Frankham et al. 2011, p. 78) to 2.55 individuals per hectare (Bennett 1987, cited in Frankham et al. 2011, p. 78). In Tasmania, home ranges have been estimated from between 5 to 20 ha, (Kitchener 1973a, cited in Seebeck & Rose 1989, p. 23).

Live capture studies, such as undertaken by Franklin et al. (2011) which observed low recruitment and turnover of individuals, support Seebeck's (1981) notion that *Potorous tridactylus* may be well suited to existing as small stable populations in relatively small and somewhat isolated patches of vegetation. At a site "Narringal" in south Western Victoria encompassing forty-eight remnant patches all less than 100 ha (typically isolated by less than 2 km with limited connectivity), Holland and Bennet (2007) observed the species to occur in eight of the sites. The smallest patch size in which individuals were caught was 10 ha.

An earlier study by Bennet (1990) conducted within the same study area, found that whilst the probability of occurrence significantly increased with patch size, in a few instances, individuals were recorded in patches of even less than 10 ha. He also trapped two transient individuals, as well as two residents, in roadside corridor vegetated linkages between 20-30 m wide. Whilst the two resident individuals were also utilising a larger adjoining patch of vegetation as part of their home range, the transients moved distances of greater than 1 km, along a narrow fenced vegetated corridor (including crossing a small gravelled road) to connecting vegetated patches.

In coastal Northern NSW, Andren et al. (2013) identified ten distinct areas of potential habitat ranging from 24 to 1,423 ha. Based upon a review of known surveys within the areas, they surmised that extant populations were only considered likely or known to still occur in two ranging from 206 to 1,423 ha. Five other sites, in which recent surveys undertaken in four had failed to confirm presence, were considered to possibly contain extant populations. With respect to one of these (Tyagarah Reserve/Brunswich Heads, approximately 1,100 ha), Mason (1997) based upon field survey had estimated a population size of between eighty to ninety individuals in 1992 in the Tyagarah Reserve component. However, at the time he suggested that the long term viability was at risk given the estimated small population size and susceptibility to demographic stochastic and deterministic events. Recent surveys within the area since 2009 failed to confirm presence (Andren et al. 2013). With respect to the remaining three sites identified by Andren et al. (2013), the species was considered unlikely to be present primarily due to their small size (all of which were less than 50 ha).

Similarly, it is interesting to note, that in regards to the two studies undertaken by Bennet (1990) and Holland and Bennet (2007), individuals were not observed in patch sizes less than 10 ha in the subsequent study. Clearing within the region commenced in the 1800s, with only 50% of remnant vegetation remaining by the mid-twentieth century and 9% at the time of the 2007 study (Holland & Bennet 2007).

Kitchener (cited in Mason 1997), based upon home range sizes in Tasmania, suggested the species may require an area of approximately 1,500 ha to maintain a viable population of between two to three hundred individuals. Notwithstanding, given estimates of the species potentially relative small home range size on the mainland, capacity for overlap, as well as its potential longevity in the wild and the ability to breed throughout the year, under certain conditions (i.e. where external negative deterministic pressures are minimal and suitable available resources are present within an area), the species may be well suited to persist in relatively small vegetated patches where interconnected via suitable linkages.

3.4 Potential Habitat Variables

Based upon the preceding, the variables listed in Table 1 below were identified as those likely to affect the species distribution at the regional scale. These variables formed the basis by which subsequent effort was directed in terms of compiling and/or developing environmental predictor datasets by which to compare species occurrence. The final suite of environmental predictor datasets used as initial modelling inputs, and their process of development and compilation are outlined in the proceeding Chapter.

Table 1: Potential climatic, biophysical and causal (anthropogenic) variables.

Environmental Variable	**Description**
Bioclimatic	
Precipitation	Reasonably high levels of mean annual rainfall are generally related to species occurrence, potentially reflective of mycorrhizae abundance and diversity. Additionally, the study by Bateman et al. (2011) also suggested that precipitation in the driest quarter may be a significant variable with respect to truffle availability.
Temperature	Claridge and Barry (2000) found that the minimum temperature in the coldest month of the year was found to be inversely correlated to species occurrence, and

Environmental Variable	Description
	suggested one explanation may be due thermoregulatory functions. Given the current study reflects the species northern most distribution, maximum temperatures of the warmest month may also potentially regulate the species distribution. The study by Bateman, Abell-Davis and Johnson (2011) conducted in the Queensland Wet Tropics suggested that the maximum temperature in the warmest month and mean annual temperature also impact on truffle diversity and abundance.
Biophysical	
Vegetation, undergrowth cover	A commonality of studies with respect to the focal species, is that dense undergrowth is always present to some extent within occupied areas. As such, broad areas with sparse undergrowth cover presumably limits the species greater distribution.
Vegetation, greater canopy cover	Similar to dense undergrowth cover, a number of studies have purported that the species does not occur within areas where a higher shrub or tree canopy cover is limited, presumably to minimise the risk of aerial predation.
Soil friability/soil hardness	The literature suggests that the species exhibits a preference for light friable soils. ‘Harder’ soils due to coherence properties or compaction presumably incur greater levels of energy expenditure to access food resources and potentially impede foraging in some areas. Additionally, soils which consist of a large component of coarse soil fragments (i.e. gravels), may also limit suitability.
Soil, depth to bedrock	As above, broad areas reflective of shallow soils where the underlying bedrock is close to the surface presumably inhibit the species occupation.
Soil nutrients	Studies have suggested that small mammal species may be negatively related to increasing soils nutrients. With respect the focal species, the study by Claridge and Barry (2000) suggested that the chance of occurrence was negatively correlated to soil nitrogen content.
Anthropogenic	
Patch size	Broad scale clearing resulting in reduced patch sizes with limited to no connectivity is considered to be a major factor resulting in the loss of the species preferred habitat and subsequently, reduced populations. Whilst the species have has been found to occupy small patches connected by narrow strips of remnant vegetation, the potential long term viability may be questionable. Heavily fragmented landscapes, with little to no connection are potentially unlikely to support viable populations.
Introduced species - predation	Impacts of predation from non-native predators is considered a major factor contributing to a reduction in the species distribution. Whilst suitable habitat may be available in some areas, levels of high predation may impede the ability to

Environmental Variable	Description
	occupy such areas, reducing the species potential to occupy a large proportion of its fundamental niche.
Vegetation condition	The types and intensity of land use practices likely impact on the condition of remnant patches of vegetation. Patches subject to intensive grazing for example, or which have been significantly cleared may result in reduced habitat complexity, especially in terms of low understory cover.

Chapter 4. Compilation of Environmental Predictor Datasets

The current chapter identifies the sources and/or method of development of the environmental predictor datasets (subject to data availability and suitability) and based upon those themes considered of potential relevance to the focal species occurrence identified in the preceding chapter. These datasets formed the base inputs upon which the species distribution was subsequently modelled (refer to Chapter 5). The key datasets referred to in the preceding sections are included in Appendix F.

4.1 Software and Nomenclature

The following sections outline the Geographic Information System (GIS) software used for the purpose of the current study and the adopted nomenclature. In addition to the GIS software listed below, Microsoft Excel and Word 2013 were respectively used for the purposes of data interrogation and in producing this document.

4.1.1 Geographic Information System Software and Spatial Data Formats

Spatial data was processed predominantly using the geographic information system software, QGIS Wien, Version 2.8.1 (Quantum GIS Development Team 2015). The QGIS processing framework integrates both native and third party algorithms. In addition to standard QGIS processing algorithms, non-native algorithms from the following third party providers was used via the QGIS interface: Grass 6.4.3 (GRASS Development Team 2012), Saga 2.1.2 (SAGA Development Team 2014), GDAL 1.11.0 (GDAL/OGR development team 2014) as well as the QGIS plugins, Group Stats version 2.0.30 (Szostok 2013) and the Point Sampling Tool, version 2.0.0 (Jurgiel 2013).

The spatial data formats of all base and intermediate datasets software described in the subsequent sections, were ESRI's Shapefile format (shp) and Georeferenced tagged image file format (geotiff) for vector and raster datasets respectively. The final format for environmental predictor datasets as required by the adopted species distribution modelling software (refer to Chapter 5), was ESRI's Arc/Info ASCII Grid format.

4.1.2 Nomenclature

The following conventions were used for the current and proceeding chapter (i.e. Chapters 4 and 5):

- Attribute fields - [a*ttribute/database field name*].
- GIS algorithm, name of the software and parameters - *{Software; algorithm; parameters where applicable, or not stated elsewhere}.*

Where involved geoprocessing steps were required, individual steps are listed hierarchically as <u>*Process 1*</u>, <u>*Process 2*</u> etc. under each section.

4.2 Study Area

Biogeographic regions are broad geographic areas with common geological, climatic, landform and ecological patterns. Bioregions are further refined into subregions, which reflect more localised and homogenous geomorphological units within a bioregion (Australian Government Department of Environment 2015). Historic occurrence records for the focal species obtained for the purpose of the current study, have been recorded from all bar one of the South East Queensland biogeographic subregions. With respect to the later, the Burnett - Curtis Coastal Lowlands subregion, occurrence records were observed in adjoining subregions to the North, South, East and West.

The dataset "Bioregions and subregions of Queensland, version 5.0" was downloaded from Queensland Governments "Queensland Spatial Catalogue" website <http://qldspatial.information.qld.gov.au/catalogue/custom/index.page>. The study area therefore encapsulated all South East Queensland biogeographic subregions. In addition, the Western extent of the South East Queensland subregions were buffered {*QGIS; Buffer}* by 10 km to allow for bordering records and one record located in the Brigalow Belt Bioregion. Small coral islands and those with no remnant vegetation mapped as present were removed. The resultant vector dataset was dissolved *{QGIS; Dissolve}* and reprojected *{QGIS; Save as}* to the projected coordinate system, EPSG:28356, Map Grid of Australia, Zone 56 (MGA zone 56) and titled "StudyArea.shp".

The retainment of only those subregions primarily in which records were located, was adopted to minimise the range of broad scale climatic and environmental variation encountered to known regions suspected of accommodating the species, so as to provide better discrimination within its observed northern distributional limit. Similarly, it reduces the likelihood of extrapolating modelled climatic and environmental inferences to ranges well outside of that by which occurrence records were assessed.

4.2.1 Defined Spatial Extent

Based upon the extent of the dissolved modified bioregion coverage discussed above, the following reflect the “defined spatial parameters” to which all subsequent environmental predicator datasets were made to confirm:

- Spatial reference system: EPGS: 28356, Map Grid of Australia, Zone 56 (MGA Zone 56);
- Bounding extents: 265250 E, 554750 W, 6852000 S, 7406000 N;
- Cell resolution: 100 m.

A cell resolution of 100 m was selected, as the majority of the compiled base datasets used to reflect environmental predictors were of a relatively fine scale. The equal area projection, MGA Zone 56 was adopted as the species distribution modelling software discussed in the subsequent chapter assumes grid cells are of equivalent area when assigning probabilities (Elith et al. 2011).

4.3 Environmental Predictor Datasets

The following environmental predictor datasets reflective of those variables listed in section 3.4 where available were compiled or developed as based inputs for modelling the species distribution.

4.3.1 Vegetation

Three environmental predictor datasets were developed to reflect those vegetation characteristics identified in section 3.4. The first was to reflect low undergrowth density as suggested in the literature of being of significant importance as a refuge from predation. At the landscape scale, broad areas with sparse undergrowth vegetation in the form of either a low shrub and/or groundcover layer presumably inhibit the species greater distribution. The second, also suggested as being of import, was to reflect the density of the combined shrub and tree canopies to minimise risks associated with aerial predation.

Lastly, as an alternative to the above, a dataset was also compiled to reflect broad vegetation types currently remaining within the study area. Specific suites of broad vegetation types, whilst inherently encompassing variations in environmental parameters such as low undergrowth and overall canopy cover densities, may also encompass other elements in terms of essential habitat resources, whilst others may inhibit the species chance of occurrence due to less suitable environmental attributes.

4.3.1.1 Low Undergrowth Cover

The base spatial unit to which a low undergrowth density category was assigned, was the remnant regional ecosystem unit. Regional ecosystems are vegetation communities in a bioregion which are consistently associated with a particular combination of geology, landform and soil (Sattler and Williams (1999)). Regional ecosystems are denoted by a numerical field which hierarchically identifies the bioregion and land zone in which it occurs and its associated vegetation structure and composition. For example, individual codes in the regional ecosystem 12.3.4, reflects the bioregion “South East Queensland” (12), the land zone “alluvial river and creek flats” (3) and the vegetation composition, “open forest to woodland of *Melaleuca quinquenervia* and *Eucalyptus robusta*” (4).

Regional ecosystems can also be grouped into Broad Vegetation Groups (BVGs), higher level groupings of vegetation communities independent of bioregions and landzones which facilitate comparisons at the regional (1 Million BVG), state (2 million BVG) and international scale (5 million BVG) (Nelder et al. 2014). For the purpose of this study, the regional Broad Vegetation Group classification (i.e. 1 million) was adopted and any references hereafter refer to this classification scale.

The spatial data package, “Biodiversity status of pre-clearing and remnant regional ecosystems - South East Qld, Version 9” was downloaded from the Queensland Spatial Catalogue website <http://qldspatial.information.qld.gov.au/catalogue/custom/index.page> for the South East Queensland region. Metadata (refer to Appendix E) indicates mapping of regional ecosystems by the Queensland government, is undertaken at scales of between 1:100, 000 and 1:50, 000 over South East Queensland. Spatial accuracies of polygons are generally +/- 100 m and a nominal attribute accuracy is given as 80%. The downloaded package contained vector datasets spatially referenced in EPSG: 4283, Geocentric Datum of Australia 1994 (GDA94), reflective of both the pre-clearing (i.e. prior to European settlement) and 2013 remaining extent of distinct mature native vegetation communities (remnant regional ecosystems) within South East Queensland (“preclear_v9.shp” and “re13_v9.shp” respectively). For reasons discussed in the later Section 5.2.1, only the remnant regional ecosystem dataset was used to depict undergrowth density.

Attribute information for each polygon (hereafter referred to as a "remnant unit") identified the individual regional ecosystem(s) present within the remnant unit (denoted in the attribute fields [RE1] – [RE5]), the estimated percent area each regional ecosystem contributed to the total area of the remnant unit ([PC1] – [PC5]) and its respective BVG classification ([BVG1M]), as well as the remnant units dominant BVG ([DBVG]).

Remnant units identified as not containing any regional ecosystems (e.g. cleared areas, water, plantation forest, regrowth etc.) were initially removed from the coverage, and the resultant dataset clipped *{QGIS; Clip}* to the study area described in Section 4.2 (i.e. StudyArea.shp). Similarly, remnant units were removed where the dominant BVG reflected estuarine vegetation communities, or permanent and near-permanent freshwater bodies (refer to those BVGs highlighted in Appendix B), as they were considered as unsuitable habitat for the focal species. From the remaining remnant units, a list of 300 unique regional ecosystems were derived which in turn related to 47 BVGs (refer to Appendix C).

The resultant vector dataset was reprojected to the projected coordinate system MGA zone 56 *{QGIS; Save as}* and titled "StudyArea_SelectedRegionalEcosystems.shp".

Categorising regional ecosystems undergrowth density

To categorise each regional ecosystem within the study area, a low undergrowth density matrix was developed to reflect combined ground (i.e. graminoids, forbs, ferns, sprawling vines, seedlings) and low shrub layer cover densities. For the purpose of this study, low shrub layers were defined as distinct strata with a mean height of less than 1.5m, as they were considered likely to contribute to low undergrowth density.

Information on ground and low shrub covers which could be related to regional ecosystems was primarily compiled from two sources, the publication "The Vegetation of Queensland, Descriptions of Broad Vegetation Groups" (Queensland Herbarium, 2014a) and available draft[1] regional ecosystem technical descriptions (obtained upon request from the Queensland Herbarium for the South East Queensland and Brigalow Belt bioregions) (Queensland

[1] A smaller number of finalised available technical descriptions were also available, however, following discussions with staff at the QLD Herbarium (2014, pers. comm., July), draft technical descriptions were used as they reflect working documents to which additional sites may have been added.

Herbarium 2014b). With respect to the latter, Draft Regional Ecosystem Technical Descriptions were provided specifically for the purpose of the current study and the information included in Appendix C cannot be reused or extracted for any third party use or derivatives works. Any queries or requests relating to this information, must be directed to the Queensland Herbarium, the Queensland Department of Science, Information Technology and Innovation.

Technical descriptions provide detailed information in regards to a regional ecosystem's structure and species composition, including the mean height and percent cover of the various strata associated with the emergent, tree, shrub and ground layers based upon field survey. Initially, it was intended to use technical descriptions to classify individual regional ecosystems ground and shrub strata. Appendix C lists the remnant regional ecosystems within the study area and where available, compiled summary information on the ground and shrub strata from draft technical descriptions.

Unfortunately, at the time of this study, draft descriptions were available for only 180 of the 300 remnant regional ecosystems relative to the current study, and for a large proportion of these, assessment of ground and low shrub cover strata were based upon only a handful of field surveys for which significant variation in percent covers were observed. Furthermore, regional ecosystem draft technical descriptions are subject to additional vetting processes before finalising, which includes the removal of field survey sites considered to be of poor condition (for example, due to anthropogenic factors such as grazing) (Queensland Herbarium 2015, pers. comm., February). Consequently, it was decided to utilise BVG descriptions contained within the recent publication "The Vegetation of Queensland, Descriptions of Broad Vegetation Groups" (Queensland Herbarium 2014a) as the initial information source to categorise regional ecosystems with respect to undergrowth cover.

In the majority of instances, BVG descriptions in the publication categorised the ground layer and combined shrub layer covers in accord with Table 2 below (i.e. 'dense/closed', 'mid-dense', 'sparse' and 'very sparse'), or presented information on the structural formation classes which in turn could be used to derive a ground or shrub cover density category.

Table 2: Cover density categories. Derived from Table 29 of the "Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland" (Neldner et al. 2012, p. 100)

Density category	Dense/closed	Mid-dense	Sparse	Very sparse
Projective foliage cover (ground cover)	>70%	> 30-70%	10-30%	<10%
Crown cover (shrub layer)	>80%	> 50-80%	20-50%	<20%
Growth form	**Structural formation classes (qualified by height)**			
Shrubs 2 – 8m	closed-scrub	open-scrub	tall shrubland	tall open-shrubland
Shrubs 1 – 2m	closed-heath or closed-shrubland	open-heath or shrubland	shrubland	open-shrubland
Shrubs <1m	dwarf closed-shrubland	dwarf open-heath or dwarf-shrubland	dwarf shrubland	dwarf open-shrubland
Groundlayer	closed-tussock grassland/ herbland/ forbland/ rushland/ vineland/ fernland/ sedgeland	tussock grassland/ herbland/ forbland/ rushland/ vineland/ fernland/ sedgeland	open-tussock grassland/ herbland/ forbland/ rushland/ vineland/ fernland/ sedgeland	sparse-tussock grassland/ herbland/ forbland/ rushland/ vineland/ fernland/ sedgeland

With respect to shrub cover however, BVG descriptions did not generally differentiate between lower and higher strata. As such, where the combined shrub layer was stated in the BVG description to be ‘sparse’, ‘mid-dense’ or ‘dense/closed’, then in conjunction with the BVG description, available draft technical descriptions for all regional ecosystems within the study area were used to characterise heuristically the density of the low shrub layer. Where a BVG description indicated that shrub layers were ‘very sparse’, lower shrub layers were assumed ‘very sparse’. Similarly, BVG descriptions did not categorise the density of the ground layer cover in some instances. Again, available technical descriptions for all regional ecosystems for the BVG within the study area were used.

For some BVGs where sufficient information in the BVG description was not available to categorise ground and/or shrub strata, regional ecosystem technical descriptions were also not available or limited. For these BVGs, additional information from the Queensland Governments Regional Ecosystem Description Database (REDD) (Queensland Herbarium 2015) and/or available biocondition benchmarks (Queensland Herbarium 2014a, 2014b) were used to estimate cover. Appendix B lists the BVGs relevant to the study area, the derived ground and shrub layer cover categories and associated justification for their categorisation.

This information was then related to each regional ecosystem (based upon its BVG identifier) within the study area to assign ground and low shrub layer density categories as per Table 2 above and a combined overall low undergrowth vegetation density category assigned as indicated in Table 3 below.

Table 3: Low undergrowth vegetation density category. *3 – dense low undergrowth; 2 – mid-dense low undergrowth; 1- very sparse to sparse low undergrowth*.

Low Undergrowth Cover Category	Ground cover: dense/ closed	Ground cover: mid-dense	Ground cover: sparse	Ground cover: very sparse
Low shrub cover: dense/Closed	3	3	3	3
Low shrub cover: mid-dense	3	3	2	2
Low shrub cover: sparse	3	2	2	1
Low shrub cover: very sparse	3	2	1	1

With respect to Table 3, reasons for reducing the potential range of density categories to only a few were:

- To ensure that each category was reasonably represented in terms of its extent within the study area;
- It was considered more appropriate given the classification is based upon the combination of different vegetation strata (i.e. low shrub and ground layers) which in turn are classified using different cover indexes (refer to Table 2); and similarly
- Given considerable variation was often observed in terms of ground and shrub cover densities within regional ecosystems and BVGs (refer to Appendix C).

As indicated in Table 3, all regional ecosystems which contained either a ‘dense’ ground or low shrub layer, or which were identified as having both ‘mid-dense’ ground and low shrub layers, were assigned a value of 3 (i.e. dense low undergrowth). Similarly, regional ecosystems for which either the ground or shrub layer was categorised as ‘mid-dense’, or when both ground and shrub layers were categorised as ‘sparse’, were assigned a value of 2 (i.e. mid-dense low undergrowth). Finally, all regional ecosystems where the ground and shrub layers were identified as ‘very sparse’, or a mixture of ‘sparse’ and ‘very sparse’, were assigned a value of 1 (i.e. sparse to very sparse low undergrowth).

Appendix D lists the remnant regional ecosystems within the study area, their associated BVG identifier, the ground and shrub strata cover density categories as per Table 2 and the combined low undergrowth vegetation density category (refer to Table 3).

Final data processing

The information contained in Appendix D was in turn used to attribute mapped remnant units as to whether they contained dense low undergrowth, mid-dense low undergrowth or were dominated by very sparse to sparse low undergrowth vegetation by the method outlined below.

Process 1: As a result of map scale limitations, whereby individual regional ecosystems within a remnant unit area cannot be delineated, or are too small individually to be mapped by the Queensland Herbarium, remnant units in some instances (i.e. approx. 30% of all remnant unit polygons within the study area) are attributed as containing multiple regional ecosystems (heterogeneous remnant units). Specifically, although uncommon, up to five regional ecosystems can be identified as present within a single remnant unit and are identified by the attribute fields [RE1] – [RE5], whilst the fields [PC1] – [PC5] reflect the estimated percent area that each regional ecosystem contributes to the remnant unit.

In order to assign an overall low undergrowth density category to each remnant unit whilst accounting for the presence of multiple regional ecosystems within heterogeneous polygons, the information contained in Appendix D was consecutively joined *{QGIS, Properties Dialog Box/Join function}* to the target fields [RE1] to [RE5] within the modified remnant regional ecosystem dataset ("StudyArea_SelectedRegionalEcosystems.shp"), to produce 5 new fields ([RE1_UG_CAT] to [RE5_UG_CAT]) reflective of each regional ecosystem's low undergrowth density category.

Process 2: Three new fields were then added ([UGCAT1_PC], [UGCAT2_PC] and [UGCAT3_PC] and calculated to equal the sum of percent fields [PC1] - [PC5] which were associated with a specific density category of 1, 2 and 3 respectively (refer to Table 3). For example, Table 4 below reflects a single remnant unit record in which 3 regional ecosystems are mapped as present. The field [UGCAT3_PC] was calculated to represent the sum of the percent areas (i.e. [PC2] + [PC3]) of the regional ecosystems present within a remnant unit assigned a low undergrowth density category of 3 (i.e. in the instance below, the two sub-dominant regional ecosystems were assigned density categories of 3, as denoted by the fields [RE2_UG_CAT] + [RE3_UG_CAT]).

Table 4: Example - assigning remnant units an overall undergrowth density category.

RE1	RE2	RE3	RE4	RE5	PC1	PC2	PC3	PC4	PC5	RE1_UG_CAT	RE2_UG_CAT	RE3_UG_CAT	RE4_UG_CAT	RE5_UG_CAT	UGCAT1_PC	UGCAT2_PC	UGCAT3_PC	UG_CAT
11.10.1	11.11.4	11.11.15	Null	Null	90	5	5	0	0	1	3	3	Null	Null	90	0	10	1

Process 3: A new integer field was created titled [UG_CAT] to reflect a remnant units overall low undergrowth density category. The field was calculated *{QGIS, Field Calculator}* so that remnant units composed of 25% or more of regional ecosystems that contained dense undergrowth vegetation were assigned a value of 3. Of the remaining remnant units, those which were composed of 25% or more of vegetation types with mid-dense or a mix of mid-dense and dense undergrowth vegetation were assigned a value of 2. All remaining remnant units were assigned a value of 1. Thus a general description of the low undergrowth category assigned to remnant units is as follows:

1- Remnant units where the low undergrowth strata is dominated by very sparse to sparse vegetation;
2- Remnant units where the low undergrowth strata reflects mid-dense or a mix of mid-dense and dense vegetation for 25% or more of the remnant unit's area, however, where the dense low undergrowth component does not exceed 25% of the remnant unit's area; and
3- Remnant units where the low undergrowth strata encompasses dense vegetation for 25% or more of the remnant unit's area.

In the example presented in Table 4, 90% of the remnant unit contained a regional ecosystem assigned a density category of 1, thus, the overall low undergrowth density category assigned to the remnant unit was 1 (i.e. a remnant unit where the low undergrowth strata is dominated by very sparse to sparse vegetation).

The primary reason for adopting a conservative 25% threshold was based upon the species suggested preference for mosaics and ecotones of dense low undergrowth surrounded or interspersed by more open areas for foraging (Bennet 1993; Claridge, Cunningham & Tanton 1993; Tory et al 1997; Claridge & Barry 2000; Norton, French & Claridge 2010). Based upon this premise, remnant units which contain a mixture of dense or mid-dense and sparse low undergrowth vegetation may represent suitable habitat.

<u>Process 4:</u> The final vector dataset was converted to geotiff format *{SAGA, Shapes to grid}* with grid values derived from the attribute field [UG_CAT] and with the bounding extents and cell resolution consistent with those defined in section 4.2.1 and titled "UndergrowthDensity.tif". The "maximum" parameter option was selected for situations where cells intersected more than one remnant unit in the vector dataset so that the highest low undergrowth density numerical category was assigned to each cell. For example, all cells which intersected a remnant unit with dense undergrowth present (i.e. 25% or more of the remnant unit area) as well as either a mid-dense, sparse community or both, were attributed with a value of 3. Again, this was to capture the species suggested preference for areas of dense vegetation surrounded by more open areas for foraging purposes (i.e. to capture ecotones adjoining dense and mid-dense communities were captured).

4.3.1.2 Canopy Cover

To assess the effect of canopy cover on species occurrence, the dataset "Wooded extent and foliage projective cover - Queensland 2013" was downloaded from the Queensland Spatial Catalogue <http://qldspatial.information.qld.gov.au/catalogue/custom/index.page> provided in the spatial reference system, EPSG: 3577, GDA 94/Australian Albers. This product is produced by the Queensland Department of Science, Information Technology and Innovation, and reflects the vertical foliage projective cover (FPC) of woody vegetation, thereby providing an estimate of the overall shrub and tree cover density.

Based upon the datasets associated metadata (refer to Appendix E), estimates of FPC are derived from multi-date Landsat imagery so as to remove seasonal effects present in any individual image. Values in the dataset range from 100 - 200 which are equivalent to 0 - 100% FPC and with nodata cells assigned a value of 0. Grid cell resolution is 30 m, and spatial accuracy indicated as +/- 50 m. Attribute accuracy is stated as having a Kappa statistic of 85.12%.

Final data processing

<u>Process 1:</u> The data type in the downloaded dataset was initially converted *{GDAL; Translate; Value type: Float 32}* from Integer to float to allow for subsequent resampling.

Process 2: The resultant dataset was resampled *{GDAL; GDAL_Warp; Resample method: average}* to conform with the defined spatial extent and resolution as listed in section 4.2.1 and with values calculated as the average of the intersected input cells. The output dataset was titled, “Canopy_FPC.tif”.

4.3.2 Soil

The primary source of base data used for the purpose of investigating soil characteristics in the current study, was via the “Soil and Landscape Grid of Australia” data portal <http://www.clw.csiro.au/aclep/soilandlandscapegrid/ProductDetails-SoilAttributes.html>. Soil datasets from the portal were provided as geotiffs in the geographic coordinate system, World Geodetic System 1984 (EPSG:4326), with a cell resolution of 3 arc-seconds (approximately 90 m). A metadata extract is included in Appendix E.

Other sources of data were investigated, such as those available via the “Australian Soil Resource Information System” <http://www.asris.csiro.au/index_ie.html>, for which only selected relevant soil datasets (i.e. clay content, bulk density) were available at a courser resolution (250 m). Similarly, a vector dataset maintained by the Queensland Department of Science, Information Technology and Innovation was available upon request, however, reflected combined mapping products produced at scales of between 1 : 2,000,000 and 1 : 100,000 (DSITI 2014, pers. comm., July), considered unsuitable for the purpose of the study.

Of the potential soil variables identified, only a single environmental predictor dataset reflective of soil hardness was developed. As suggested in section 3.2.2, species occurrence is generally associated with loose friable soils. Soil hardness may impact on the species greater distribution given that a large component of its dietary intake requires excavation of the upper soil profile to access hypogeal fungi.

Other soil characteristics considered of potential importance, however not assessed, included soil nutrients, depth to bedrock and coarse earth (gravel) content. Data with respect to soil nutrients and depth to underlying bedrock was available via the “Soil and Landscape Grid of Australia” portal, however, due to low confidence in the data accuracy at the coastal margin (discussed in the proceeding section in process 3), and as no suitable surrogate datasets were available to remedy the issue, soil nutrient datasets were not used. With respect to the theme “depth to bedrock”, from initial assessment it was determined that large areas of the study area, including where species presence records were located, contained no data. A dataset reflective of coarse fragments from the portal was not available at the time of this study.

4.3.2.1 Soil Hardness

A categorical soil hardness dataset was produced to encompass combinations of bulk density and soil texture across the study area, possibly limiting factors with respect to the species greater distribution. Categories were derived based only upon observed values within areas of potential habitat.

To develop the categorical dataset, it was necessary to classify soil texture types within the study area. Soil textures are based upon the ratio of sand, silt and clay of the fine earth (<2 mm soil particles) component. For the purpose of the study, sandy soils were defined as those soils for which the percent sand (of the total sand, silt, clay component), was greater than 85%. Clay soils were classified as soils with equal to or greater than 35% clay content and the remainder of soils types classified as loams (i.e. soils with < 85% sand and < 35% clay).

The 85% and 35% thresholds were derived based on information contained within Table 4 of the "Soil Quality Test Kit guide" (USDA 2001, p57), which suggests that impacts on root growth from increasing bulk densities of loamy sands and sands vary significantly from the majority of loams, as do clay textures. Due to variations in the silt and sand particle size ranges between American and Australian systems and texture classifications systems, a conversion diagram, Figure 2(a), in a publication by Minasny and McBratney (2001, p. 1447) was used to estimate the percent sand component in Australian soils with respect to sand and loamy sand textures in the American system. Clay particle size range is the same for both systems and a 35% threshold generally encompasses light to heavy clays.

Combining soil texture and bulk density

The following steps set out the processes used to develop the categorical soil hardness dataset.

<u>Process 1:</u> Eight Raster geotiff datasets reflective of the upper 0-5 cm and 5-15 cm soil horizons for sand, clay and silt percent content for fine earth soil particle sizes (i.e. < 2 mm and inclusive of organic content) and bulk density (whole earth component inclusive of coarse fragments such as gravels > 2 mm) were downloaded via the "Soil and Landscape Grid of Australia" data portal.

Four datasets reflective of the proportion of sand, silt, clay (of the fine earth component inclusive of organic matter) and bulk density (g/cm^3) in the upper 0-15 cm soil horizon were calculated *{QGIS; Raster calculator function}* by summing the respective 0-5 cm and 5-15 cm sand, clay, silt and bulk density raster geotiff datasets whilst accounting for the proportion each dataset reflected of the total 15 cm soil horizon. An example of the expression used to calculate the total proportion of sand in the 0-15 cm soil horizon is as follows:

Expression: 1/3 * "0_5_Sand.tif" + 2/3 * "5_15_Sand.tif".

The soil depth of 15 cm was selected based upon the observed foraging depths of the species for hypogeal fungi as discussed in section 3.2.2. The resultant datasets were titled, “0_15_Sand.tif”, “0_15_Silt.tif”, “0_15_Clay.tif” and “0_15_Bulk_Density.tif”.

<u>*Process 2:*</u> A further three datasets for sand, silt and clay ("Percent_Silt.tif”, "Percent_Clay.tif","Percent_Sand.tif"), were produced *{QGIS; Raster calculator function}* to reflect the percent contribution of each with respect to the total content of sand, silt and clay (i.e. exclusive of organic content) in the upper 15 cm soil horizon. An example of the expression with respect to the percent silt is as follows:

Expression: Percent Silt = "0_15_Silt.tif" / ("0_15_Silt.tif" + "0_15_Sand.tif" + "0_15_Clay.tif") * 100.

<u>*Process 3:*</u> One issue encountered with respect to the soil data, was that at the coastal margin sand content was observed to be substantially underestimated, whilst silt and clay components overestimated. This was especially apparent with respect to the sand islands Fraser, Moreton and Stradbroke. From discussion with the Queensland Department of Science, Information Technology and Innovation (2015, pers. comm., February), this is due to the density and distribution of collected soil samples which are sparse at the immediate coastal margin (and adjacent islands) and was therefore not accounted for by the modelling process employed in developing the Australian soil and landscape grid data.

To reduce issues associated with this, land zone mapping produced by the Queensland Herbarium for vegetation classification purposes was used as a surrogate to identify sandy soils at the coastal interface. Land zones reflect variations in major geologies, landforms and geomorphic processes (Wilson and Taylor 2012). Land zone 2 reflects Quaternary coastal sand deposits for which the upper horizon excluding organic content, is primarily sand (Wilson and Taylor 2012). A land zone 2 coverage was obtained by dissolving *{QGIS; Dissolve}* all polygons within the preclearing regional ecosystem mapping dataset (refer to section 4.3.1.1) attributed as 2 in the field [Landzone]. This dataset was rasterised *{GDAL; gdal_rasterize}* to produce a new dataset “Landzone2_Rasterised” at a resolution and spatial extent consistent with the original soil raster datasets and with all cells which intersected the dissolved polygon assigned a value of 100 and all other values, 0.

<u>*Process 4:*</u> Values from the resultant land zone 2 rasterised dataset were summed *{QGIS; Raster calculator}* with the dataset, "Percent_Sand.tif", to produce an intermediate output, i.e.:

Expression: "Landzone2_Rasterised.tif" + "Percent_Sand.tif".

The resultant dataset was reclassified *{SAGA; Reclassify grid values }* so that all cells greater than or equal to 85 were assigned a value of 100 and all remaining cells, including nodata cells, a value of 0. The output geotiff, reflective of sandy soils was titled "LZ2_PercentSand_Reclass.tif".

<u>*Process 5:*</u> A similar process as described above was used to derive clay soils which encompassed all cells estimated to contain greater than or equal to 35% clay within the upper 15cm soil horizon. To ensure areas corrected for sand content were not included, values in the dataset "Percent_Clay.tif" were summed *{QGIS; Raster calculator}* with the output dataset from process 4 above, "LZ2_PercentSand_Reclass.tif" to produce to produce an intermediate dataset, i.e.:

Expression: "LZ2_PercentSand_Reclass.tif " + "Percent_Clay.tif".

The resultant dataset, was reclassified *{SAGA; Reclassify grid values}* so that all cell values greater than or equal to 35 and less than 100[2] were assigned a value of 300 and all remaining cells, including nodata cells, 0. The output dataset was titled "LZ2_PercentClay_Reclass.tif".

<u>*Process 6:*</u> All remaining cells which contained a mixture of sand, clay and silt contents, were therefore considered loams. To depict loam soils, the dataset "Percent_Silt.tif" created in process 2 was summed *{QGIS; Raster calculator}* with the two output datasets from processes 4 and 5 above, i.e.

Expression: "Percent_Silt.tif" + "LZ2_PercentSand_Reclass.tif" + "LZ2_PercentClay_Reclass.tif".

[2] Note: no cells were identified as composed of 100% clay within the study area, cells with values of 100 related only to sandy soils as produced in step 4.

The output dataset was reclassified *{SAGA; Reclassify grid values}* so that all cells less than 100 and greater than 0 were assigned a value of 200 with all remaining cells, including nodata cells, 0. The output dataset was named "LZ2_PercentSilt_Reclass.tif".

Process 7: Cell values within the three datasets were summed *{QGIS; Raster calculator}* to produce an intermediate raster dataset with values of 100 (sand), 200 (clay) and 300 (silt) and 0 (i.e. marine areas).

> Expression: "LZ2_PercentSilt_Reclass.tif" + "LZ2_PercentSand_Reclass.tif" + "LZ2_PercentClay_Reclass.tif".

This dataset in turn was reclassified *{Saga; Reclassify grid values}* to values of 10 (sand), 20 (silt) and 30 (clay) to produce the soil texture dataset, "Sand_Silt_Clay.tif".

Process 8: To combine bulk density and soil textures, the soil texture dataset was summed *{QGIS; Raster calculator}* with the dataset produced in process 1 which reflected the average bulk density of the whole earth component in the upper 15 cm soil horizon:

> Expression: "Sand_Silt_Clay.tif " + "0_15_Bulk_Density.tif".

The output geotiff was titled "Sand_Silt_Clay_BD.tif".

Process 9: Finally, the dataset was reprojected *{GDAL; GDAL_Warp; Resampling Method: nearest neighbour}* to the defined study area extents and cell size and titled "Sand_Silt_Clay_BD_WarpSA.tif".

Process 10: Next, a mask was produced (hereafter referred to as the "study area masked extent") to reflect the extent of grid cells within the defined study area, where values were present for all environmental predictor datasets outlined in this Chapter. As climatic variables listed in the following section 4.3.3 were continuous across the entire study area, only three datasets which did not have continuous values across the study area were used to produce the mask. Values from the three datasets "UndergrowthDensity.tif" (refer to section 4.3.1.1), "Canopy_FPC.tif" (refer to section 4.3.1.2) and the dataset produced in Process 9 above, "Sand_Silt_Clay_BD_WarpSA.tif" were summed *{QGIS; Raster calculator}* and the result divided by itself to so that cells with values present from all environmental predictor datasets were assigned 1, and all other cells, nodata. The output dataset was titled "AllEnvVars_Mask_StudyArea.tiff".

Expression: ("UndergrowthDensity.tif" + "Canopy_FPC.tif" + "Sand_Silt_Clay_BD_WarpSA.tif") / ("UndergrowthDensity.tif" + "Canopy_FPC.tif" + "Sand_Silt_Clay_BD_WarpSA.tif").

Process 11: The dataset produced in process 9 (“Sand_Silt_Clay_BD_WarpSA.tif”) was then multiplied by the mask, “AllEnvVars_Mask_StudyArea.tiff”, with null values not propagated so that only cells where values were present from all environmental predictor datasets were retained.

Expression: "Sand_Silt_Clay_BD_WarpSA.tif" * "AllEnvVars_Mask_StudyArea.tif".

The output dataset was titled “Sand_Silt_Clay_BD_WarpSA_Mask.tif”. The reason for retaining only cells within the study area masked extent, was to ensure that only relevant ranges of values within potentially suitable habitat were used to define soil hardness categories.

Final data processing

Process 12: The output dataset “Sand_Silt_Clay_BD_WarpSA_Mask.tif” was converted to vector format *{SAGA; Grid values to points}* and a series of selection queries *{QGIS; Select by expression}* undertaken to assess the percent area that sand, loam and clay soils encompassed of the total masked extent and are listed in Table 5 below.

Bulk densities ranges, with respect to clays and loams were similarly assessed and are indicated in the table below. For reasons discussed previously, soil grid data from the “Soil and Landscape Grid of Australia” portal, inclusive of bulk density estimates, was considered to be compromised at the coastal interface due to limited numbers of soil samples used in the original modelling process (2015, pers. comm., February). This was especially apparent with respect underestimation of the extent of sandy soils. As a result bulk density values with respect to sandy soils were not used.

Table 5: Proportion of sand, loam and caly soils within the study area masked extent.

Soil Type	**Bulk density (g/cm3) ranges**	**Frequency of cells**	**Percent of all cells within the study area**
Sands	NA	289900	8.2%
Loams	0.79 – 1.48	3164265	89.7%
Clays	0.80 – 1.43	72393	2.1%
Total		3526558	100.0

To simplify ecological interpretation at subsequent stages, account for uncertainty with respect to soil data attributes at the coastal margin and as clay soils made up only a small proportion of the masked extent within the study area (i.e. 2.1%), only three categories of soil hardness with soil textures combined were developed and are indicated in Table 6.

Clay and loam soils with bulk densities estimated to be less than 1 g/cm^3 (generally considered as friable, soft soils) accounted for approximately only 1.35% of the total masked extent, they were grouped with clay and loam soils with bulk density ranges of between 1 – 1.1 g/cm3. Additionally, sandy soils were also included in category "1" as such soils whilst generally having high bulk densities, due to low coherence properties (unless severely compacted) reflect loose 'soft' soils (Ariel at al. 2013). The remaining two categories were based on increasing equal intervals of bulk density at 0.2 g/cm^3 increments.

Another reason for limiting the range of soil hardness categories, is that the bulk density estimates used in the current study were based upon whole earth component, inclusive of gravels. As a result, bulk densities in areas where medium to heavy gravel content makes up a reasonable proportion of the soil content, may overestimate fine earth bulk density.

Table 6: Assigned soil hardness categories.

Soil Texture	**Relative "soil hardness"**	**Assigned soil hardness category**	**Bulk density range (*lower value < cell value <= higher value*)**	**Corresponding cell value range (*lower value < cell value <= higher value*)**	**Frequency of cells (*% with respect to all cells within the masked extent*)**
Sandy soils	"soft"	1	*NA*	10 - 11.5	289900 (8.22%)
Loams and clays	"soft"	1	0.79-0.9	20.79 - 20.9 & 30.8 – 30.9	6899 (0.20%)
Loams and clays	"soft"	1	0.9 - 1	20.9 - 21 & 30.9 – 31	40614 (1.15%)
Loams and clays	"soft"	1	1 – 1.1	21 - 21.1 & 31 - 31.1	190060 (5.39%)
Loams and clays	"medium"	3	1.1 - 1.2	21.1 - 21.2 & 31.1 - 31.2	481089 (13.64%)
Loams and clays	"medium"	3	1.2 - 1.3	21.2 - 21.3 & 31.2 - 31.3	885737 (25.12%)
Loams and clays	"hard"	4	1.3 - 1.4	21.3 - 21.4 & 31.3 - 31.4	1,428,653 (40.51%)
Loams and clays	"hard"	4	1.4 - 1.5	21.4 - 21.5 & 31.4 - 31.5	203,606 (5.77%)

Process 13: Lastly, the dataset "Sand_Silt_Clay_BD_WarpSA_Mask.tif" was reclassified *{SAGA; Reclassify grid values}* as per

Table 6 above to produce an intermediated dataset. Nodata cells were reassigned *{GDAL; gdal_warp}* a value of -9999 and the output dataset titled “SoilHardness.tif”.

4.3.3 Precipitation and Temperature

Bioclimatic data (Queensland Bioclimatic Parameter (BIOCLIM) Surfaces) maintained by the Queensland Department of Science, Information Technology and Innovation was obtained upon request. The data was produced in ANUCLIM version 5.1, which uses modelled surfaces of climatic data from 1921 to 1995 (Xu, T & Hutchinson, M 2011). The ANUCLIM software requires a digital elevation model for the area of interest as an input. For the purpose of developing the Queensland Bioclimatic Parameter (BIOCLIM) Surfaces data, the Queensland GEODATA 9 SECOND DEM VERSION 2 was used. Cell resolution was at 3 arc seconds (approximately 90m). Metadata is attached as Appendix E.

The five bioclimatic variables identified in the literature (refer to section 3.2.3) as of potential relevance to the focal species were:

1. Mean annual precipitation (mm).
2. Precipitation in the driest quarter (mm).
3. Mean annual temperature (degrees Celsius * 10).
4. Mean minimum temperature of the coldest month (degrees Celsius * 10).
5. Mean maximum temperature of the warmest month (degrees Celsius * 10).

The above variables were suggested of potential importance with respect to the species distribution possibly due to thermoregulatory functions, or alternatively, by influencing key species resources, such as hypogeal fungi abundance and diversity.

Final data processing

Process 1: As climatic variables reflect continuous surface data, the five climatic datasets descried above were resampled using bilinear interpolation *{GDAL; gdal_warp}* to the defined study area spatial parameters (refer to section 4.2.1). The output datasets were titled “BIO1AP_MGA_100.tif”, “BIO17PDQ_MGA_100.tif”, “BIO1AMT_MGA_100.tif”, “BIO6MTCP_MGA_100.tif” and “BIO5MTWP_MGA_100.tif” respectively.

4.3.4 Anthropogenic

Continuous land use mapping produced by the Department of Science, Information Technology and Innovation which covered the study area was available which provided broad primary and secondary land use descriptions, however, was not adopted for the purpose of the current study. The primary reason was that consistent information on intensity within different land use categories was not readily available. Without accounting for intensity and land management practices, classifying vegetation condition on broad land use categories only was not considered appropriate. Similarly, pest mapping produced by the Queensland Department of Agriculture and Fisheries for introduced predators such as the European fox and feral cat were available however, at 10 km gridded intervals, considered too course for the purpose of the current study and given the resolution of other available predictor datasets.

As an indication of potential available habitat and given the species has been observed to utilise narrow vegetated linkages between adjoining patches of up to at least 1 km distant, a moving window approach was adopted to identify the total extent of potential vegetated habitat within a 1 km zone around each grid cell to discriminate against areas with limited vegetation.

Final data processing

Process 1: To ensure remnant vegetation located outside but adjacent to the western extent of the subregion was incorporated in the neighbourhood analysis, the study area coverage (StudyArea.shp) (refer to section 4.2), was buffered *{QGIS; Buffer}* by a further 10 km and titled "BufferedStudyArea_10km.shp". The resultant dataset was then used to clip *{QGIS; Clip}* the downloaded remnant regional ecosystem dataset (refer to section 4.3.1.1) which in turn was titled, "REs_BufferedStudyArea_10km.shp". As described in section 4.3.1.1, remnant units identified as not containing any regional ecosystems (e.g. cleared areas, water, plantation forest, regrowth etc.) as well as where the dominant BVG reflected estuarine vegetation communities, or permanent and near-permanent freshwater bodies (refer to those BVGs highlighted in Appendix B) were removed (i.e. considered as unsuitable habitat for the focal species).

Process 2: To reduce issues of significantly overestimating the total extent of remnant vegetation within approximately a 1 km zone around each cell (i.e. due to 100 m cells which overlap only a small area of remnant vegetation), the dataset "REs_ BufferedStudyArea_10km.shp" was converted to raster format *{GDAL; gdal_rasterize}* accommodating the increased spatial extent (bounding co-ordinates: 255350 W, 554750 E, 6846800 S, 7411300 N) and at a cell resolution of 6.25m. All cells which intersected a remnant unit were assigned value of 39.0625 (i.e. 39.0625 m^2, equivalent to a cell's area).

Process 3: The resultant dataset was then resampled *{GRASS; r.resample.stats; resample method: sum}* to a cell resolution of 100 m based upon the sum of the cell values contained within.

Process 4: To estimate the total area of potential habitat within approximately 1 km of each cell, a moving window neighbourhood analysis *{GRASS; r.neighbors; resample method: sum}* was performed on the proceeding dataset with a circular neighbourhood defined by a diameter of 21 cells. The output dataset was titled "PotentialVegegatedHabitat1km.tif".

4.3.5 Environmental Predictors - Final Data Preparation

The selected species distribution modelling software, Maxent, requires that environmental predictor datasets are in ESRI's Arc/Info ASCII Grid format, have consistent bounding extents, are spatially referenced in a projected coordinate system (or alternately, for spatial references systems where the base units are latitude and longitude, a bias grid be implemented to account for differences in cell sizes with changes in latitude) and are assigned the same no data value.

All of the environmental predictor datasets outlined in the proceeding sections were therefore transformed to meet the stated requirements. In addition, a subset of each dataset was produced using the mask "AllEnvVars_Mask_StudyArea.tiff", so that only cells where values were present for all environmental predictor datasets and which were considered as potential areas of suitable habitat were retained.

Final data formatting

Process 1: To ensure consistency, subsets of all dataset were extracted based upon the study area masked extent *{QGIS; Raster calculator}*. An example of the expression used to extract a subset of each dataset is as follows:

Expression: "UndergrowthDensity.tif" * "AllEnvVars_Mask_StudyArea.tif".

Process 2: The resultant datasets were transformed *{GDAL; gdal_warp}* to ensure they were consistent with the defined study area extents, and so that all nodata cells were reassigned a value of -9999 where they differed.

Process 3: Finally, all datasets were converted *{GDAL; gdal_tranlsate}* to ESRI's Arc/Info ASCII Grid format.

The final list of datasets compiled for input as environmental predictors for the purpose of developing a species distribution model described in the proceeding chapter, are listed in Table 7 below. Figures 3 to 6 provide a graphic representation of each of the final environmental predictor datasets.

Table 7: Formatted final environmental predictor datasets.

Description	**Original dataset**	**Formatted environmental predictor dataset**	**Variable type**
Bioclimatic: annual precipitation	BIO1AP_MGA_100.tif	bio12ap.asc	continuous
Bioclimatic: precipitation of the driest quarter	BIO17PDQ_MGA_100.tif	bio17pdq.asc	continuous
Bioclimatic: mean annual temperature	BIO1AMT_MGA_100.tif	bio1amt.asc	continuous
Bioclimatic: maximum temperature of the warmest period	BIO5MTWP_MGA_100.tif	bio5mtwp.asc	continuous
Bioclimatic: minimum temperature of the coldest period	BIO6MTCP_MGA_100.tif	bio6mtcp.asc	continuous
Biophysical: low undergrowth cover	UndergrowthDensity.tif	udrgwth.asc	categorical
Biophysical: index of combined woody vegetation canopy cover	Canopy_FPC.tif	cpycov.asc	continuous
Biophysical: soil hardness	SoilHardness.tif	soil_hds	categorical
Anthropogenic: potential vegetated habitat within approximately 1 km of each location	PotentialVegegatedHabitat1km.tif	pt_hab_1km	continuous

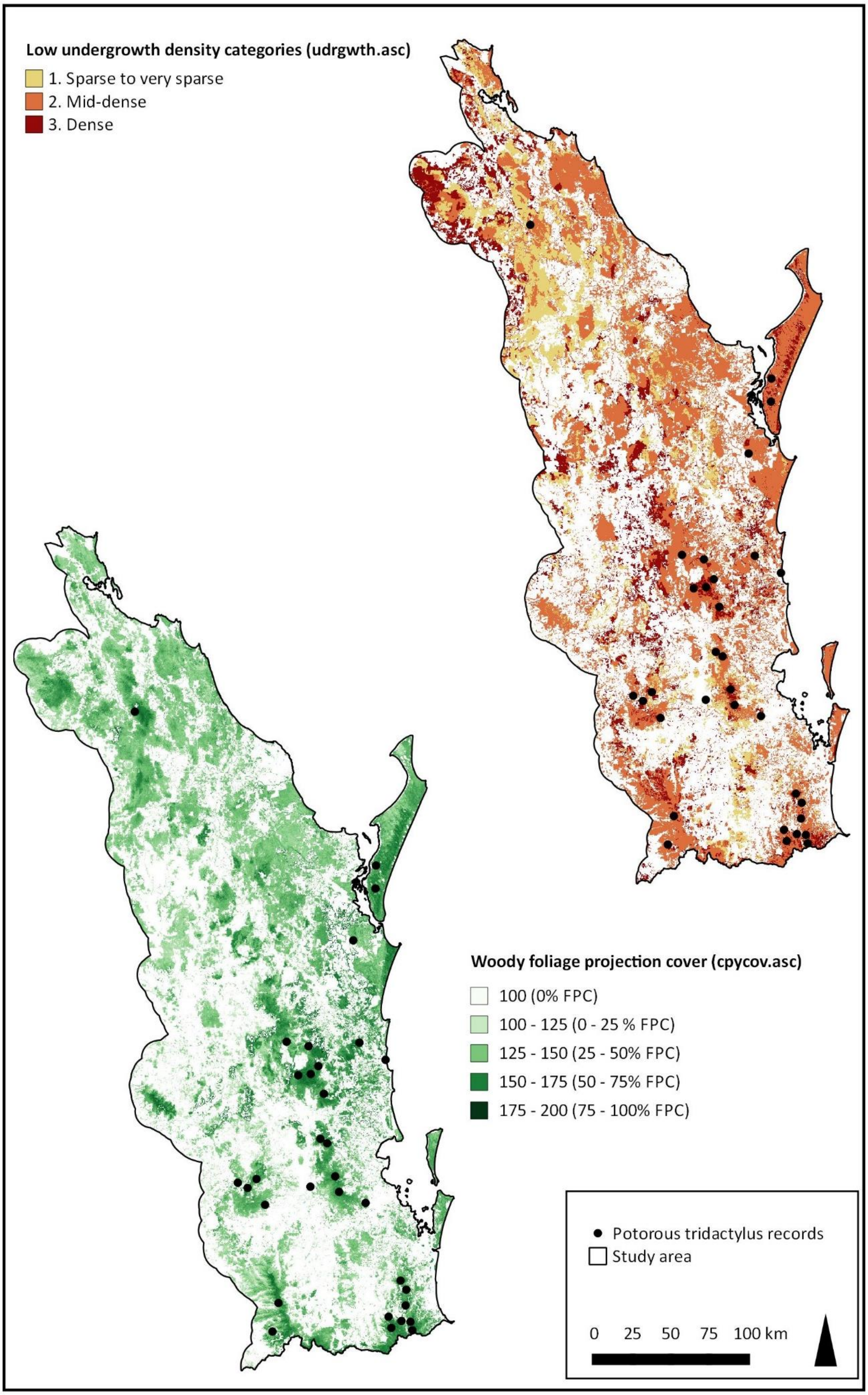


Figure 3: Environmental predictors, low undergrowth and woody vegetation canopy cover.

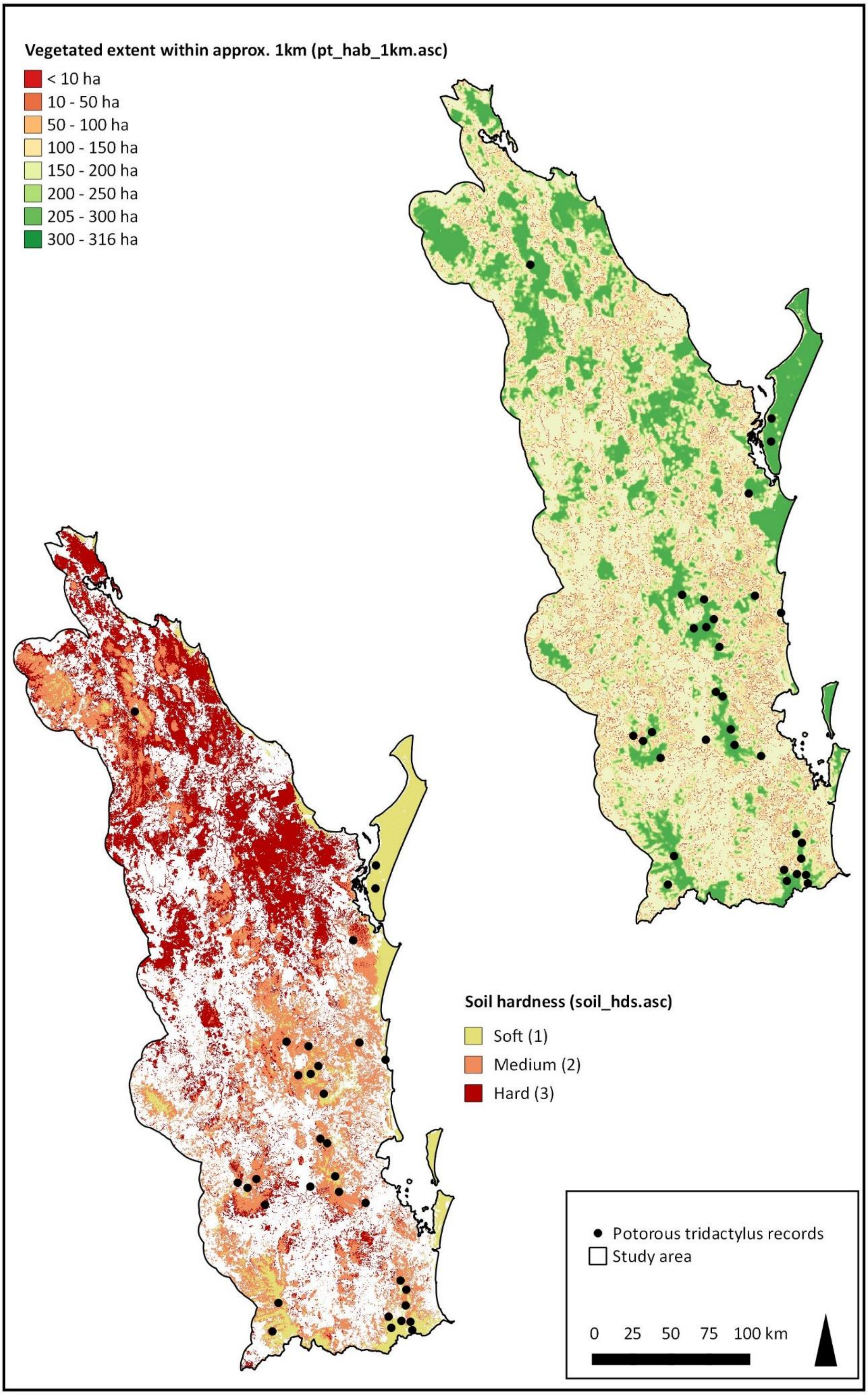


Figure 4: Environmental predictors, potential habitat (1 km of each cell) and soil hardness.

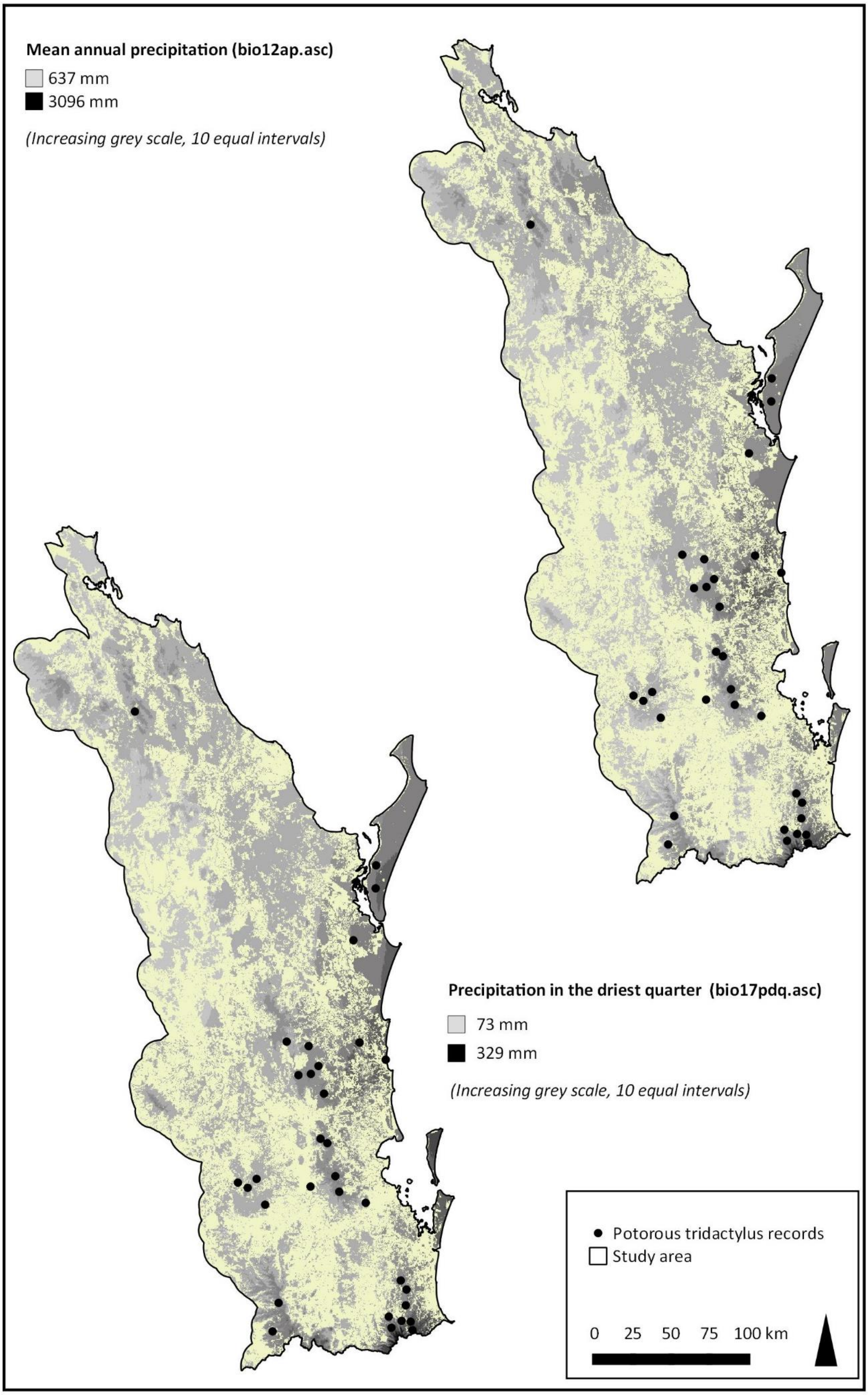


Figure 5: Environmental predictors, precipitation (annual and driest quarter).

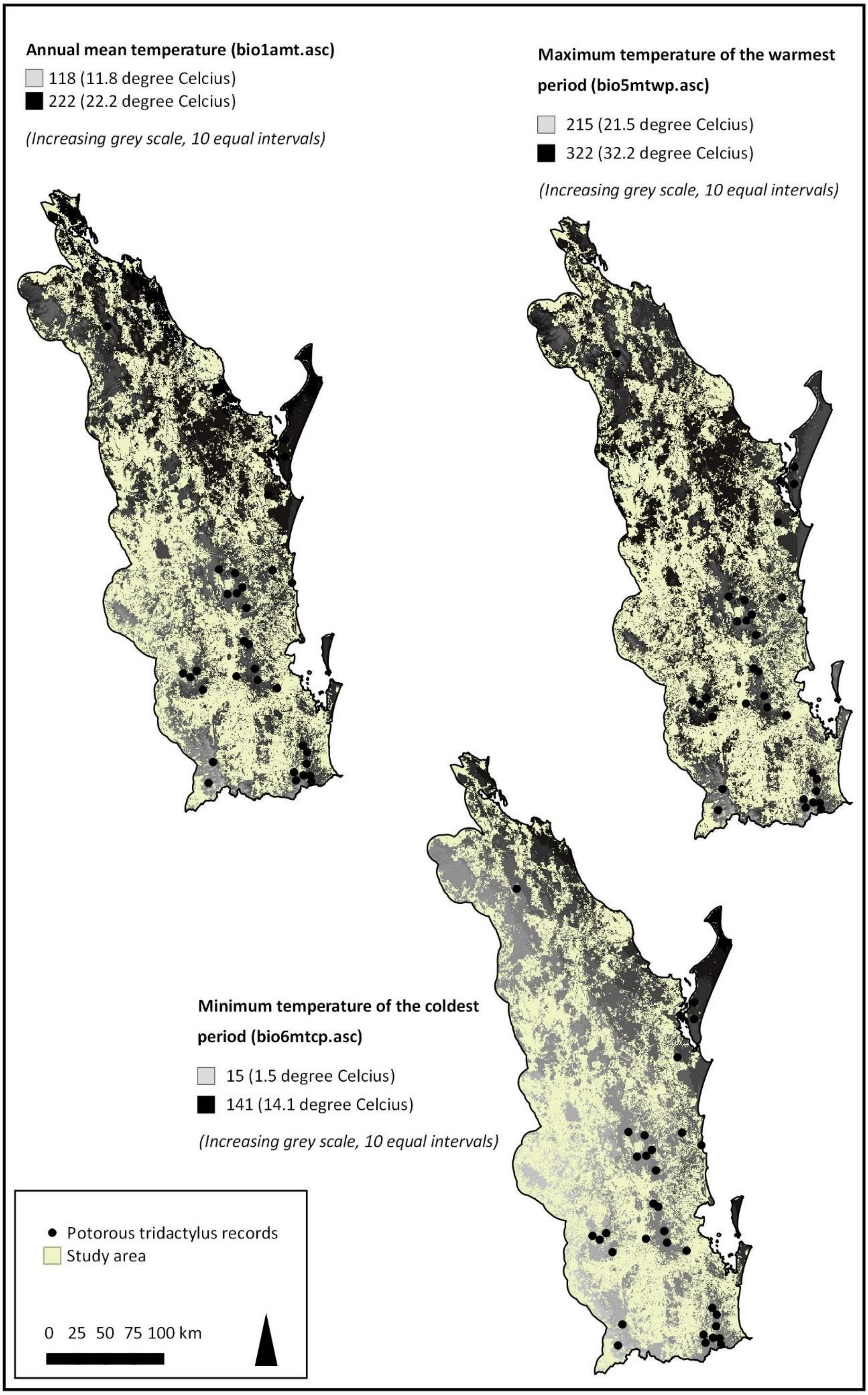


Figure 6: Environmental predictors, temperature.

Chapter 5. Species Distribution modelling

The current chapter provides a description of the species distribution modelling software used for the purpose of the current study and its implementation with respect to model selection and evaluation. In addition to the adopted species distribution modelling software, the software and nomenclature described in section 4.1 applies to the proceeding sections within this chapter. ESRIs ArcGIS desktop software (Version 10.2.1) with ArcInfo licence and Spatial Analyst extension, was also used to perform selected geoprocesses (ESRI 2014). The key datasets and outputs from individual species distribution model runs referred to in the preceding sections are included digitally as Appendix F.

5.1. Maxent – A Modelling Approach Based on Presence only Records

The current release of the Maxent software, version 3.3.3k (Phillips, Anderson & Schapire 2006) was selected for modelling the focal species distribution. Whilst a review of species distribution modelling approaches is outside the scope of the present study, Maxent was selected primarily on the basis that a number of studies that have trialled the software with respect to other species distribution modelling techniques have found it to provide similar or better discrimination where presence only data is available (Elith et al. 2006; Ward 2007; Phillips et al. 2009). Additionally, studies have purported that it can provide a reasonable level of discrimination even when relatively few records are available (Elith et al. 2006; Pearson et al. 2007; Phillips et al. 2009), as was the case of the current study post record vetting.

Other major advantages (Phillips, Anderson & Schapire 2006; Elith et al. 2006; Elith et al. 2011) of the software is that it can accept both continuous and categorical data as variables, sampling bias can be addressed by the use of grids developed to reflect survey effort, statistical outputs are generated through the package for the purpose of model selection and evaluation, it provides for complex nonlinear species responses to environmental variables and employs efficient deterministic algorithms which converge to the optimal probability distribution.

5.1.1 Maxent – A Description

Maxent utilises a machine based learning approach which makes inferences in regards to the variables present at occurrence locations given the variation within a defined study area and then expresses the suitability at each location as a function of these. To achieve this, it initially assumes that each location (i.e. a grid cell) has an equal probably of occurrence, following which it employs an optimisation routine involving multiple iterations to improve 'model fit', measured as the gain. Variable weights are incrementally adjusted until the most diffuse (or most spread out) probability distribution subject to constraints imposed by each predictor is achieved. Specifically, it estimates the target probability distribution by finding the distribution of maximum entropy, that is, the closest to uniform, and again, subject to the constraints that the expected value of each variable imposes on a target species occurrence or presence (Phillips, Anderson & Schapire 2006).

5.1.1.1 Feature Types

Maxent transforms environmental variables by a suite of functions which it terms "linear", "quadratic", "hinge", "threshold", "product" and "discrete" features. With respect to continuous data, linear features impose a constraint that the value of an environmental variable at a location should match the empirical (or observed) mean of the values of that variable at occurrence locations. Quadratic features, when used in conjunction with linear features impose weights based upon the empirical average, however, take into account the observed variance (i.e. tolerance for variation from its optimal conditions) (Phillips, Anderson & Schapire 2006; Phillips & Dudík 2008).

More complex features such as product features, assess interactions between pairs of continuous variables and impose the constraint that the covariance is close to the observed values. Threshold features employ stepped functions in response to changes in values so that the proportion of a model output that has values above a threshold for a continuous variable should be close to the observed proportion, whilst hinge features reflect threshold features fitted with piece-wise linear splines. (Phillips, Anderson & Schapire 2006; Phillips and Dudík 2008, Elith et al. 2011)

With respect to categorical variables, Maxent uses discrete features to assign constraints. Each value of a categorical variable is treated as a separate feature in itself and at each location is either present, or not. The model imposes a constraint on the output probability distribution that it is similar to the observed proportion (Phillips, Anderson & Schapire 2006).

To reduce overfitting a model by strictly enforcing multiple feature constraints, Maxent uses a regularisation process to relax the constraints so that they need not exactly meet their empirical or observed averages. In part this is due to the fact that empirical averages only approximate real values (Phillips, Anderson & Schapire 2006). Maxent's regularisation process similarly reduces some feature coefficient weightings to zero or close to zero for variables which contribute little information. As a result, Maxent is generally considered fairly robust with respect to issues associated with the inclusion of highly correlated predictor variables (Elith et al. 2011). Notwithstanding, if the intent of a study is to use modelled inferences to extrapolate to new areas, or to identify the core drivers of a species distribution, then screening of variables which covary is appropriate (Elith et al. 2011, Merow, Smith & Silander 2013)). Whilst users can alter regulation parameters should they choose, Maxent employs default settings validated on a diverse range of species (Phillips & Dudik 2008).

By default, Maxent will use all features types if the number of records is sufficient. In situations where records are limited, to reduce over complexity of the model and given limitations in the inferences which can be made from fewer observations, certain feature types are not employed (Elith et al. 2011). For example, product and threshold features are not automatically implemented unless 80 or more records are available.

5.1.1.2 Maxent Outputs

The standard output probability distribution from the Maxent software is termed the "raw" output, which is scaled so that the sum of values across all background sample and presence locations equates to 1. Thus, cell values tend to be extremely small, making interpretation difficult (Baldwin 2009; Merow, Smith & Silander 2013). Maxent also allows users to select from two additional output formats, its "logistic" format and "cumulative" format. All three are monotonically related and will not influence rank based measures, however, may be used for different purposes dependent upon the intent of the modelling exercise (Baldwin 2009).

The cumulative output format is calculated as the sum of the raw values of all background sample locations equal to or less than itself multiplied by one hundred (Phillips, Anderson & Schapire 2006). Output values, therefore lie between 0 and 100. Thus, a cell value of 10, reflects that fact that 10% of all background samples have raw values equal to or less than the raw value at that cell. One issue associated with the cumulative probability, is that for study areas where raw values are similar across the majority of the region, cell values are still rescaled from zero to one hundred and large differences in values therefore do not necessarily correspond proportionally to the probability of presence or habitat suitability (Phillips and Dudík 2008).

To account for this, Phillips and Dudík (2008) introduced Maxent's logistic format which is calculated based upon a transformation of the raw value at each cell, so that larger output cell values correspond to higher probabilities of occurrence or suitability. Similar to the raw output, values lie between 0 and 1. In order to fit the probability distribution, Maxent makes certain assumptions in regards to prevalence (i.e. probability of occurrence) and assigns a default value of 0.5 based upon average conditions at occurrence sites (Elith et al. 2011). The logistic output is the most commonly used output for providing a relative assessment of the probability of occurrence or as a general index of habitat suitability (Baldwin 2009).

5.1.1.3 Model Selection and Evaluation Measures

The most common used evaluation parameter to assess model performance in Maxent, is the area under the curve (AUC) developed from receiver-operator characteristic curves (ROC) (Merow, Smith & Silander 2013). With respect to presence only modelling, the AUC essentially reflects a ranked based assessment as to the probability of whether the output value at an occurrence location is higher than a randomly selected background location (Phillips, Anderson & Schapire 2006). The AUC is a threshold independent measure, in that it doesn't require a threshold value to evaluate model discrimination. Values range from 0 to 1 with a value of 0.5 reflecting no better than a random selection, whilst values of 0.75 and above are generally considered potentially useful (Elith 2002, cited in Phillips and Dudík 2008, p. 166).

A common criticism of the use of the AUC, is that studies which encompass broad geographic extents relative to a focal species distribution tend to inflate the AUC value due to inclusion of ranges of variables well outside the species known distribution (Merow, Smith & Silander 2013). Whilst this may be appropriate for the purpose of country or global distribution maps for example, if the intent is to assess a species regional distribution, the inclusion of large study areas is unlikely to generate species distribution models which discriminate at the regional or local scale. For this reason, the current study was limited to only those biogeographic subregions in which the species has been observed to occur historically (refer to section 4.2).

Notwithstanding, the AUC is considered an appropriate measure to assess performance of competing models built for the same species, background sample and study area location (Merow, Smith & Silander 2013).

5.1.1.4 Base Inputs

With respect to the minimum base data inputs, the software only requires a set of presence locations of the focal species in a comma separated delimited file format and the environmental predictor datasets in ESRI's ArcInfo ASCII Grid format. The software uses the predictor grids to generate a random background sample, as well as to produce output maps and grids reflective of the modelled probability. Alternatively, Maxent also allows users to enter both occurrence locations and a predefined background sample to be entered in a modified comma separated delimited text file (described as an "SWD", or "samples with data" format in Maxent), which for both occurrence and background sample locations, must contain the values associated with each of the environmental predictors. The two SWD files must contain fields which identify the species (or the fact that a record reflects a backgrounds sample if Maxent's SWD format is used for the later), the associated coordinates, as well as individual fields which contain the values of each of the environmental predictor variables selected for assessment.

In order to produce model probability maps when using SWD files, Maxent allows users to also define a directory which contains the environmental predicators grids in ESRI's ArcInfo ASCII Grid format. It can then project the modelled inferences (derived from the SWD files) using the input predictor grids to create maps of modelled suitability.

For the purpose of the current study, Maxent's SWD format was used for both occurrence and background sample locations. The formatted environmental predictor datasets listed in section 4.3.5 were used in the final Maxent model so as inferences could be extrapolated based upon the environmental variables present at each location within the study area to produce a relative grid of habitat suitability.

5.2 Occurrence Records and Background Sample Preparation

The preceding sections 5.2.1, 5.2.2 and 5.2.3 outline the process by which the focal species occurrence records and the background sample were prepared, whilst adjusting for survey bias using a background target group sample of small native mammal species and for other issues such as spatial autocorrelation as discussed in section 2.2.

Focal and background target group sample species records contained in Appendix F were obtained for the purpose of the current project and its formative assessment and cannot be copied, reused or extracted for any third party use or derivative works. Any queries or requests relating to this information, must be directed to the relevant custodian, the Queensland Department of Science, Information Technology and Innovation, or the Queensland Department of Environment and Heritage Protection, dependent upon the source.

5.2.1 Initial Vetting of Occurrence Records

Whilst a reasonable number of studies have been undertaken to investigate *Potorous tridactylus*'s potential habitat preferences, as well as biological, population ecology and behavioural elements, its cryptic nature and small size has impeded observations (Norton, French & Claridge 2010). Additionally, the majority of surveys undertaken have occurred in southern NSW, Victoria and Tasmania, with fewer studies in northern New South Wales and Queensland. As such, only presence records were readily available.

By agreement and for the purpose of the current study, records were compiled from three primary sources, the Queensland Department of Environment and Heritage Protection's Historical Species database (DEHP 2014), the Queensland Department of Science, Information Technology and Innovation's Wildnet database (DSITIA 2014) and a few additional records were obtained from a senior ecologist at the Queensland Herbarium (Daniel Ferguson 2014, pers. comm. 22 May).

Two hundred and seventy records were initially compiled from three sources (titled "ConsolidatedRecords.csv"). Records were vetted to remove those with spatial accuracies of more than 1,300 m and captured prior to 1987. The associated spreadsheet was imported into QGIS desktop *{QGIS; Import csv}* and the projection defined as the Geocentric Datum of Australia 1994, EPGS:4283 (consistent with the coordinate system specified in the attribute information). The dataset was exported *{QGIS; Save As}* to the projected coordinated system, Map Grid of Australia, Zone 56 (EPGS 28356) and titled "potorous_tridactylus.shp".

Duplicate records were removed so that only a single record per location was retained. Records identified in the database suspected of being of low confidence in terms of species identification were excluded. Of the seventy-five records remaining, fourteen were located outside of remnant vegetation. Eleven of these however were located just outside or on the QLD border for which remnant vegetation mapping was not available and another was of an individual crossing a road between two remnant tracts. With respect to the remaining two records, one involved the sighting of an individual within a narrow vegetated linkage (presumably to narrow to be mapped as remnant vegetation) surrounded by plantation forestry and which connected two larger remnant patches approximately 1 km distant. The remaining record however, was of an individual adjacent a road within what appeared to be an area of dense regrowth vegetation connected to a large tract of remnant vegetation approximately 500 m distant. For the purpose of this study, all records outside of remnant vegetation were removed.

The adoption of records post 1987 and with spatial accuracies of less than 1300 m was essentially a trade-off between maintaining a selected minimum number of records, whilst reducing the potential for significant environmental change having occurred at and surrounding presence locations, as well as to retain the highest spatial accuracy possible. Whilst a number of studies suggest Maxent can be used with very few localities to derive useful information, it is generally recommended that a minimum of thirty records be retained where possible (Wisz cited in Baldwin 2009, p. 857).

Some of the base environmental datasets used for the purpose of the study reflect recent environmental conditions and therefore the use of records which substantially predate such is potentially erroneous. Statistics on clearing rates of native remnant vegetation produced by the Queensland herbarium date back to 1997 and indicate that the majority of clearing within the South East Queensland bioregion occurred prior to this period, with approximately only 1 % of the bioregion extent lost since (http://www.qld.gov.au/environment/plants-animals/plants/ecosystems/remnant-vegetation/). The rate of clearing in the ten years prior is uncertain, but for the purpose of the current study, it is assumed that the period post approximately 1987 reflects a reasonably static interval in terms of vegetated habitat extent.

5.2.2 Spatial Bias and Autocorrelation

As discussed in section 2.2, spatial bias and/or the inclusion of non-independent records can impede the final accuracy of a model by influencing the calibration range of target niche parameters. If the effect of sample bias is known, or can be estimated, the importance of individual records with respect to environmental predictor variables can be weighted accordingly, or alternatively, records may be spatially filtered to reflect a more random selection.

To reduce problems associated with spatial autocorrelation, record clustering and broad geographical sample bias, similar to the study undertaken by Peers, Thornton and Murray (2013), both approaches were adopted. Specifically, spatial filtering of presence records to ensure record independence, to reduce the chance of overweighting environmental conditions at clustered sites whilst also maximising the environmental heterogeneity encountered between locations, as well as the development of a bias grid to account for residual broader geographic bias.

5.2.2.1 Spatial Filtering - Occurrence Records

Following the initial vetting process (refer to section 5.2.1), the remaining one hundred and thirty-seven records were spatially rarefied manually in QGIS so that no record was situated within 5 km of another. Given estimates of the species home range are between 2 and 20 ha, and taking into account spatial accuracy of records (i.e. 1300 m), a 5 km radius is considered to negate the chance of overlap between individuals. Preferably, a larger proximity radius would have been adopted to increase the amount of environmental variation encountered between records, however, 5 km was the maximum distance whereby the recommended minimum number of records could be retained.

Selection principles for the retainment of records at clustered locations were (in order of preference), 1 - to maintain the maximum number of records, whilst generally maintaining the maximum distance between records, 2 - to retain records with the highest spatial accuracy, and 3 - to retain records attributed with the most recent date of capture.

From the initial two hundred and seventy record's compiled, and post removal of duplicates and vetting with respect to the adopted timeframe, spatial accuracy and proximity radius, thirty-two records were retained. Based upon the original source of the record (primarily ecological surveys, siting's by experts, institutions such as the QLD Museum) and where available information relating to record identification confidence, all retained records were considered to be of high confidence with respect to species identification.

5.2.2.2 Residual Bias

Systematic survey effort in Queensland is greatest per unit area in South East Queensland, however, effort within this region is biased towards the coastal margin, particularly around areas of human habitation and public land managed for natural area management (i.e. National Parks) (Smith 2013).

Even subsequent to the process of spatially rarefying occurrence records, retained records still occurred at greater densities towards the southern and southeast portions of the study area, presumably in part a reflection of survey effort. To account for this, and given little information was available, as per Phillips et al. (2009) study (refer to section 2.2), a bias grid was developed to reflect broad geographic areas of survey effort using a target group background sample of small mammal species records.

An extract of small mammal records from the Queensland Department of Environment and Heritage Protection's historical fauna database (DEHP 2014) was obtained upon request. Selected species were excluded so that only small native ground dwelling mammal species were retained (i.e. aquatic, estuarine, predominantly arboreal and exotic species were removed, as survey methods for such species likely differ to the focal species). Records were vetted in a manner consistent with that undertaken for the focal species so that only records captured post 1987 with accuracies of less than or equal to 1300 m were retained and which were located within remnant vegetation. Similarly, for each target group background species, records were spatially filtered so that no record was situated within 5 km of another.

To provide a simplified estimate of sample effort based upon the assumption that broad geographic areas subject to higher levels of sampling effort exhibit greater spatial densities of surveyed sites, all grid cells in areas considered of potential suitable habitat which contained a record were attributed with a value of one (i.e. surveyed) and all cells with no records, a value of zero (i.e. not surveyed). This approach was adopted over weighting cells based upon record counts to try to reduce the impact of overweighting areas that exhibit higher species abundance and richness potentially resulting in higher capture rates, rather than as a result of survey effort.

Surveyed grid cells (i.e. cells with a value of one) were then converted to points based upon cell centroids and a kernel distance decay analysis performed to provide a continuous output reflective of point density generated within a defined neighbourhood surrounding each cell. To account for edge effects outside of which records could not be located (i.e. seaward of the coastline and outside areas of remnant vegetation not considered as potentially suitable habitat), the output was adjusted by dividing by the weighted number of vegetated cells (in which records could potentially occur) within the specified neighbourhood, similar to the approach by Elith, Kearney and Phillips (2010).

Using Jenks natural breaks optimisation, the resultant bias grid was classified into three broad geographic areas reflective of estimated sample effort and weighted based upon the proportion of surveyed sites located within each. These weightings were then used to proportionately select random cells from each of the three survey effort regions to be used as the background sample locations against which focal species records would be assessed (i.e. with respect to environmental variables), thereby minimising the potential for error arising from broad geographic bias.

Bias grid development: data processing

The following steps list the processes by which the bias grid was developed.

Process 1: With respect to the target group background sample, following removal of records with spatial accuracies of less than 1300 m and which were captured prior to 1987, the spreadsheet was imported into QGIS, and reprojected to Map Grid of Australia, Zone 56, EPGS: 28356 (originally in the geographic coordinate system, the Geocentric Datum of Australia 1994, EPGS: 4283). A spatial selection *{QGIS; Spatial Query}* was performed using remnant units within the buffered study area extent developed in section 4.3.4 (i.e. "REs_ BufferedStudyArea_10km.shp", hereafter referred to as the "bias analysis extent") to extract target group background species records. This process was undertaken to capture records both within and adjoining the study area (i.e. to be used for the purpose of point density grid anaylsis) and which were situated in areas of potential vegetated habitat. A new field was added to the dataset, [Wt], and all records calculated to equal one *{QGIS, Field Calculator}*.

Process 2: The resultant dataset was split into individual datasets reflective of each species *{QGIS; Split vector layer}* resulting in twenty-five individual datasets and duplicate records within each removed *{QGIS; Delete duplicate geometries}*. To reduce the time that would have been required to manually spatially filter each dataset, records for each target group background species were filtered iteratively using QGIS's Distance matrix function.

The QGIS function, Distance matrix, was used to output a comma separated delimited (csv) file which identified the nearest neighbour to each record within a species dataset. For pairs of records where the nearest neighbours were each other and the distance less than 5 km, the first record was flagged for removal. The resultant CSV file was then imported into QGIS and joined to the original dataset based upon an identification field [SP_ID], and the dataset edited to remove flagged points. This process was repeated until no records were located within 5 km of each other. Once all twenty-five datasets had been spatially filtered, they were merged into a single dataset *{SAGA; Merge layers}* titled "5km_All_TGBS.shp" reflective of 1,510 points. Individual species and their counts are listed in Table 8 below.

Table 8: Target group background species, count of records for each species.

Species	Count
Aepyprymnus rufescens	75
Antechinus argentus	2
Antechinus arktos	2
Antechinus flavipes	155
Antechinus mysticus	8
Antechinus stuartii	3

Species	Count
Antechinus subtropicus	45
Dasyurus hallucatus	4
Dasyurus maculatus maculatus	31
Isoodon macrourus	200
Melomys burtoni	72
Melomys cervinipes	150
Perameles nasuta	120
Planigale maculata	68
Potorous tridactylus tridactylus	30
Pseudomys delicatulus	13
Pseudomys gracilicaudatus	30
Pseudomys novaehollandiae	7
Pseudomys oralis	7
Pseudomys patrius	12
Rattus fuscipes	147
Rattus sordidus	1
Rattus tunneyi	72
Sminthopsis murina	77
Tachyglossus aculeatus	179

Process 3: The point dataset was converted to a raster grid *{SAGAs Shape to Grid}*, consistent with the study area resolution, however, accommodating the increased spatial extent associated with the bias analysis extent (i.e. bounding co-ordinates: 255350 W, 554750 E, 6846800 S, 7411300 N). Grid cells which intersected one or more records were attributed with a value of one based upon the field [Wt].

Process 4: This raster dataset was then reconverted to a polygon file *{SAGA, Grid values to Points}*[3] with output polygons reflective of individual grid cells attributed with a value of one (nodata cells were excluded). Polygons in the resultant dataset were in turn converted to points *{SAGA, Polygon centroids}* based upon cell centres. The resultant dataset, titled "SurveyedSites.shp", reflected the centroids from 1,106 unique cells considered to have been subject to some survey effort (with respect to process 6 below, the resultant dataset was titled "PotenialSurveySites.shp" and contained 3,783,770 records).

Process 5: Similar to the approach adopted by Elith, Kearney and Phillips 2010, a Gaussian kernel point density analysis *{SAGA; Kernel density estimation}* was used to produce a continuous output of weighted cells across the bias analysis extent based upon 'surveyed' sites (or, with respect to process 6 below, sites which potentially could be surveyed) within a defined neighbourhood. Output cell resolution was 100 m and a bandwidth of 30 km was adopted. This was the minimum bandwidth in increments of 5,000 m that provided a

[3] Saga's "Grid to Points" algorithm converts either to grid nodes, or cell polygons, i.e. not centroids.

continuous coverage across the bias analysis extent. The output dataset was titled "TGBS_GauPDAnalysis.tif" (and "RE_GauPDAnalysis.tif" with respect to process 6 below).

<u>*Process 6:*</u> In order to reduce down weighting of cells close to boundaries outside of which records could not occur (i.e. marine areas, large freshwater waterbodies and areas of non-remnant), processes 4 and 5 above were repeated, however, with the input raster dataset reflective of all cells within the bias analysis extent which intersected terrestrial remnant vegetation considered as potentially suitable habitat (refer to section 4.3.1.1) (i.e. which *could* potentially be surveyed).

This raster dataset was produced by adding a new field [Wt] to the dataset "REs_ BufferedStudyArea_10km.shp" and then calculating each record to equal one. As previously mentioned (refer to section 4.3.4), "REs_ BufferedStudyArea_10km.shp" excluded cleared areas of water, plantation forest, regrowth etc. and remnant units where the dominant BVG reflected estuarine vegetation communities, or permanent and near-permanent freshwater bodies. The dataset was then converted to raster format *{SAGA, Shapes to grid}*. Each grid cell in the resultant output was assigned a value of 1, reflective of its "potential" to be surveyed. Following this, processes 4 to 5 were repeated.

<u>*Process 7:*</u> A relative survey effort grid which accounted for boundary effects was produced by dividing *{QGIS; Raster calculator}* the value obtained in the first point density analysis, reflective of the target group background sample over the second point density analysis output (reflective of the maximum potential survey effort within the defined neighbourhood of each cell).

Expression: "TGBS_GauPDAnalysis_Final.tif" / "RE_GauPDAnalysis.tif".

The output dataset was exported as per the defined spatial extent spatial parameters (refer to section 4.2.1) and was titled, "TGBSGDAnl_div_REGDAnl_Final.tif".

<u>*Process 8:*</u> A new grid was then produced which only contained cells where values were present for all environmental predictor datasets. This was achieved by multiplying *{QGIS: Raster calculator}* cell values with those in the dataset "AllEnvVars_Mask_StudyArea.tif" (i.e. in which values were either one or nodata) and with nodata values not propagated. This dataset was titled "TGBSGDAnl_div_REGDAnl_Mask_Final.tif".

Expression: "AllEnvVars_Mask_StudyArea.tif" /
"TGBSGDAnl_div_REGDAnl_Mask_Final.tif".

<u>*Process 9*</u>: This dataset was then converted to vector format *{SAGA; Grid values to point}* to produce an intermediate dataset, for which three natural ranges of survey effort were identified using Jenks Natural Breaks optimisation[4] *{QGIS; Layer Properties -> Style -> Graduated -> Mode: Natural breaks (Jenks)}*. Cell values within "TGBSGDAnl_div_REGDAnl_Mask_Final.tif" were then reclassed *{SAGA; Reclassify grid values}* to reflect the three levels of survey effort as indicated in Table 9 below with all remaining cells assigned as nodata *{GDAL; gdal_warp}*. The final dataset was titled "SurveyEffort.tif".

Table 9: Adjusted point density reclasses using natural breaks (Jenks) optimisation.

Survey Effort	**Natural break (Jenks) ranges rounded to 0.0001 with respect to cell values in TGBSGDAnl_div_REGDAnl_Mask_Final**	**Reclassed values**
Low	0 < cell value <= 0.0003 (0.000002 - 0.000309)	1
Medium	0.0003 < cell value <= 0.0008 (0.000309 - 0.000759)	2
High	0.0008 < cell value <= 0.0020 (0.000759 - 0.001821)	3

Figure 7 displays the three estimated broad areas of survey effort (a) and with the target group background sample and focal species points overlaid (b).

[4] Jenks natural breaks optimisation could only be performed on vector files in QGIS.

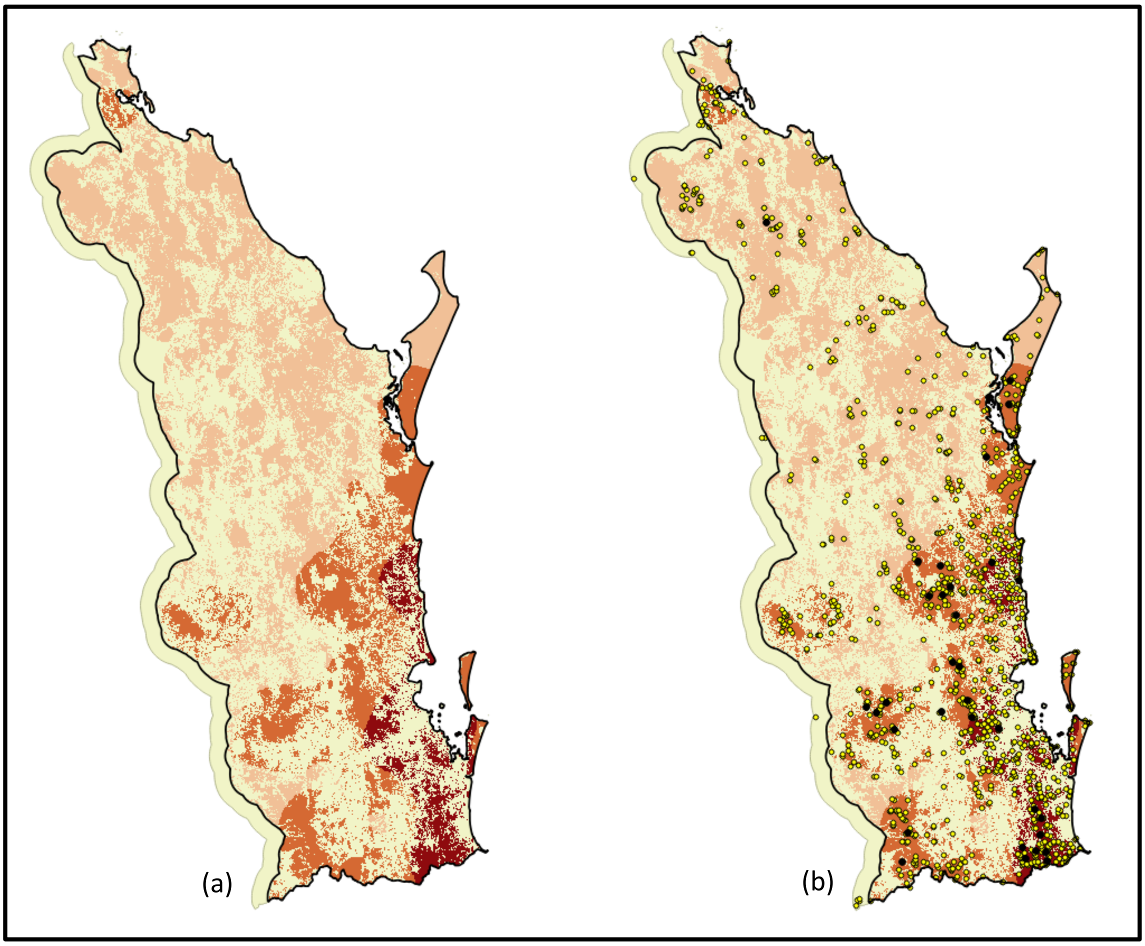


Figure 7: Estimated survey effort within the study area. Part (a) - darker shades indicate higher levels of survey effort. Part (b) – survey effort regions with the focal species records (black points) and target group background sample (yellow points) overlaid. The yellow background reflects the bias analysis extent and the black outline, the study area.

Process 10: To derive a relative estimate of sample effort between the regions to be used to proportionately select background locations for input into Maxent, surveyed sites of target groups background species ("SurveyedSites.shp") within the bias analysis extent were attributed *{QGIS; Point Sampling Tool (plugin)}* as to whether they were located within low, medium or high survey effort regions as indicated in the dataset, "SurveyEffort.tif". The resultant dataset was titled "SurveyedSites_SurveyEffortRegion.shp".

Table 10 below lists the count *{QGIS; Group Stats (Plugin)}* of unique target group background sample sites located with each of the three classes of survey effort. Thirty-three cells were located within nodata cells (i.e. outside of the study area, but within the bias analysis extent, or situated within areas where all environmental predictor values were not present).

Table 10: Count of unique sample sites within the three classes of survey effort.

Survey Effort Region	Count of TGBS surveyed sites	Percentage of TGBS surveyed sites
Low (1)	232	21.6%
Medium (2)	502	46.8%
High (3)	339	31.6%
nodata	33	*NA*
Total	1106	*NA*
Adjusted Total	1073	100

5.2.3 Occurrence and Background Sample Selection

Whilst Maxent software allows users the option of implementing a bias grid directly which it can use to proportionately select background samples from environment predictor grids, to increase processing time and ensure the same background sample was used for each repeated model run, as mentioned previously, Maxent's SWD (i.e. csv format) option was adopted as the input format for background samples. To account for broad geographic bias, the number of samples selected from each region of sample effort was proportional to the number of target group surveyed sites observed in each. A background sample size of 10,000 sites was selected across the entire study area as recommended by Phillips and Dudík (2008).

A random selection of cells was performed within each region of survey effort relevant to the proportion of surveyed sites. Cell centroids were extracted and attributed with values from all environmental predictor datasets. In the same manner, the final selection of the focal species occurrence records were also attributed with values from all environmental predictor datasets.

Background sample preparation

The following steps outline the process used to prepare the background and occurrence "samples with data" files as base inputs for the Maxent software.

<u>Process 1</u>: In order to create three regions of survey effort from which random selections of cells could be made, the dataset "SurveyEffort.tif" was converted *{GDAL; gdal_polygonize}* to vector format (and titled "SurveyEffort.shp") and then subsequently split *{QGIS; Split vector*

layer} into three separate shapefiles each reflective of a region of survey effort. These datasets were then transformed back to raster *{GDAL: gdal_rasterize}* to produce three geotiffs each reflective of an individual survey effort region (and consistent with the defined spatial parameters listed in section 4.2.1).

<u>*Process 2:*</u> Grid cells from within each survey effort region were randomly selected without replacement *{GRASS; r.random}* in accord with Table 11 below (i.e. proportionate to the number of observed surveyed sites for the target group background sample and so as to provide a total sample size of 10,000 sites across all three regions).

Table 11: The number of background sample locations per region of survey effort.

Survey effort region	Percentage of TGBS surveyed sites	# of random background samples per region
Low (1)	21.6%	2,160
Medium (2)	46.8%	4,680
High (3)	31.6%	3,160
Total	100	10,000

<u>*Process 3:*</u> The three point datasets were merged *{SAGA: Merge layers}* into a single layer titled "BackgroundSample.shp". Each point was then attributed *{QGIS; Point Sampling Tool (plugin)}* with values from each of the environmental predictor datasets and the dataset saved as "BackgroundSample_Final_SWD.shp". Three attribute fields were added ([species], [x], [y]) and calculated *{QGIS; Raster calculator}* to equal "background" (i.e. to identify the record as a background sample) and each points easting and northing coordinates respectively (Map Grid of Australia, Zone 56). The associated database file was opened in Microsoft Excel (2013) and exported to coma delimited format and titled, "BackgroundSample _SWD".

Occurrence sample preparation

<u>*Process 4:*</u> As per process 3 above, occurrence records were attributed *{QGIS; Point Sampling Tool (plugin)}* with values from all of the environmental predictor datasets and the dataset saved as "potorous_tridactylus_final_SWD.shp". Three attribute fields were added ([species], [x], [y]) and calculated *{QGIS; Raster calculator}* to equal "potorous_tridactylus" and each records associated easting and northing coordinates respectively (Map Grid of Australia, Zone 56). Again, the database file was opened in Microsoft Excel (2013) and exported to coma delimited format and titled, "Potorous_tridactylus_SWD.csv".

5.3 Model Selection

To assess correlations between environmental predictors, correlation analysis (Spearman's rank correlation coefficient) using Microsoft Excel was initially performed on the selected background sample locations (i.e. "BackgroundSample _SWD.csv") prior to initial model runs to identify those considered strongly correlated (for the purpose of this study, a Spearmans rank correlation coefficient >= 0.6 was considered as "strongly" correlated). For the purpose of assessing potential relationships, the categorical variables "low undergrowth cover" and "soil hardness" were treated as discrete ordinal variables.

Following this, several combinations of variables were derived each which incorporated the maximum number of variables exclusive of those identified as strongly correlated. As climatic variables are considered among the most important drivers of species distributions at the macro scale (Guisan cited in Hirzel & Lay 2008), initial combinations were derived based upon all possible pair-wise combinations of these. To each, the full suite of biophysical predictors and the single anthropogenic variable (refer to Table 7, section 4.3.5) were then added (again, subject to the exclusion of correlated variables). In addition to the above, a further combination was also included, which encompassed only the biophysical predictors and single anthropogenic variable.

Based upon these variable combinations, repeated Maxent models were developed using the occurrence and background SWD files as based inputs created in the preceding section 5.2.3 (i.e. "Potorous_tridactylus_SWD.csv" and "BackgroundSample _SWD.csv" respectively). For each full model combination, variables were sequentially removed based upon their contribution to that models predictive performance in a stepwise manner, and a subsequent model run undertaken at each step, until a final model was produced for the remaining variable retained from each original combination. The selected 'successful' final model was the subset of environmental predictors from all combinations which exhibited the highest model predictive performance.

The performance measures and process by which predictor variables were assessed based upon Maxent outputs is outlined in the proceeding section.

5.3.1 Method Settings and Performance Measures

As the current study included only a single species within a defined study area and adopted the same background sample between model runs, the area under the curve value (AUC) value (refer to section 5.1.1.3) was used as the primary mechanism to discriminate between competing models (Merow, Smith & Silander 2013). As previously discussed, AUC values of greater than 0.75 are considered potentially useful. The stepwise removal of environmental predictors for each potential combination of variables was undertaken to minimise the number of environmental predictors which contributed no or little independent information and the final 'successful' model selected based upon the combination of modelled variables which produced the highest AUC values (exclusive of strongly correlated variables).

To try to account for variation within and between models and the importance of individual environmental predictors, *K*-fold cross validation was undertaken for each model run. Occurrence locations were resampled in Maxent so that eight sets of "test" and model "training" data for each model run were used to produce an averaged output AUC value, based upon the test locations. Each sub-model run was therefore trained on twenty-eight records and modelled inferences tested with respect to the remaining four. Withholding a portion of the occurrence locations provides a measure by which to assess variable importance weightings based upon the trained models with respect to their capability to successfully predict withheld records. The averaged test AUC value from each model run was used as the benchmark to compare model performance between competing modelled combinations of predictor variables.

To assess the importance that each variable contributed with respect to the overall AUC output for each model run on each combination of variables, Maxent's "Do Jackknife tests" option was selected. Maxent's jackknife test forces the software to run further additional subsets of models whereby each variable is excluded from the combination of variables as well as modelled independently. Results are presented graphically and provide information as to how each variable impacts on the model test AUC value associated with withheld locations. Thus, the variable which contributed the least to the overall average test AUC value, or which impacted negatively, was removed, and the process repeated with the reduced subset of variables until only a single variable remained. A final model run was also undertaken on the remaining variable, so as to produce an average test AUC value based upon that variable alone.

Finally, based upon the most successful modelled combinations of environmental variables from the cross validation runs, further runs were then undertaken without cross validation (i.e. a single replication) so that all 32 records were used for training purposes, and the AUC training values compared for the three highest ranked competing variable combinations.

With respect to Maxent feature selection, given the number of occurrence records were substantially below that recommended for use of product and threshold features, these were not used in the current study. Additionally, to produce smoothed ecological response curves, simplify subsequent ecological interpretation and limit the potential for overfitting to environmental noise, only simple linear and quadratic features were selected (i.e. hinge features were excluded). Notwithstanding, such features are often considered to produce more ecological realistic response curves (Bateman, Abel-Davis & Johnson 2011; Merow, Smith & Silander 2013). For categorical variables (i.e. “low undergrowth cover” and “soil hardness” categories), Maxent’s discrete feature type was automatically implemented. With respect to all remaining Maxent user options, default settings were used.

5.4 Final Model – Output and Evaluation

A final model run based upon the successful combination of variables, was undertaken in Maxent using all records to train the model (i.e. a single replicate run without *K*-fold cross validation) and the resultant modelled inferences projected to the study area to produce a raster grid in Maxents logistic output format and reflective of modelled relative habitat suitability (refer to Appendix F). Similarly, for comparison, two additional models were created in the same manner for the two closest competing models.

Maxent’s heuristic ‘percent contributions’ and ‘permutation importance’ relative weightings were used to examine variable importance in the final model (as well as the two competing models). As mentioned in section 5.1.1, Maxent undertakes multiple iterations whereby the model fit, measured as the gain, is incrementally improved until either a set number of iterations occur, or a minimum convergence threshold is reached. In doing so, it tracks which variables are used most with respect to the overall model training gain.

The percent contributions reflect a relative scaling (out of 100%) with respect to each variable’s contribution to the overall model training gain based upon the particular path that MaxEnt used to produce the optimal solution. The permutation importance, is based only upon the final model and provides a relative weighting of variable importance by randomly permuting values of each variable used in a model and measuring the resultant decrease in the AUC value. Higher permutation importance weightings suggests higher reliance upon that variable. Similarly, species response curves were also produced for the final model for discussion. Response curves indicates how each variable affects the MaxEnt predictions.

To assess whether the output AUC value from the final model differed significantly from randomly selected sets of locations subject to the same broad geographic survey bias, and with respect to the same set of environmental predictors used in the final ‘successful’ model, an approach similar to that developed by Raes and Steege (2007) was adopted. Specifically, 1000 bias corrected null models were produced by randomly selecting locations within areas of potential habitat within each of the biased surveyed regions (refer to section 5.2.2.2) and in proportion to the number of observed occurrences of the focal species within each. Each null model therefore contained 32 records. Additionally, the random selection of records for each null model was undertaken in a manner to mimic the effect of spatially rarefying the focal species records, so that no record was situated within 5 km of another.

Similar to the process by which occurrence and background samples were prepared, records in all null models were attributed with values from all environmental predictor datasets. A Maxent model was then created for each set of null models records to produce 1000 AUC values using only the final subset of successful predictor variables, so that a 95% confidence interval could be constructed by which the AUC value for the focal species (produced from the final single replicate Maxent run, refer to the start of this section) could be compared.

<u>*Process 1:*</u> To develop the null model point locations, ESRI’s ArcGIS desktop software *{ESRI; Create Random Points; Minimum allowed distance: 5000 m}* was used. In a similar manner as described in the preceding section 5.2.3, point generation was restricted to the three regions of survey effort in the dataset “SurveyEffort.shp”, so that records were only generated within vegetated areas considered of potential suitable habitat (and where values were present for all environmental predictor datasets), however, with the additional constraint that no record was situated within 5 km of another.

For each null model, the number of points generated in the low, medium and high survey effort regions was 1, 19 and 12 respectively, consistent with the number of observed focal species records observed within each. Three attribute fields were added to each null model titled ([species], [x], [y]) and calculated to equal “nullmodel*1-1000*” (i.e. nullmodel1, nullmodel2…. nullmodel1000 for each null model set of 32 records) and each points associated easting and northing coordinates respectively (Map Grid of Australia, Zone 56, EPGS: 28356). This process was looped 1000 times and the resultant files appended.

<u>*Process 2:*</u> As per section 5.2.2.2, (refer to process 10 within this section), each point was then attributed *{QGIS; Point Sampling Tool (plugin)}* with values from each of the environmental predictor datasets and the dataset saved as “Null_Model_Points_SWD.shp”. The associated

database file was opened in Microsoft Excel (2013) and exported to coma delimited format and titled, “Null_Model_Points_SWD.csv”.

<u>Process 3:</u> Maxent was then used to develop 1000 models based upon each set of null model records, and with respect to the final selected combination of environmental predictors. The resultant AUC values were automatically compiled in the output file, “maxentResults.csv”. These values were used to create a frequency histogram with the intent of developing a 95% confidence interval threshold by which to compare the AUC value associated with the final single Maxent replicate run which utilised all 32 focal species occurrence records based upon the ‘successful’ subset combination of environmental predictors.

Chapter 6: Results

The current chapter presents the results based upon the methodology outlined in Chapter 5. Individual outputs of consecutive model runs are included in Appendix F, as well as the results from the correlation analysis. The final modelled habitat suitability map for *Potorous tridactylus* is included in section 6.4.

6.1 Correlated Predictors

Results of Spearman's rank correlation coefficient test suggested the environmental predictor's "mean annual precipitation" (bio12ap), "precipitation of the driest quarter" (bio17pdq) were both positively correlated. Additionally, both were found to be negatively correlated to the "maximum temperature of the warmest period" (bio5mtwp). "Mean annual temperature" (bio1amt) and "minimum temperature of the coldest period" (bio6mtcp) were also indicated as strongly correlated. Finally, the biophysical predictor "soil hardness" (soil_hds), was found to be positively correlated to "precipitation in the driest quarter" (bio17pdq) and "maximum temperature of the warmest period" (bio5mtwp).

Table 12: Spearman's Rank Correlation Test

	bio12ap	bio17pdq	bio1amt	bio5mtwp	bio6mtcp	pt_hab_1km	cpycov	udrgwth	soil_hds
bio12ap	-	**0.94**	0.21	**-0.62**	0.57	0.12	0.43	0.16	-0.55
bio17pdq	-	-	0.02	**-0.76**	0.39	0.16	0.46	0.18	**-0.69**
bio1amt	-	-	-	0.46	**0.87**	-0.11	-0.20	-0.05	0.28
bio5mtwp	-	-	-	-	0.02	-0.29	-0.50	-0.13	**0.73**
bio6mtcp	-	-	-	-	-	0.02	0.05	0.01	-0.03
pt_hab_1km	-	-	-	-	-	-	0.45	0.04	-0.31
cpycov	-	-	-	-	-	-	-	0.07	-0.47
udrgwth	-	-	-	-	-	-	-	-	-0.15
soil_hds	-	-	-	-	-	-	-	-	-

6.2 Model Selection

As a result of the correlation analysis, only six potential models from bioclimatic predictors could be constructed exclusive of combinations of strongly correlated variables:

1. "Mean annual precipitation" (bio12ap) and "mean annual temperature" (bio1amt);
2. "Mean annual precipitation" (bio12ap) and "minimum temperature of the coldest period" (bio6mtcp);

3. “Precipitation of the driest quarter” (bio17pdq) and “mean annual temperature” (bio1amt);
4. “Precipitation of the driest quarter” (bio17pdq) and “minimum temperature of the coldest period” (bio6mtcp);
5. “Mean annual temperature” (bio1amt) and “maximum temperature of the warmest period” (bio5mtwp);
6. “Maximum temperature of the warmest period” (bio5mtwp) and “minimum temperature of the coldest period” (bio6mtcp).

Based upon the precedent that climatic predictors are the most important drivers at the upper hierarchical scale (Guisan cited in Hirzel & Lay 2008; Gils et al. 2014), to each of the above bioclimatic variable combinations, the biophysical and single anthropogenic variable(s) were added (again, excluding those identified as strongly correlated). In addition, to the above, for the sake of completeness, a separate model using only the biophysical and single anthropogenic variable(s) was also constructed. The seven “full” predictor combinations that were assessed are listed in Table 13 below.

Table 13: Environmental predictor combinations

Variable combination	Environmental predictors
Combination 1	bio1amt, bio12ap, udrgwth, cpycov, soil_hds and pt_hab_1km
Combination 2	bio12ap, bio6mtcp, udrgwth, cpycov, soil_hds and pt_hab_1km
Combination 3	bio1amt, bio17pdq, udrgwth, cpycov, soil_hds and pt_hab_1km
Combination 4	bio17pdq, bio6mtcp, udrgwth, cpycov and pt_hab_1km
Combination 5	bio5mtwp, bio1amt, udrgwth, cpycov and pt_hab_1km
Combination 6	bio5mtwp, bio6mtcp, udrgwth, cpycov and pt_hab_1km
Combination 7	Udrgwth, cpycov, soil_hds and pt_hab_1km

As discussed in the preceding Chapter 5, initial Maxent model runs (with cross validation) were undertaken for each of the full predictor combinations (i.e. inclusive of all variables). For each subsequent run and based upon the results of the jackknife test which related to the average test AUC, the predictor that contributed the least to (or impacted negatively) on the AUC value with respect to test locations, was removed. This was repeated until only a single variable was retained from each of the full model combinations.

Figure 8 and Figure 9 below relate to variable combination 1 (refer to Table 13 above) and illustrate the process by which the results of jackknife tests were used to assess predictor importance so as to determine the subsequent stepwise removal of each predictor. The Maxent summary outputs for all model runs for all variable combinations, inclusive of when only a single variable was retained are included in Appendix F (refer to the Maxent summary html files, each titled "potorous_tridactylus.html"[5] under the relevant folder). In each of the graphs below, the red bar reflects the overall test AUC value associated when all variables are modelled, whilst the darker and lighter green-blue bars, reflect the average test AUC value associated with running a model using only the respective variable and alternatively, the test AUC value associated with running the model with all other predictor variables, however, exclusive of that variable.

In regards to the initial model run for combination 1 for example, the darker blue bar for the variable "canopy cover" (cpycov) suggests that when modelled in isolation it's reasonably effective in terms of discriminating between test and background locations. However, the lighter green-blue bar indicates that the test AUC value actually increases if the variable is removed. This suggests that the Maxent feature assigned to cpycov is not contributing any additional discriminatory information not already captured by the other variables (potentially as a result of correlations not identified through the spearman's rank correlation analysis), and in fact, reduces the models capability to differentiate between presence and random background locations when used in combination with other variables.

With respect to the subsequent jackknife test, the next variable identified for removal was the categorical predictor, "soil hardness" (soil_hds). In this instance the variable was found to have the lowest potential to discriminate test locations from random background locations when modelled in isolation, and again reduced the overall models capability to discriminate between test and background locations. This process was repeated until only the variable annual mean temperature remained. A final cross validation model run was undertaken (without the jack-knife test as it included only a single variable) to determine the averaged test AUC associated with the remaining variable.

[5] Additional html files titled "potorous_tridactylus_#.html" are also included and reflect the outputs from the 8 individual cross validation runs used to produce the averaged output file titled "potorous_tridactylus.html".

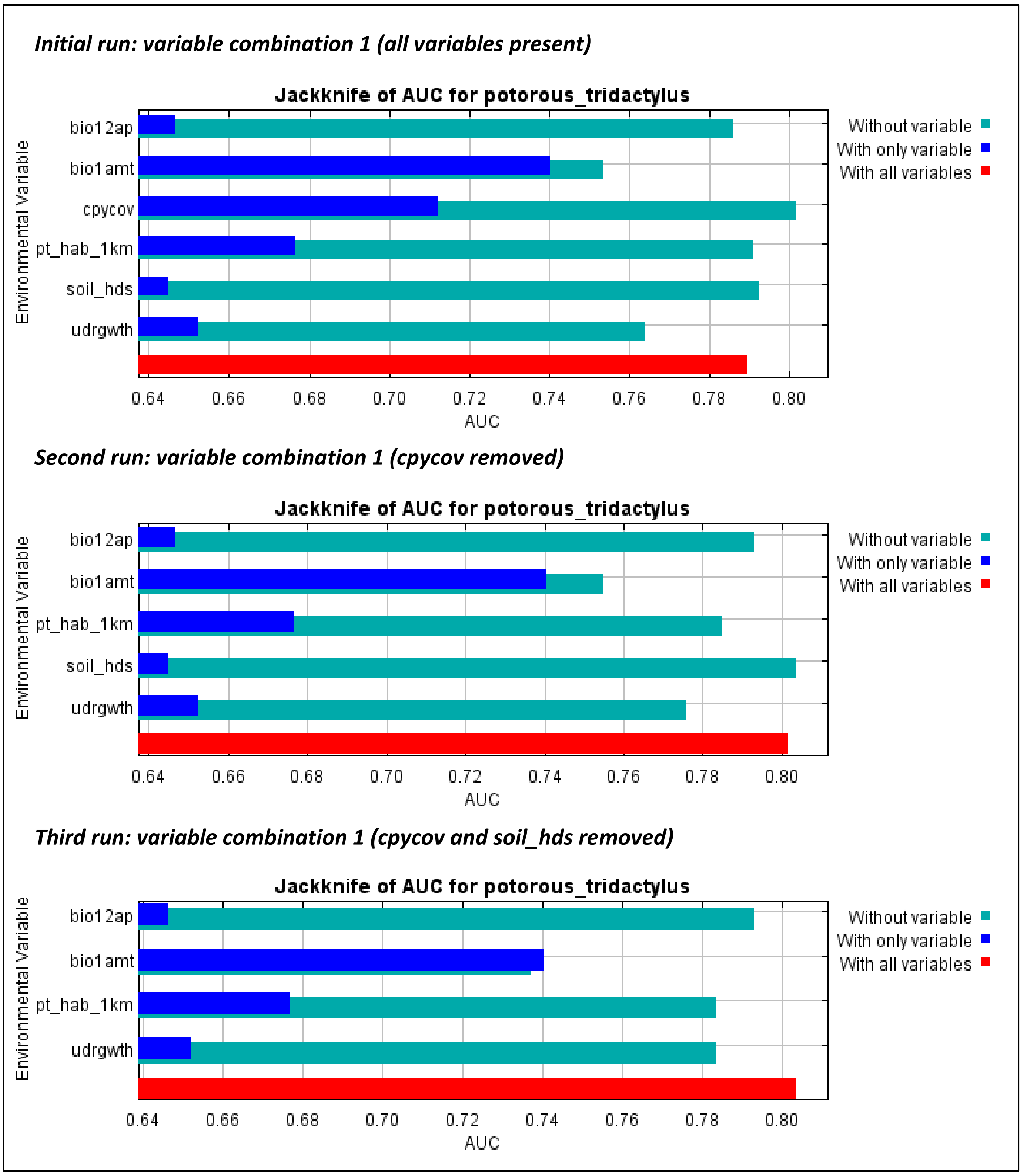
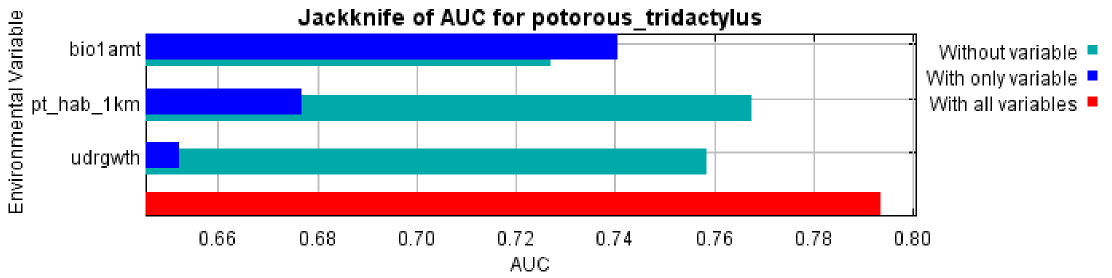


Figure 8: Jackknife tests – process of variable exclusion (part a).

Fourth run: variable combination 1 (cpycov, soil_hds and bio12ap removed)



Fifth run: variable combination 1 (cpycov, soil_hds, bio12ap and pt_hab_1km removed)

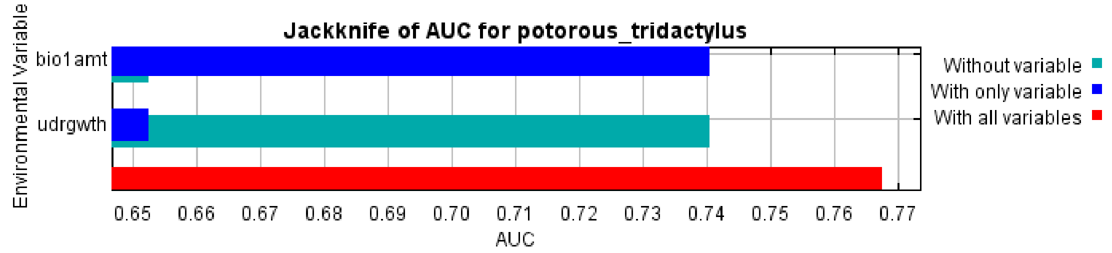


Figure 9: Jackknife tests – process of variable exclusion (part b).

The following table summarises the resultant changes to the average test AUC value from the *k*-fold cross validation runs as each predictor was removed step wise based upon the jackknife tests. The average test AUC values listed below for each model run were extracted from the relevant summary output file "potorous_tridactylus.html" (included in Appendix F).

Table 14: Averaged AUC test values associated with the stepwise removal of predictors. Nt: com # refers to the full variable combination number in Table 13. The number of variables present in the initial run for each combination are included in brackets in the top row.

	Com. 1 (6)	**Com. 2 (6)**	**Com. 3 (6)**	**Com. 4 (5)**	**Com. 5 (5)**	**Com. 6 (5)**	**Com. 7 (4)**
Full model (all variables initially included): average test AUC	0.789 (0.092)	0.767 (0.074)	0.788 (0.091)	0.771 (0.068)	0.791 (0.097)	0.790 (0.095)	0.760 (0.079)
1st variable removed	cypcov	cypcov	cypcov	cypcov	cypcov	cypcov	pt_hab_1km
Resultant test AUC	0.801 (0.107)	0.781 (0.089)	0.799 (0.108)	0.780 (0.088)	0.798 (0.113)	0.798 (0.111)	0.757 (0.093)
2nd variable removed	soil_hds	soil_hds	soil_hds	udrgwth	bio1amt	bio6mtcp	soil_hds
Resultant test AUC	**0.804** (0.107)	0.781 (0.087)	**0.799** (0.110)	0.757 (0.080)	**0.801** (0.107)	**0.801** (0.107)	0.744 (0.092)
3rd variable removed	bio12ap	undgrwth	bio17pdq	pt_hab_1km	pt_hab_1km	pt_hab_1km	udrgwth

	Com. 1 (6)	Com. 2 (6)	Com. 3 (6)	Com. 4 (5)	Com. 5 (5)	Com. 6 (5)	Com. 7 (4)
Resultant test AUC	0.793 (0.118)	0.759 (0.085)	0.793 (0.118)	0.725 (0.155)	0.788 (0.127)	0.788 (0.127)	0.712 (0.119)
4th variable removed	pt_hab_1km	pt_hab_1km	pt_hab_1km	bio6mtcp	udgrwth	udgrwth	-
Resultant test AUC	0.767 (0.143)	0.725 (0.161)	0.767 (0.143)	0.667 (0.091)	0.774 (0.139)	0.774 (0.139)	-
5th variable removed	udgrwth	bio6mtcp	udgrwth	-	-	-	-
Resultant test AUC	0.741 (0.16)	0.647 (0.097)	0.741 (0.160)	-	-	-	-

Similarly, Figure 10 provides a graphic representation of the subsequent changes to the test AUC value for each combination of variables as the least contributing predictors were removed piecewise. As indicated in both Table 14 and Figure 10, subsets of the full variable combinations 1, 3 and 5 (and 6, which post removal of its second variable, converged to the same three variables as per the subset derived from the “full” combination 5), were the most effective predictors out of all of the subset combinations.

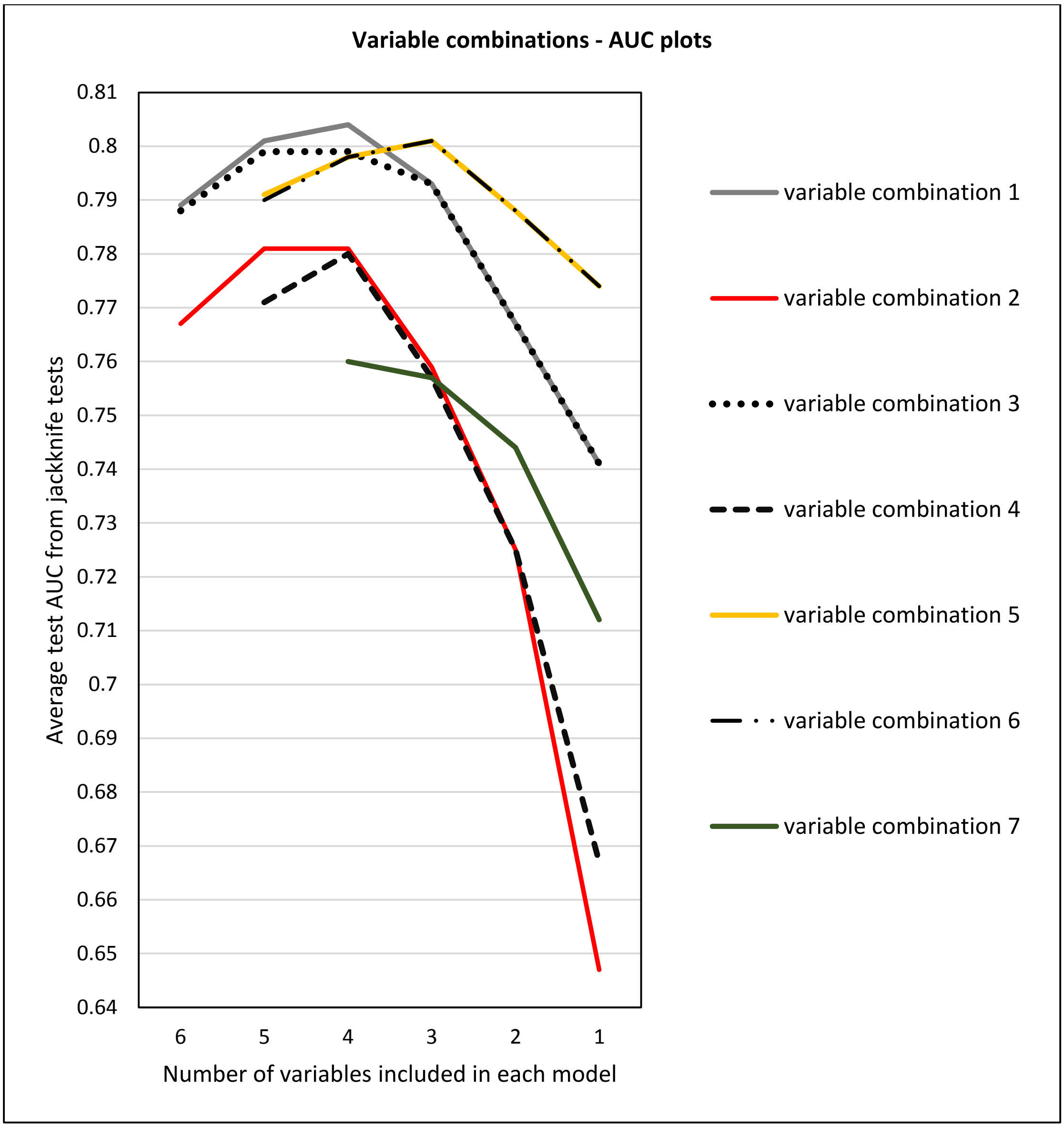


Figure 10: Test AUC values for variable combinations 1-7 (predictors removed piecewise).

Based upon the three most successful subset variable combinations, additional Maxent model runs without cross validation (i.e. single replicate runs) were also undertaken to assess the AUC value when trained on the full 32 focal species occurrence records, and are presented in Table 15.

Table 15: AUC values based upon single model runs. (With respect to the three highest ranking variable sub-combinations only).

Original full variable combination	AUC - single replicate run	Test AUC – cross validation test	Subset of variables of the full combination which produced the highest AUC value	Percent contribution	Permutation importance
Combination 1	8.22	0.804	bio1amt	43.6%	40.2%
			pt_hab_1km	25.2%	30.7%
			udrgwth	20.3%	13.6%
			bio12ap	10.9%	15.5%
Combination 3	8.19	7.99	bio1amt	44.3	39.9
			pt_hab_1km	26.4	33.5
			udrgwth	21.5	15.7
			bio17pdq	7.8	10.9
Combination 5 & 6	8.16	8.01	bio5mtwp	59.9	62
			pt_hab_1km	21	18.4
			udrgwth	19.1	19.6

As per the results of the cross validation test, the AUC associated with the subset of variables from the original full combination 1, again produced the highest AUC values when a single replicate run was undertaken using all 32 records.

With respect to all three of the subset combinations of variables which produced the highest AUC values, both "low undergrowth cover" (udgwth) and "potential vegetated habitat within 1km" (pt_hab_1km) were present. Similarly, the most important contributing factor to all three models was either the "mean annual temperature" or the "maximum temperature of the warmest period" (bio5mtwp). As indicated in Table 14, both of these variables were found to produce reasonable AUC variables when modelled in isolation (0.774 and 0.741 respectively).

The three highest ranked predictors which contributed the most to both the precent contribution and permutation importance measures (refer to section 5.4) were the same for both subsets of the original "full" variable combinations for 1 and 3. With respect to both of these subsets, the lowest ranked variable was either "mean annual precipitation" (bio12ap) or "precipitation of the driest quarter" (bio17pdq), both of which were found to be strongly correlated. The categorical variables "potential vegetated habitat within 1 km" and "low undergrowth cover" were consistently ranked as the second and third most important predictors used in training the models for all three variable subsets.

For the purpose of comparison, Figure 11 on the following page provides a graphic representation of Maxent's output logistic format, used as a proxy for habitat suitability for the three highest ranking subsets (the three outputs grids are included in Appendix E). The subsets of predictors derived originally from the “full” variable combinations 1 and 3 are very similar in terms of the relative rankings of habitat suitability across the study location, as expected given that the three most important variables based upon Maxent’s heuristic percent contributions measure were the same for both. Similarly, whilst the final variable for each differed, both related to the correlated precipitation variables “mean annual precipitation” and “precipitation in the driest quarter respectively”.

The subset from combination 5 however (inclusive of the variables, “maximum temperature of the warmest period”, “low undergrowth cover” and “potential vegetated habitat within 1 km of each location”), whilst identifying similar areas of suitability, also displays reasonable variations in modelled suitability, especially apparent at the coast margin with broader areas assigned higher levels of suitability.

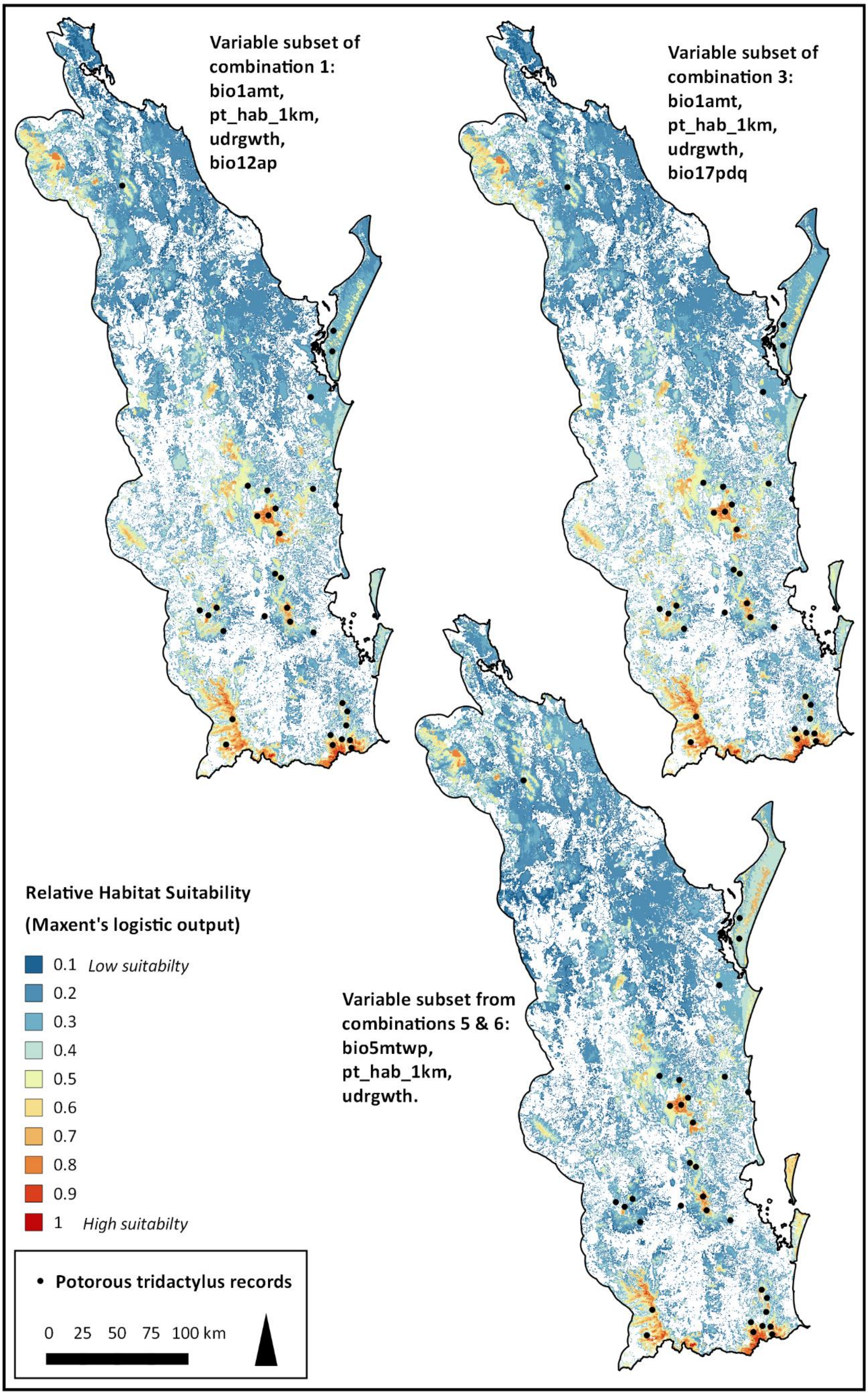


Figure 11: Habitat suitability maps, for the three highest ranked variable combinations.

Notwithstanding, as the subset of original variables from the full predictor combination 1 was found to produce the highest AUC values, for the purpose of the current study this was considered as the "successful predictor subset" and incorporated the variables, "mean annual temperature", "potential habitat within 1 km of each location", "low undergrowth cover" and "mean annual precipitation".

6.3 Model Evaluation

As discussed in section 5.4, to assess whether the AUC value associated with the single replicate model run for the "successful predictor subset" was significant, 1,000 null models were developed to mimic random occurrence records subject to the same broad geographic bias and proximity limitations as the focal species occurrence records to derive a 95% confidence interval.

Figure 12 below represents the frequency histogram constructed from the 1,000 null modelled AUC output values (in increments of 0.1). The minimum and maximum AUC values observed from all compiled null model runs was 0.52 and 0.73 respectively (mean of 0.62, standard deviation of 0.04). Given the maximum and minimum ranges of values produced by all null models, the final AUC value of 8.22 (refer to Table 15) produced via the single replicate Maxent run using all 32 of the focal species records and based upon "successful predictor subset", was considered to be statistically significant (i.e. $p < 0.001$).

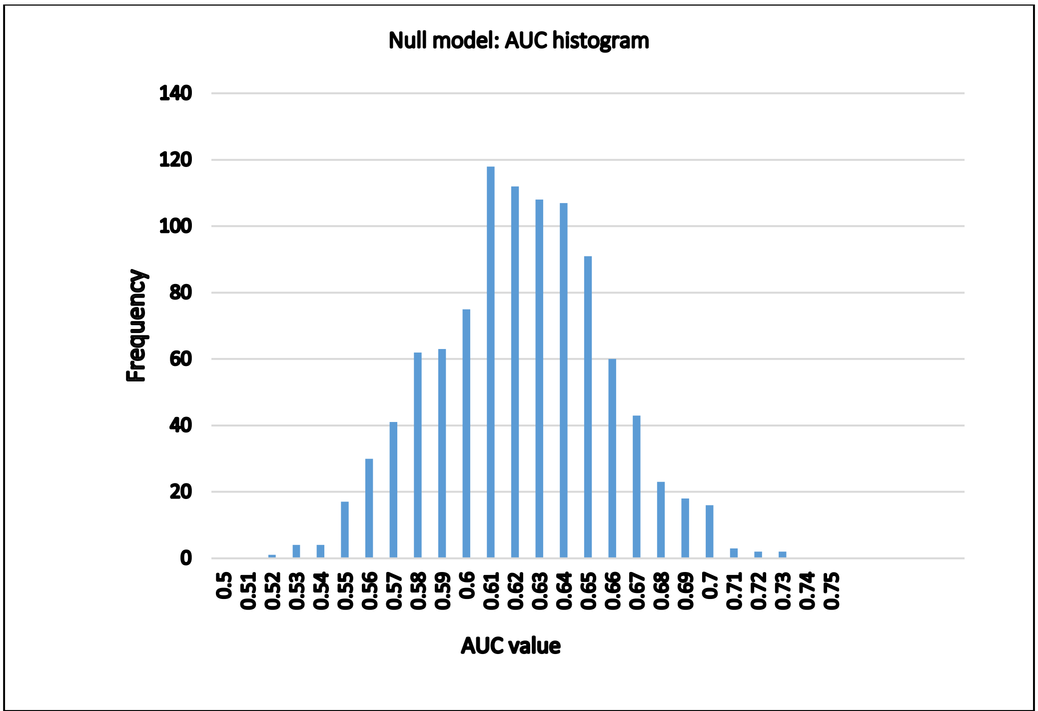


Figure 12: Null model AUC histogram.

6.4 *Potorous tridactylus* - Modelled Distribution

Figure 13 below reflects the marginal species response curves to each of the environmental predictors in the "successful" subset. Increasing habitat suitability is indicated by increasing values

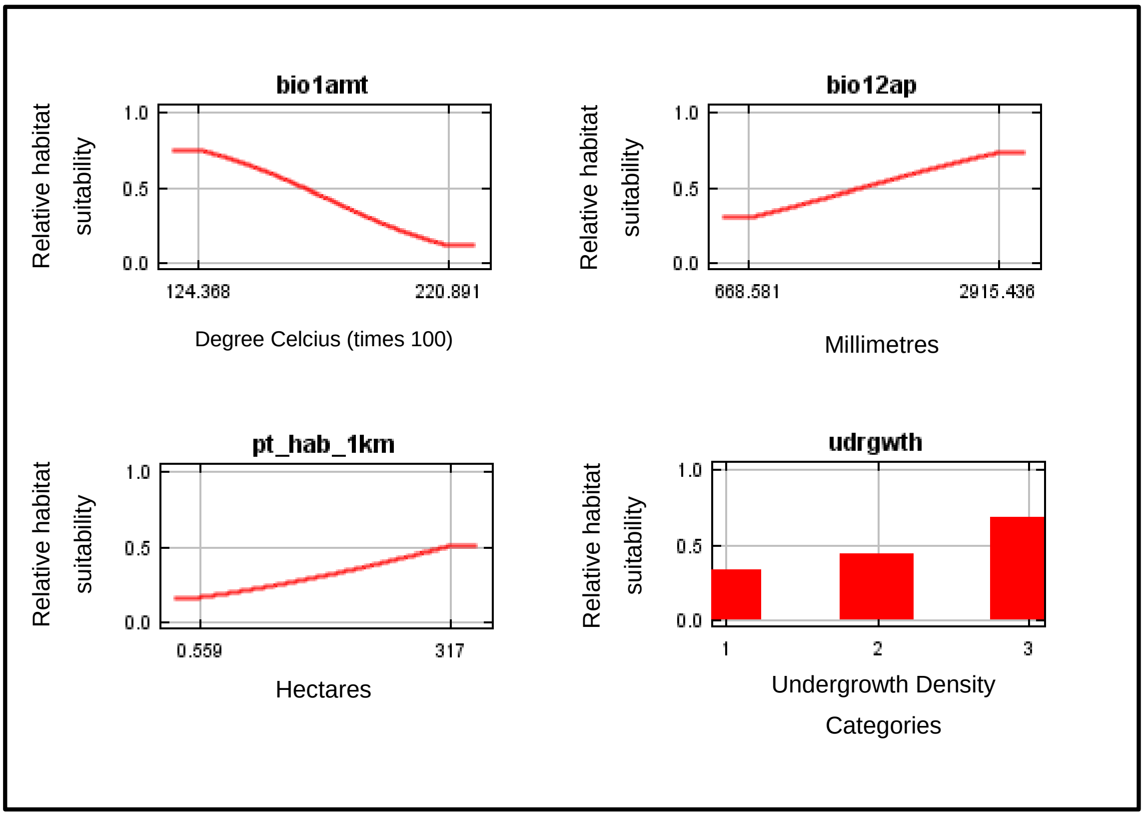


Figure 13: Response curves with respect to the "successful predictor subset".

Finally, Figure 14 reflects the output modelled representation of habitat suitability derived from the single replicated run for the "successful predictor subset".

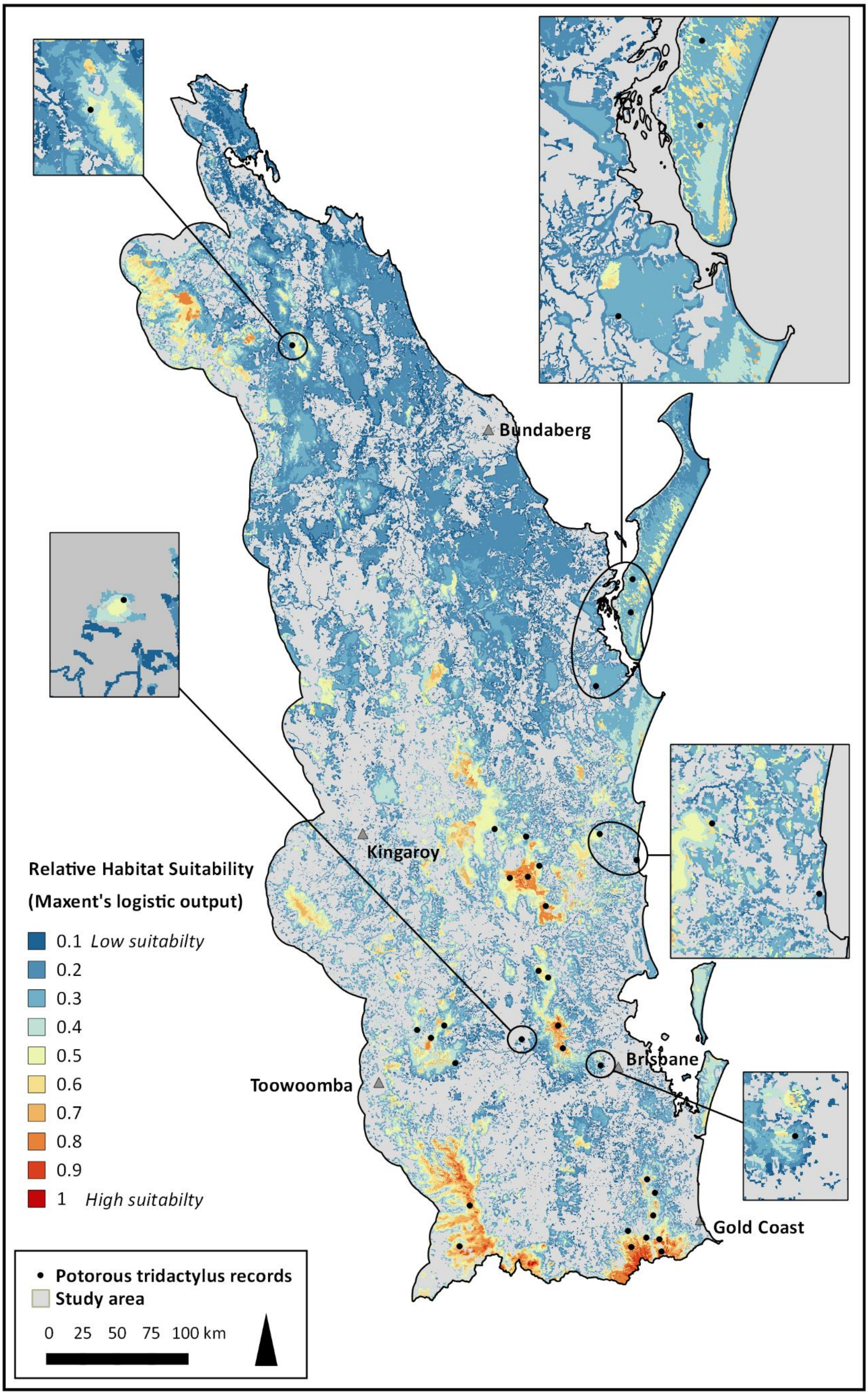


Figure 14: Representation of the final habitat suitability map.

Chapter 7: Discussion

The final output probability map with respect to the current study should not be interpreted as an index of the probability of occurrence, or a reflection of population density. Rather, the intent of the current study was to provide a relative assessment of potential habitat suitability given the observed ranges of environmental variables under which the species is known to occur and with respect to its broader geographic distribution within QLD, subject to recent constraints.

Within the defined study area, and based upon the environmental predictors included in the current modelling exercise, the variables “mean annual temperature”, “potential vegetated extent within 1 km of each cell location”, “low undergrowth cover” and “mean annual precipitation” (in order of importance), when modelled in conjunction and exclusive of highly correlated variables, were found to produce the highest AUC values (both with respect to cross validation tests, and the final single replicate run using all 32 records).

All four of these variables are suggested in the literature as being of potential import with respect to the species greater distribution. The study by Bateman, Abell-Davis and Johnson (2011) in the Queensland Wet Tropics, suggested that the abundance and diversity of hypogeal fungi is negatively impacted by increasing temperatures and more extreme reductions in seasonal precipitation (i.e. areas subject to longer periods of drought). The three variables they concluded which had the most substantial effect on truffle habitat, were the “maximum temperature of the warmest period”, “precipitation in the driest quarter” and “mean annual temperature” (in order of importance).

With respect to the current study, “mean annual temperature” was found to be the most important variable for two of the three highest competing modelled predictor subset combinations (including the “successful” predictor combination) and the “maximum temperature of the warmest period”, for the remaining subset. Similarly, with respect to the first two subset combinations (i.e. which excluded the “maximum temperature of the warmest period”) “mean annual precipitation” was incorporated in one, and “precipitation of the driest quarter” the other. However, as indicated in section 6.2, both precipitation predictors were found to be strongly correlated (i.e. correlation coefficient of 0.94) and as a result, the output representations of habitat suitability (refer to Figure 11) are largely similar.

As discussed in section 3.2.1, a commonality in the literature with respect to the *Potorous tridactylus*’s preferred habitat, is the presence to some extent of a dense groundcover to avoid predation and which provides shelter during the day (Bennet 1993; Claridge, Cunningham & Tanton 1993; Tory et al 1997; Claridge & Barry 2000; Norton, French & Claridge 2010). In general, a consistent response was observed with a greater preference associated with broad vegetation groups which inherently encompass denser low undergrowth strata. As shown in the previous Chapter, this variable was retained in all three of the highest ranked subset combinations. The continued ongoing development of existing, as well as the release of new regional ecosystem technical descriptions produced by the Queensland Herbarium, will likely provide an invaluable information source by which to discriminate potential habitat at a finer scale.

The variable reflective of the total "potential vegetated extent within one km of each cell location", was also present in all three of the most successful models in discriminating presence against random background locations. However, it must be noted, the use of a moving cell window approach to assess the total extent of potential vegetated habitat within a specified neighbourhood of each location, is substantially overly simplistic and was adopted more as a element to discriminate against areas with a very low chance of accommodating the species. In truth, it may have been more appropriate to initially exclude areas which fell below an ecologically justified threshold prior to modelling.

7.1 Limitations

Adoption of the model with the highest test AUC based primarily on jackknife tests is also overly simplistic. Maxent provides a number of other statistical and graphical outputs, such as additional jackknife tests which relate to training and test gain and which can assist users in interpreting, along with ecological justification, which variables are the more important. Unfortunately due to time constraints, full use of these measures hasn't been incorporated and substantial further work needs to be completed.

It must be noted, that there were a number of competing models, all of which provided AUC values of greater than 0.75 (i.e. suggestive of being potentially useful) and all of which could be equally valid. For example, out of the three top competing models, the subset from the "full" combination of variables 5 (and 6) had an AUC value only slightly less than the "successful predictor subset" whilst incorporating one less variable, reflective of a more parsimonious, simpler model.

Similarly, as suggested by Bateman, Abell-Davis and Johnson's (2011) study, if the variable "maximum temperature of the warmest period" is the most important variable than affects the distribution of suitable resources such as hypogeal fungi within South East Queensland, and hence, potentially the focal species geographic distribution, then this model may well be the more appropriate of the highest three ranked subsets. When modelled in isolation, this variable also produced the highest test AUC value of all environmental predictors.

The step-wise exclusion of variables in the manner undertaken to reduce model complexity, is also inherently flawed. For example, re-inclusion of variables initially removed from the full model combinations following subsequent removal of potentially related correlated variables (i.e. which may have initially resulted in the original variable's removal), could have in some instances produced higher test AUC values.

Notwithstanding, the variables which were most commonly removed during the initial two runs were "woody vegetation canopy cover" and "soil hardness". A plausible explanation for this, and which is supported by the results of the correlation analysis, is that both of these variables were found to have strong to moderate relationships with increasing precipitation and decreasing maximum temperatures, commonly associated with higher elevations, as well as at the coastal interface.

As suggested by Figures 3 to 6, "woody vegetation canopy cover" is observed to be denser at higher elevations (e.g. associated with rainforests and wet eucalypt communities), and similarly "softer" soils (i.e. clays and loams with low bulk densities and sandy soils – refer to section 4.3.2) were also common at both higher elevations and the coastal interface (presumably as a reflection of the high soil organic content within moist sclerophyll and rainforest communities and the presence of sandy soils at the coastal margin).

Given that maximum temperatures and precipitation were highly correlated and were retained in different combinations by all three of the highest ranked subset variable combinations, it's considered unlikely that the variables "woody vegetation canopy cover" and "soil hardness" would have been re-included post their initial removal.

Whilst for the purpose of this study, an attempt was made to exclude strongly correlated variables, their inclusion in some instances is also probably justified. For example, inclusion of the categorical variable "soil hardness" with the variables, "maximum temperature of the warmest period" (to which a strong correlation was observed), "low undergrowth cover" and "potential vegetated habitat within 1 km", yielded an AUC value of 0.83 based upon a single replicate run trained on all 32 occurrence records[6].

The marginal species response curves contained in the associated Maxent output file suggest that whilst habitat suitability was substantially reduced with respect to "softer" soils in contrast to what would be expected given the species preference for lighter friable soil types, for other areas identified as being of "medium" to "hard" soil category types, Maxent's assigned predictor feature appeared to discriminate as would be expected with reduced suitability assigned to locations with increasing bulk density (i.e. "harder" soil types). Again, the reason for the reduced response with respect to lighter soil types, is perceived to be due to the fact that it was already accounted for by the strongly correlated variable, the "maximum temperature of the warmest period". Notwithstanding, the inclusion of this correlated variable resulted in an overall increase in the AUC value.

Finally, as discussed by Phillips, Anderson an Schapire (2008), a number of limitations must be realised when undertaking species distribution modelling based upon presence only records, including survey effort and temporal bias, spatial autocorrelation of records, location and identification error, the accuracy and resolution of the predictor data, as well as the requirement that records encompass the range of environmental variables suitable for habitation. Whilst attempts have been made to address such elements within the current study, if the presence records used do not adequately encompass the range of environmental variation suitable for occurrence, or still exhibit levels of spatial bias (for example associated with proximity to roads and within National Parks) then the model may not reflect a true representation of its geographic extent.

[6] This information was not presented in the proceeding Chapter - the summary model results are included in Appendix F in the file, "potorous_tridactylus.html" in the folder titled "Auxiliary_Tests"

References

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Appendix A: ENG8002 Project Specification

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For: Stephen Trent (*Student #: W0050018740*)

Topic: A Species Distribution Model for *Potorous tridactylus tridactylus*

Supervisor: Armando Apan

Examiner: Karu Karunasena

Sponsorship: Faculty of Health, Engineering & Sciences

Project Aim: To assess habitat factors based upon recorded sightings and development of a species distribution model for the Long-nosed Potoroo (*Potorous tridactylus tridactylus*) in South East Queensland.

Date: 24/03/2014

Program:

1. Review of current literature to identify the species potential preferred habitat requirements;
2. Review of geospatial and statistical methods used to assess habitat factors and associated weightings relevant to habitat preference;
3. Compilation of species sighting records (*and absence data if available*) from government databases;
4. Compilation/development of environmental and topographic datasets with respect to potential habitat requirements;
5. Analysis of compiled environmental and topographic datasets with respect to presence data (*and absence data if available*) to determine core habitat weightings with respect to species presence;
6. Application of the findings to develop a species distribution model;
7. Assessment of "fit" of the model against known records.

As time and resources permitting:

1. Review and modify the species distribution methodology and developed product to assess its potential suitability for inclusion into the Department of Environment and Heritage's Core and Non-core threatened species habitat mapping.

Agreed:

Student: Stephen Trent

Supervisor: Armando Apan

Examiner: Karu Karunasena

Appendix B: Broad Vegetation Groups, Ground and Shrub Layer Cover Categories

Appendix B: Broad Vegetation Groups, Ground and Shrub Layer Cover Categories

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
2a	Complex evergreen notophyll vine forests frequently with *Araucaria cunninghamii* from foothills to ranges.	Sparse	Sparse	Encompasses five remnant regional ecosystems within the study area. GC: BVG description describes groundcover as generally 'sparse'. LSBC: BVG description describes a 'mid-dense shrub or low tree layer'. Two of the three available technical descriptions for regional ecosystems of this BVG group within the study area suggest the lower shrub layer is generally ‘sparse’ (the other does not identify a low shrub layer - i.e. 'very sparse'). The average foliage projection cover for the upper shrub canopy for available technical descriptions is 'sparse' (i.e. potentially combine to form a mid-dense shrub layer). The lower shrub layer is assumed 'sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
3a	Evergreen to semi-deciduous, notophyll to microphyll vine forests/ thickets on beach ridges and coastal dunes, occasionally *Araucaria cunninghamii* (hoop pine) microphyll vine forests on dunes. *Pisonia grandis* on coral cays.	Sparse (exception 12.2.3 - 'very sparse')	Very sparse	Encompasses three regional ecosystems within the study area, 12.2.3, 12.2.2 and 11.2.3. GC: Within South East Queensland and Brigalow Belt bioregions, BVG description suggests the ground cover is generally 'sparse'. On Fraser Island (12.2.3), the ground layer is described as patchy. Assumed 'very sparse' for this regional ecosystem. LSBC: Within South East Queensland and Brigalow Belt bioregions, BVG description suggests a 'sparse' shrub layer for these communities on parabolic dunes on Fraser and Cooloola (12.2.3) and 'mid-dense' elsewhere. Only one available technical description (12.2.2) which did not identify a low shrub layer, only a 'very sparse' bordering on 'sparse' higher shrub layer (based upon four reference sites). An available biocondtion benchmark for 11.2.3 suggests that a 'sparse' shrub layer is present (36% canopy cover) for this regional ecosystem. Four other technical descriptions within SEQ, however, which are restricted to coral cays/islands outside of the study area, suggest a 'very sparse' lower shrub cover, and a 'very sparse' to 'mid-dense' higher shrub cover. Assumed 'very sparse' lower shrub cover for all regional ecosystems.
4a	Notophyll and mesophyll vine forests with feather or fan palms in alluvia and in swampy situations on ranges or within coastal sand masses.	Very sparse (Fraser Island & Cooloola - 12.2.1); Sparse to Mid-dense (Conondale Range, Mt Glorious, Kroombit & Bulburin - 12.12.1 & 12.11.1)	Very sparse	Three remnant regional ecosystems are present within the study area. GC: BVG description describes a 'very sparse' groundcover for vegetation communities on Fraser Island & Cooloola (i.e. 12.2.1) and a 'sparse' to 'mid-dense' groundcover elsewhere in SEQ (Conondale Range, Mt Glorious, Kroombit & Bulburin, i.e. 12.12.1 & 12.11.1). Only one available technical description (12.12.1) which indicates a sparse ground cover (based on two sites only). Assumed potentially 'mid-dense' for the latter two. LSBC: BVG describes an 'open shrub layer' for SEQ - ‘very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
4b	Evergreen to semi-deciduous mesophyll to notophyll vine forests, frequently with *Archontophoenix* spp., fringing streams.	Sparse	Very sparse	Only a single remnant regional ecosystem type within the study area (12.3.1) reflective of this BVG. GC: No BVG description. Technical description (derived from five sites) suggests groundcover is 'sparse'. LSBC: No BVG description. Technical description identifies a 'very sparse' higher SC (average FPC 19.1%, ten sites), however, no low shrub cover. Biocondition benchmark indicates native shrub cover is 20%. Assumed 'very sparse' LSBC.
5a	Araucarian notophyll/microphyll and microphyll vine forests of southern coastal bioregions.	Very sparse	Very sparse	Encompasses seven regional ecosystems within the study area. GC: BVG description describes groundcover as 'very sparse'. LSBC: BVG description describes a 'mid-dense shrub or low tree layer'. Of the five available technical descriptions for regional ecosystems within the study area, four do not recognise a lower shrub canopy, one based upon a single site assessment, suggests 'mid-dense'. Upper shrub covers range from 'sparse' to 'mid-dense'. Assumed generally 'very sparse' low shrub cover.
6a	Notophyll vine forests and microphyll fern forests to thickets on high peaks and plateaus of southern Queensland.	Mid-dense	Sparse	Four remnant regional ecosystems within the study area. No available technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG description indicates only that a 'shrub /low tree layer' is present. Photographic plates in publication suggest 'sparse/very sparse' shrub layer. No technical descriptions/biocondtion benchmarks available for any of the four regional ecosystems within the study area. Shrub layers assumed 'sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
7a	Semi-evergreen vine thickets on wide range of substrates.	Sparse	Sparse	Encompasses nineteen regional ecosystems within the study area. Only four available technical descriptions. GC: BVG description describes groundcover as 'sparse'. LSBC: BVG describes a 'mid-dense shrub or low tree layer'. The four available technical descriptions suggest that both upper and lower shrub layers may be present, however are generally both 'sparse' (combined would form a 'mid-dense' shrub cover). Assumed 'sparse' low shrub layer.
8a	Wet tall open forests dominated by species such as *Eucalyptus grandis* (flooded gum) or *E. saligna*, *E. resinifera* (red mahogany), *Lophostemon confertus* (brush box), *Syncarpia glomulifera* (turpentine), *E. laevopinea* (silvertop stringybark).	Dense/closed	Very sparse	Encompasses twenty-one regional ecosystems within the study area. GC: BVG description describes groundcover as 'dense'. LSBC: BVG describes shrub layer as 'sparse'. Available technical descriptions only identify a low shrub layer in three of the eleven technical descriptions, and where present as 'very sparse'. Assumed 'very sparse'.
8b	Moist open forests to tall open forests mostly dominated by *Eucalyptus pilularis* (blackbutt) on coastal sands, sub-coastal sandstones and basalt ranges. Also includes tall open forests dominated by *E. montivaga*, *E. obliqua* (messmate stringybark), *E. campanulata* (New England ash) and *Syncarpia hillii* (turpentine).	Mid-dense	Very sparse	Encompasses fifteen regional ecosystems within the study area. Fourteen available draft technical descriptions. GC: No BVG description with respect to groundcover. Available technical descriptions suggest GC ranges from 'sparse' - 'dense/closed', with majority as 'mid-dense'. Assumed 'mid-dense'. LSBC: BVG description only refers to 'shrub / low tree' layer as present. Of the 14 available technical descriptions, 10 do not identify a distinct lower shrub layer, 2 identify a 'very sparse' low shrub layer and the remaining two suggest a 'sparse' lower shrub layer. Assumed 'very sparse' low shrub layer.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
9a	Moist eucalypt open forests to woodlands dominated by a variety of species including *Eucalyptus siderophloia* (red ironbark), *E. propinqua* (small-fruited grey gum), *E. acmenoides* (narrow-leaved white stringybark), *E. microcorys* (tallowwood*), E. carnea* (broad-leaved white mahogany), *E. tindaliae* (Queensland white stringybark*), Corymbia intermedia* (pink bloodwood), *Lophostemon confertus* (brush box).	Mid-dense	Very sparse	Encompasses nine regional ecosystems within the study area. Seven available draft technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG description describes shrub layer as 'sparse'. Six of the seven available technical descriptions do not identify a low shrub layer, the other identifies a 'sparse' (21% FPC) low shrub cover. Six indicate a higher shrub layer which is generally 'very sparse', and one as 'sparse'. Assumed 'very sparse' low shrub layer.
9b	Moist to dry woodlands dominated by *Eucalyptus platyphylla* (poplar gum) and/or *E. leptophleba* (Molloy red box). Other frequent tree species include *Corymbia clarksoniana* (grey bloodwood), *E. drepanophylla* (grey ironbark) and occasionally *E. chlorophylla*.	Mid-dense	Very sparse	One regional ecosystem within the study area (11.5.8a). No technical description available. GC: BVG description describes groundcover as 'mid-dense'. Biocondition benchmark for the related regional ecosystem 11.5.8 suggests a native perineal grass cover of 44%. Assumed 'mid-dense'. LSBC: BVG suggests shrub layer is 'very sparse'. Biocondition benchmark for the related regional ecosystem 11.5.8 suggests native shrub cover is only 6%. Assumed 'very sparse'.
9c	Open forests of *Corymbia clarksoniana* (grey bloodwood) (or *C. intermedia* (pink bloodwood) or *C. novoguinensis*), *C. tessellaris* (carbeen) ± *Eucalyptus tereticornis* (blue gum) predominantly on coastal ranges. Other frequent tree species include *Eucalyptus drepanophylla* (grey ironbark), *E. pellita* (large-fruited red mahogany), *E. brassiana* (Cape York red gum) and *Lophostemon suaveolens* (swamp box)	Mid-dense	Very sparse	One regional ecosystem within the study area (12.11.20). GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG suggests a 'sparse' shrub layer may be present. Available technical description (based on two sites) suggests, a 'very sparse' lower shrub layer. No biocondition benchmark available. Assumed 'very sparse' low shrub layer.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
9f	Woodlands dominated by *Corymbia* spp. e.g. C. intermedia (pink bloodwood), *C. tessellaris* (Moreton Bay ash) and/or Eucalyptus spp. such as *E. tereticornis* (blue gum), frequently with *Banksia* spp., *Acacia* spp. and *Callitris columellaris* (Bribie Island pine) on coastal dunes and beach ridges.	Mid-dense	Very sparse	Encompasses two regional ecosystems within the study area. Two available draft technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG description describes shrub layer as 'Sparse'. Both available technical descriptions indicate lower shrub layers of 'very sparse' and higher covers which of 'very sparse' to sparse.. Lower shrub cover assumed 'very sparse'.
9g	Moist to dry woodlands to open forests dominated by stringybarks or mahoganies such as *Eucalyptus tindaliae* (Queensland white stringybark), *E. latisinensis* (white mahogany), *E. acmenoides* (narrow-leaved white stringybark); or *E. racemosa* (scribbly gum) or *E. seeana* or *E. tereticornis* (blue gum) and *Corymbia intermedia* (pink bloodwood).	Mid-dense	Very sparse	Encompasses twenty-two regional ecosystems for which twenty draft technical descriptions are available. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG description describes shrub layer as 'very sparse'. Eighteen of the available technical descriptions do not identify a low shrub layer, or identify a 'very sparse' lower shrub layer', two identify a 'sparse' lower shrub layer. Low shrub layer assumed 'very sparse'.
9h	Dry woodlands dominated by species such as *Eucalyptus acmenoides* (narrow-leaved white stringybark) (or *E. portuensis* or E. helidonica), *E. tereticornis* (blue gum), *Angophora leiocarpa* (rusty gum), *Corymbia trachyphloia* (yellow bloodwood) or *C. intermedia* (pink bloodwood), and often ironbarks including *E. crebra* (narrow-leaved red ironbark) or *E. fibrosa* (dusky-leaved ironbark). A heathy shrub layer is frequently present. On undulating to hilly terrain.	Mid-dense	Very sparse	Encompasses twenty-four regional ecosystems within the study area, twenty-one available draft technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG describes shrub layer as 'generally very sparse'. Seventeen of the available technical descriptions do not identify a low shrub layer, or identify a 'very sparse' lower shrub layer', two identify a 'sparse' lower shrub layer. Low shrub layer assumed 'very sparse'.
10a	Dry woodlands to open woodlands dominated by *Corymbia citriodora* (spotted gum).	Sparse	Very sparse	Encompasses seven regional ecosystems within the study area. Three available technical descriptions. GC: BVG description describes groundcover as ‘sparse’. LSBC: BVG description describes shrub layer as 'very sparse'. Available technical descriptions indicate a 'very sparse' low shrub cover.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
10b	Moist open forests to woodlands dominated by *Corymbia citriodora* (spotted gum).	Sparse	Very sparse	Encompasses thirteen regional ecosystems within the study area. Ten available technical descriptions. GC: BVG description describes groundcover as 'sparse'. LSBC: BVG description describes shrub layer as 'very sparse'. Available technical descriptions indicate a 'very sparse' low shrub cover.
11a	Moist to dry open forests to woodlands dominated by *Eucalyptus orgadophila* (mountain coolibah). Some areas dominated by *E. tereticornis* (blue gum), *E. melliodora* (yellow box), *E. albens* (white box), *E. crebra* (narrow-leaved red ironbark) or *E. melanophloia* (silver-leaved ironbark).	Mid-dense	Very Sparse	Encompasses eight regional ecosystems within the study area. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG description describes shrub layer as generally 'sparse'. Of the seven regional ecosystems present as remnant vegetation within the study area, three had available technical descriptions. Only one identified a low shrub cover ('mid-dense'), however, this was based upon a single site out of at least six field reference sites used for the purpose of characterising the regional ecosystem (12.8.16). All three described higher shrub covers ranging from 'sparse' to 'very sparse' (based upon five - twelve sites). Low shrub cover assumed 'very sparse'.
12a	Dry woodlands to open woodlands dominated by ironbarks such as *Eucalyptus decorticans* (gum-topped ironbark), *E. fibrosa* subsp. *nubila* (blue-leaved ironbark), or *E. crebra* (narrow-leaved red ironbark) and/or bloodwoods such as *Corymbia trachyphloia* (yellow bloodwood), *C. leichhardtii* (rustyjacket), *C. watsoniana* (Watson's yellow bloodwood), *C. lamprophylla*, *C. peltata* (yellowjacket). Occasionally *E. thozetiana* (mountain yapunyah), *E. cloeziana* (Gympie messmate) or *E. mediocris* are dominant. Mostly on sub-coastal/inland hills with shallow soils.	Very sparse	Very sparse	Encompasses nineteen regional ecosystems within the study area. Nine available technical descriptions. GC: BVG description describes groundcover as 'very sparse'. LSBC: BVG description describes shrub layer as 'very sparse'. Available technical descriptions indicate a 'very sparse' lower shrub cover.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
13c	Woodlands of *Eucalyptus crebra* (narrow-leaved red ironbark), *E. drepanophylla* (grey ironbark*), E. fibrosa* (dusky-leaved ironbark), *E. shirleyi* (Shirley's silver-leaved ironbark) on granitic and metamorphic ranges.	Dense/closed	Very sparse	Encompasses twelve regional ecosystems within the study area. Eight available technical descriptions. GC: BVG description describes groundcover as 'dense'. LSBC: BVG description describes shrub layer as 'sparse'. Only three of the eight available technical descriptions identified a low shrub layer, two as 'very sparse', and one as 'sparse'). However, all eight available technical descriptions indicate a 'very sparse' upper shrub canopy is present. Low shrub cover assumed 'very sparse'.
13d	Woodlands dominated by *Eucalyptus moluccana* (gum-topped box) (or *E. microcarpa* (inland grey box)) on a range of substrates.	Mid-dense	Very sparse	Encompasses fifteen regional ecosystems within the study area. Seven available technical descriptions. **GC**: BVG description describes groundcover as 'mid-dense'. **SC**: BVG describes 'infrequent shrubs and low trees'. No draft technical descriptions identified a low shrub layer.
15b	Woodlands dominated by *Eucalyptus conica* (fuzzy box) or *E. nova-anglica* (New England peppermint) or *E. blakelyi* (Blakely's red gum) on alluvial plains.	Sparse	Very sparse	Only a single regional ecosystem within the study area reflective of this BVG, 11.3.23. No technical description available. GC: No BVG groundcover description. The Regional Ecosystem Description Database describes 11.3.23 as 'grassy woodland'. Available biocondition benchmark suggests % native grass cover (foliage projection cover) = 20%. Assumed 'sparse'. LSBC: BVG description suggests 'very scattered shrubs'. Available biocondition benchmark suggests 3% native shrub cover. Low shrub cover assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
16a	Open forests and woodlands dominated by *Eucalyptus camaldulensis* (river red gum) (or *E. tereticornis* (blue gum)) and/or *E. coolabah* (coolibah) (or *E. microtheca* (coolabah)) fringing drainage lines. Associated species may include *Melaleuca* spp., *Corymbia tessellaris* (carbeen), *Angophora* spp., *Casuarina cunninghamiana* (river she-oak). Does not include alluvial areas dominated by herblands or grasslands or alluvial plains that are not flooded.	Mid-dense	Very sparse	Encompasses two regional ecosystems within the study area. Two available technical descriptions. GC: No BVG density description. Both available technical descriptions indicate 'mid-dense'. Assumed 'mid-dense'. LSBC: BVG describes shrub layer as frequently absent. Available technical descriptions do not identify a low shrub layer, only a 'very sparse' upper shrub layer. Low shrub cover assumed 'very sparse'.
16c	Woodlands and open woodlands dominated by *Eucalyptus coolabah* (coolibah) or *E. microtheca* (coolibah) or *E. largiflorens* (black box) or *E. tereticornis* (blue gum) or *E. chlorophylla* on floodplains. Does not include alluvial areas dominated by herblands or grasslands or alluvial plains that are not flooded.	Mid-dense	Very sparse	Encompasses five regional ecosystems within the study area. GC: No BVG density description. Of the four available technical descriptions three are ‘mid-dense', and the last is 'dense' (however, the latter is based upon a single site assessment). Assumed 'mid-dense'. LSBC: BVG describes shrub layer as frequently absent. Available technical descriptions indicate 'very sparse’ shrub layers. Low shrub cover assumed 'very sparse'.
16d	River beds, open water or sand, or rock, frequently not vegetated.	Very sparse	Very sparse	Encompasses a single regional ecosystem within the study area. BVG structural formation description: "Bare to sparse herbland, occasional fringing shrubland". BVG floristics description "Sandy river beds sometimes with patches of ephemeral grassland, herbland or sedgeland and occasional shrubs". Table D, Appendix 1, of the 'Broad Vegetation Groups of Queensland' suggest the BVG is frequently devoid of terrestrial vegetation. GC and LSBC Assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
17a	Woodlands dominated by *Eucalyptus populnea* (poplar box) (or *E. brownii* (Reid River box)) on alluvium, sand plains and footslopes of hills and ranges.	Sparse	Very sparse	Encompasses six regional ecosystems within the study area. Three available technical descriptions. GC: BVG description references an 'open' ground layer (i.e. 'sparse'). Technical descriptions range from 'sparse' to 'dense'. Assumed 'sparse' consistent with BVG description. LSBC: BVG description states 'sparse to open shrub layer' (i.e. 'sparse' to 'very sparse'). Available technical descriptions indicate that a 'very sparse' higher canopy may be present, however do not identify a lower shrub canopy in any instances. Low shrub cover assumed 'very sparse'.
17b	Woodlands to open woodlands dominated by *Eucalyptus melanophloia* (silver-leaved ironbark) (or *E. shirleyi* (Shirley's silver-leaved ironbark)) on sand plains and footslopes of hills and ranges.	Mid-dense	Very sparse	Encompasses seven regional ecosystems within the study area. Three available technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG describes shrub layer as 'very sparse'. Available technical descriptions indicate 'very sparse' lower and higher shrub covers.
18b	Woodlands dominated *Eucalyptus crebra* (narrow-leaved red ironbark) frequently with *Corymbia* spp. or *Callitris* spp. on flat to undulating plains.	Mid-dense	Very sparse	Encompasses five regional ecosystems within the study area, for which there are two available technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG describes shrub layer as 'very sparse'. Of the two available technical descriptions, one does not identify a low shrub layer, and the other identifies a 'sparse' low shrub layer, however, only for a single reference site out of at least 9 sites used for the purpose of the technical description. Low shrub cover assumed 'very sparse'.
20a	Woodlands to open forests dominated by *Callitris glaucophylla* (white cypress pine) or *C. intratropica* (northern cypress pine).	Sparse	Very sparse	Includes the remnant regional ecosystems 11.12.6b & 11.10.9 within the study area. No available technical descriptions/biocondition benchmarks. GC: BVG description describes groundcover as 'sparse'. LSBC: BVG suggests sparsely scattered shrubs may occur. Photographic plates, suggest 'very sparse' lower shrub layer. Low shrub cover assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
21a	Low woodlands and low open woodlands dominated by *Melaleuca viridiflora* (coarse-leaved paperbark) on depositional plains.	Mid-dense	Very sparse	Two regional ecosystems within the study area. Both have available technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG states 'low tree/shrub layer is generally very sparse'. One of the available technical indicates a 'sparse' lower shrub layer (derived from only two sites of at least 19 sites used to characterise the regional ecosystem), and the other does not identify a lower shrub layer. Low shrub cover assumed 'very sparse'.
21b	Low open woodlands and tall shrublands of *Melaleuca citrolens* or *M. stenostachya* or other *Melaleuca* spp.	Sparse	Very sparse	Encompasses four regional ecosystems within the study area. Three available technical descriptions. GC: BVG description describes groundcover as 'sparse'. LSBC: BVG description describes shrub layer as 'very sparse'. Only one of the three available technical descriptions indicates a low shrub layer ('very sparse'), whilst the remainder do not identify a low shrub layer. Low shrub cover assumed 'very sparse'.
22a	Open forests and woodlands dominated by *Melaleuca quinquenervia* (swamp paperbark) in seasonally inundated lowland coastal areas and swamps.	Mid-dense	Very sparse	Encompasses eight regional ecosystems within the study area. Seven available technical descriptions. GC: BVG description describes groundcover as 'mid-dense'. Technical descriptions range from mid-dense to dense. Adopt mid-dense as per BVG. LSBC: BVG description suggests sparse shrubs are sometimes present. Available technical descriptions do not identify a lower shrub canopy in the majority of instances, and where present (two of the seven technical descriptions) are 'very sparse' / 'sparse'. Assumed 'very sparse' shrub layers.
22c	Open forests dominated by Melaleuca spp. (*M. argentea* (silver tea-tree), *M. leucadendra* (broad-leaved tea-tree), *M. dealbata* (swamp tea-tree) or *M. fluviatilis*), fringing major streams with *Melaleuca saligna* or *M. bracteata* (black tea-tree) in minor streams.	Mid-dense	Very sparse	Encompasses one regional ecosystem within the study area. GC: BVG description describes groundcover as 'mid-dense'. LSBC: BVG describes shrub/ low tree layer as 'very sparse'. Low shrub cover assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
24a	Low woodlands to tall shrublands dominated by *Acacia* spp. on residuals. Species include *A. shirleyi* (lancewood), *A. catenulata* (bendee), *A. microsperma* (bowyakka), *A. clivicola*, *A. sibirica* (bastard mulga), *A. rhodoxylon* (rosewood) and *A. leptostachya* (Townsville wattle).	Very sparse	Very sparse	Two remnant regional ecosystems, 11.7.2 & 11.5.2a. No available technical descriptions. GC: BVG description describes groundcover as 'very sparse'. LSBC: BVG suggests a sparse to open shrub layer is often present (i.e. 'sparse' to 'very sparse'). Appendix 1, Table C of the 'Broad Vegetation Groups of Queensland', suggests that these two inland regional ecosystems are dominated by trees or tall shrubs > 2m tall. Available biocondition benchmark for 11.7.2 indicates a 'very sparse' shrub layer. Shrub layers assumed 'very sparse' for 11.7.2. REDD describes a "sparse to mid-dense shrub/low tree layer" for 11.5.2. Based upon the REDD and given that for inland regional ecosystems low tree/shrub layers >2m may dominate (as indicated in Appendix 1, Table C), low shrub cover is assumed 'very sparse'.
25a	Open forests to woodlands dominated by *Acacia harpophylla* (brigalow) sometimes with *Casuarina cristata* (belah) on heavy clay soils. Includes areas co-dominated with *A. cambagei* (gidgee) and/or emergent eucalypts.	Sparse	Very sparse	Twelve remnant regional ecosystems, four of which have available technical descriptions. GC: BVG description describes groundcover as 'sparse'. LSBC: No BVG description with respect to shrub cover density. Available technical descriptions indicate that a lower shrub canopy is not present or 'very sparse'.
27c	Low open woodlands dominated by a variety of species including *Grevillea striata* (beefwood), *Acacia* spp., *Terminalia* spp. or *Cochlospermum* spp.	Sparse	Very sparse	Single remnant regional ecosystem, 11.2.15. No technical description available for this regional ecosystem. GC: Density not described for this BVG group. Related BVGs 27a and 27b suggest a sparse ground layer. Available bioconditon benchmark suggests native grass cover is approx. 18%. Assumed 'sparse'. LSBC: BVG description describes a 'very sparse' shrub layer. Assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
28a	Complex of open shrublands to closed shrublands, grasslands, low woodlands and open forests, on strand and foredunes. Includes pure stands of *Casuarina equisetifolia* (coastal she-oak).	Mid-dense	Very sparse	Encompasses two regional ecosystems (12.1.1 & 12.2.14) within the study area. GC: BVG description describes groundcover as 'sparse to mid-dense'. Technical descriptions for the two regional ecosystems within the study area indicate mid-dense. Assumed 'mid-dense'. LSBC: BVG describes shrub layer as 'generally very sparse'. Technical descriptions do not identify a low shrub cover. Assumed 'very sparse'.
28d	Sand blows to closed herblands of *Lepturus repens* (stalky grass) and herbs on sand cays and shingle cays.	Very sparse	Very sparse	Encompasses a single regional ecosystem within the study area, 12.2.16 (both pre-clear and remnant). REDD describes this community as "sand blows, largely devoid of vegetation". GC: BVG description describes groundcover as 'bare sand' or 'very sparse'. LSBC: BVG states very sparse emergent shrubs (0.5-1.5 m tall) and low trees (3-6 m tall) may occasionally occur. No available technical descriptions. Assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
28e	Low open forests to woodlands dominated by *Lophostemon suaveolens* (swamp box) (or *L. confertus* (brush box)) or *Syncarpia glomulifera* (turpentine) frequently with *Allocasuarina* spp. on rocky hill slopes.	Mid-dense for 12.9-10.17a and 12.3.15; Very sparse for 11.12.14	Very sparse	Only one available technical description for the three remnant regional ecosystems (11.12.14, 12.9-10.17a and 12.3.15) within the study area. GC: BVG description describes groundcover as 'very sparse to mid-dense' for this BVG group. Biocondition benchmark for 11.12.14 suggests native perennial grass cover is 'very sparse' (1%). Technical descriptions for other vegetation communities similar to regional ecosystem 12.9-10.17a (i.e. 12.9-10.17, 12.9-10.17c and 12.9-10.17d) range from 'mid-dense' to 'dense'. The average FPC for 12.3.15 listed in the technical description suggests 'mid-dense'. Assumed 'mid-dense' groundcover for 12.9-10.17a and 12.3.15. LSBC: BVG describes shrub layer when present as 'very sparse' to 'sparse'. BVG structural formation is stated as "Open forest to low open forest, to tall shrubland". Biocondition benchmark for 11.12.14 suggests the % native shrub cover is 'mid-dense' (54%). REDD describes 11.12.14 as "Lophostemon spp. shrubby woodland" - assumed 'very sparse' lower shrub cover and 'mid-dense' taller shrub cover for RE 11.12.14. Draft technical descriptions for other vegetation communities similar to regional ecosystem 12.9-10.17a (i.e. 12.9-10.17, 12.9-10.17c and 12.9-10.17d) do not identify a low shrub cover, however, do identify a 'very-sparse' to 'sparse' upper shrub canopy. The draft technical description for regional ecosystem 12.3.14, does not identify a lower shrub canopy, only a 'very sparse' higher shrub canopy. Assumed 'very sparse' low shrub cover for all regional ecosystems.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
29a	Open heaths and dwarf open heaths on coastal dunefields, sandplains and headlands.	Sparse	Sparse	Encompasses eleven regional ecosystems within the study area. GC: No BVG description of groundcover density for this community in the south (i.e. SEQ). Three of the seven available technical descriptions suggest the mean FPC is consistent with a 'sparse' groundcover (each of which is derived from more than 10 reference sites), two suggest mid-dense (each of which is derived from less than three sites) and one, 'very sparse' (based upon two reference sites). Assumed 'sparse'. LSBC: BVG describes shrub layer as 'sparse' in the south. Available technical descriptions for SEQ, however suggest combined lower shrub canopy's range from 'sparse' to 'mid-dense'. Assumed 'sparse' lower shrub canopy, consistent with BVG description.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
29b	Open shrublands to open heaths in montane frequently rocky locations.	Sparse	Sparse	BVG description states “highly variable vegetation and structure depending on the bioregion, substrate and the depth of soil in the local situation". BVG structural formation is describes as "Bare rock; frequently with patches of heath, shrubland and woodland". Five remnant regional ecosystems within the study area (11.7.5, 11.7.5a, 12.8.19, 12.12.10 and 11.12.18a). REDD describes 11.7.5 & 11.7.5a as shrubland (i.e. 'sparse' shrub cover in the 1-2m range), 12.8.19 as heath and rock pavement with scattered shrubs, 12.12.10 and 11.12.18a as shrubland or heath. GC: No BVG description with respect to groundcover. Assumed 'sparse' based upon two (each of which was based upon four reference sites) of three available technical descriptions for regional ecosystems of this BVG group within the study area. The other suggested 'very sparse', however, was based upon a single reference site. The biocondition benchmark for 11.12.18 (no technical description), a similar vegetation community to 11.12.18a, suggested a 'sparse' native perennial groundcover (24%) is present. Ground cover Assumed 'sparse'. LSBC: Available technical descriptions suggest 'very sparse' LSBC, however, two of the three are each based on only two reference sites for this strata. The BVG title suggests a 'very sparse' to 'mid-dense' shrub/heath layer (i.e. open shrublands to open heaths). Similarly, the REDD suggests the dominant ecological structure reflects a ‘sparse’ to 'mid-dense' shrub/heath layer (i.e. in the 1-2m range). The lower shrub layer is assumed 'sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
30a	Tussock grasslands dominated by *Astrebla* spp. (Mitchell grass) or *Dichanthium* spp. (bluegrass) often with *Eulalia aurea* (silky browntop) on alluvia.	Mid-Dense	Very sparse	Two remnant regional ecosystems within the study area. No draft technical descriptions. GC: Structural formation is identified as "Tussock grasslands in the east" for this BVG, i.e. 'mid-dense'. LSBC: Based upon the structural formation, assumed 'very sparse'.
30b	Tussock grasslands dominated by *Astrebla* spp. (Mitchell grass) or *Dichanthium* spp. (bluegrass) often with *Iseilema* spp. on undulating downs or clay plains.	Mid-Dense	Very sparse	Only one remnant regional ecosystem within the study area. GC: Structural formation is identified as "Tussock grasslands in the east" for this BVG, i.e. 'mid-dense'. LSBC: Based upon the structural formation, assumed 'very sparse'.
32b	Closed tussock grasslands and associated open woodlands on undulating clay plains, upland areas and headlands. Dominant species include *Heteropogon triticeus* (giant speargrass) or *Themeda arguens* or *Sarga plumosum* or *Imperata cylindrica* (blady grass) or *Mnesithea rottboellioides* (cane grass) / *Arundinella setosa*. With areas of open woodland dominated by tree species such as *Corymbia papuana* (ghost gum) / *Terminalia* spp. / *Acacia ditricha* / *Piliostigma malabaricum*.	Mid-dense	Very sparse	Only one regional ecosystem, 12.8.15. BVG description identifies structural formation as "Closed tussock grassland to grassland; open shrubland to open woodland". GC: REDD description for 12.8.15 suggests structure is "grassland" - i.e. 'mid-dense'. LSBC: Given dominant structural description, shrub cover assumed 'very sparse'.
34a	Lacustrine wetlands. Lakes, ephemeral to permanent, fresh to brackish; water bodies with ground water connectivity. Includes fringing woodlands and sedgelands.	NA	NA	Masked in study area - not suitable. BVG reflects permanent to often inundated areas.
34b	Palustrine wetlands. Generally intermittent swamps/claypans (non floodplains) in inland areas dominated by chenopods e.g. *Chenopodium auricomum* (Queensland blue bush) or *Tecticornia* spp. (samphire) or herbs.	Sparse	Very sparse	Only one remnant regional ecosystem within the study area, 11.5.17. BVG structural formation described as "Bare saline claypans, occasionally flooded". BVG floristics description suggests open grasslands (i.e. GC - 'sparse') are frequent on many of the claypans, whilst open shrublands (i.e. 'very sparse') may be present in others. GC: Assumed to range from 'sparse' to 'very sparse'. LSBC: Assumed 'very sparse'.

BVG(1M) Identifier	BVG Description	Ground layer - cover	Lower shrub layer - cover	Justification (GC - groundcover; LSBC - Low shrub Cover)
34c	Palustrine wetlands. Freshwater swamps on coastal floodplains dominated by sedges and grasses such as *Oryza* spp., *Eleocharis* spp. (spikerush) or *Baloskion* spp. (cord rush) / *Leptocarpus tenax* / *Gahnia sieberiana* (sword grass) / *Lepironia* spp. Includes small areas of estuarine wetlands.	Dense/closed	Very sparse	Two remnant regional ecosystems within the study area. Structural formation "Closed sedgeland to closed tussock grassland". GC: Assumed 'dense/closed'. LSBC: Available technical descriptions do not identify a low shrub cover. Based upon structural formation, assumed 'very sparse'.
34d	Palustrine wetlands. Freshwater swamps or billabongs on floodplains ranging from permanent and semi-permanent to ephemeral.	NA	NA	Masked in study area - not suitable. BVG reflects permanent to often inundated areas. BVG structural formation stated as "Open water to floating herbland, frequently fringed by woodland". Typical landforms include "Permanent or seasonal wetlands, including waterholes and billabongs on drainage lines".
34f	Palustrine wetlands. Sedgelands/grasslands on seeps and soaks on wet peaks, and other coastal non-floodplain features.	Dense/closed	Dense/closed	BVG description states "A complex of sedgelands, grasslands, fernlands and forblands occurs in the semi-permanent swamps of the coastal lowlands". Structural formation stated as "Sedgeland, grassland, through to low woodland". No technical description available. Only one remnant regional ecosystem within the study area, 12.9-10.22. REDD description for 12.9-10.22 is "Closed sedgeland to heathland with emergent trees" (i.e... either dense ground or low shrub layer). GC/LSBC: Either GC or LSBC assumed 'dense' dependent upon REDD description.
35a	Closed forests and low closed forests dominated by mangroves.	NA	NA	Estuarine BVG. Masked in study area - not suitable.
35b	Bare saltpans ± areas of *Tecticornia* spp. (samphire) sparse forblands and/or *Xerochloa imberbis* or *Sporobolus virginicus* (sand couch) tussock grasslands.	NA	NA	Estuarine BVG. Masked in study area - not suitable.

Appendix C: List of Remnant Regional Ecosystems relevant to the Study and Extracts from Available Draft Technical Descriptions

Appendix C: Remnant Regional Ecosystems - Extracts from Draft Technical Descriptions

Limitation of use: *The information contained in the following table which relates to ground and shrub layer statistics have been derived from* ***Draft*** *Regional Ecosystem Technical Descriptions provided specifically for the purpose of the current study and cannot be reused or extracted for any third party use or derivatives works. Any queries or requests relating to this information, must be directed to the Queensland Herbarium, the Queensland Department of Science, Information Technology and Innovation.*

Regional Ecosystem	**BVG(1M) Identifier**	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.11.10	2a	0.4m, range 0.2-0.5m/ 41.7%, range 5-60%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.1m, range 1.5-3m/ 40%, range 40.0-40.0%/ 3 sites	No shrub cover description available.
12.12.13	2a	0.5m, range 0.4-1m/ 9.3%, range 1-24%/ 10 sites	1.2m, range 1-1.2m/ 32.6%, range 12.0-50.0%/ 8 sites	No shrub cover description available.	2.1m, range 1.5-4m/ 28.2%, range 10.0-52.0%/ 17 sites	No shrub cover description available.
12.12.16	2a	0.5m, range 0.4-0.5m/ 16%, range 5-45%/ 4 sites	1.2m, range 1.2-1.2m/ 22%, range 15.0-29.0%/ 2 sites	No shrub cover description available.	2.9m, range 2-4.2m/ 43%, range 20.0-82.0%/ 4 sites	No shrub cover description available.
12.8.3	2a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.4	2a	No technical description	No technical description	No technical description	No technical description	No technical description
11.2.3	3a	No technical description	No technical description	No technical description	No technical description	No technical description
12.2.2	3a	0.4m, range 0.3-0.5m/ 5.3%, range 1-10%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 0.8-2.5m/ 19.3%, range 0.0-47.0%/ 4 sites	No shrub cover description available.
12.2.3	3a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.1	4a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.1	4a	0.4m, range 0.4-0.4m/ 12.5%, range 10-15%/ 2 sites	1.2m, range 1.2-1.2m/ 7%, range 4.0-10.0%/ 2 sites	No shrub cover description available.	2.5m, range 2.5-2.5m/ 7.5%, range 5.0-10.0%/ 2 sites	No shrub cover description available.
12.2.1	4a	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.1	4b	0.5m, range 0.4-0.7m/ 24.2%, range 4-42%/ 5 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 2-3m/ 19.1%, range 4.0-64.0%/ 10 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.11.11	5a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.12	5a	0.5m, range 0.3-0.6m/ 11.7%, range 5-15%/ 3 sites	1.4m/ 60%/ 1 site	No shrub cover description available.	2.2m, range 1.5-3.5m/ 24.8%, range 10.0-54.0%/ 4 sites	No shrub cover description available.
12.5.13	5a	No technical description	No technical description	No technical description	No technical description	No technical description
12.5.13a	5a	0.4m, range 0.2-1m/ 4.7%, range 0-20%/ 9 sites	No shrub cover description available.	No shrub cover description available.	2.6m, range 2-3m/ 35.6%, range 10.0-60.0%/ 9 sites	No shrub cover description available.
12.5.13b	5a	No ground cover description available.	No shrub cover description available.	No shrub cover description available.	2.0m/ 39%/ 1 site	4.0m/ 63%/ 1 site
12.8.13	5a	0.6m, range 0.5-0.8m/ 4.5%, range 0-15%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 1.5-3.5m/ 30%, range 15.0-55.0%/ 5 sites	No shrub cover description available.
12.9-10.16	5a	0.4m, range 0.2-0.6m/ 6.5%, range 1-10%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-2.5m/ 52.5%, range 30.0-75.0%/ 8 sites	No shrub cover description available.
12.8.18	6a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.5	6a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.6	6a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.7	6a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.4	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.10.8	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.18	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.5	7a	0.3m/ 2%/ 1 site	0.6m/ 25%/ 1 site	No shrub cover description available.	1.8m, range 1.5-2m/ 43.3%, range 20-70%/ 3 sites	No shrub cover description available.
11.11.5a	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.4	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.11	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.5.15	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.13	7a	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
11.8.3	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.9.4a	7a	No technical description	No technical description	No technical description	No technical description	No technical description
11.9.4c	7a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.13	7a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.17	7a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.18	7a	0.5m, range 0.3-0.6m/ 31.7%, range 1-50%/ 6 sites	1.0m, range 0.5-1.8m/ 28.2%, range 5.0-76.0%/ 6 sites	No shrub cover description available.	2.6m, range 2-4m/ 35.9%, range 10-67.0%/ 7 sites	No shrub cover description available.
12.5.13c	7a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.21	7a	0.5m, range 0.2-1m/ 40%, range 5-70%/ 3 sites	1.0m/ 50%/ 1 site	No shrub cover description available.	1.8m, range 1.5-2.5m/ 41.7%, range 20.0-60.0%/ 3 sites	No shrub cover description available.
12.8.22	7a	0.4m, range 0.3-0.4m/ 3%, range 2-4%/ 2 sites	0.9m, range 0.8-1m/ 24.5%, range 0.6-48.5%/ 2 sites	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.9-10.15	7a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.16x1	8a	0.7m/ 46%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m/ 70%/ 1 site	No shrub cover description available.
12.11.2	8a	0.6, range 0.4-0.8m/ 41.7%, range 10-90%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 2-3m/ 12%, range 1.0-25.0%/ 3 sites	No shrub cover description available.
12.12.15a	8a	0.4m, range 0.3-0.4m,/ 20%, range 10-30%/ 2 sites	1.3m, range 1-1.5m/ 10%, range 5.0-15.0%/ 2 sites	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.12.15b	8a	0.5m/ 20%/ 1 site	1.5m/ 13%/ 1 site	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.12.20	8a	0.5m, range 0.5-0.5m/ 36.7%, range 11-50%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 2-2m/ 2%, range 1.0-3.0%/ 2 sites	3.1m, range 0.5-5m/ 4%, range 1.0-10.0%/ 4 sites
12.12.2a	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.2b	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.3a	8a	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.3.2	8a	0.5m/ 20%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m/ 20%/ 1 site	2.8m, range 1.8-4.2m/ 15.3%, range 5.0-21.0%/ 4 sites
12.5.11	8a	0.5m, range 0.3-0.8m/ 30%, range 16-43%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.5-2.5m/ 33%, range 12.0-74.0%/ 9 sites	No shrub cover description available.
12.5.6a	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.10	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.11	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.14x1	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.2	8a	0.7m/ 70%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.5m/ 20%/ 1 site	No shrub cover description available.
12.8.8	8a	0.8m, range 0.7-0.8m/ 30%, range 20-40%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.7m/ 15%/ 1 site	2.5m, range 2-3m/ 9.4%, range 3.0-15.0%/ 5 sites
12.8.9	8a	0.7m, range 0.7-0.7m/ 11%, range 10-12%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.8m, range 2.5-3m/ 15.3%, range 11.0-20.0%/ 3 sites	No shrub cover description available.
12.9-10.1	8a	0.5m, range 0.5-0.6m/ 46%, range 40-50%/ 3 sites	0.7m/ 18%/ 1 site	No shrub cover description available.	2.1m, range 1.5-2.5m/ 22%, range 5.0-66.0%/ 4 sites	No shrub cover description available.
12.9-10.14a	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.2.4	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.1x1	8a	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.16	8b	0.5m, range 0.5-0.6m/ 17.5%, range 5-28%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1-2m, 5 sites/ 36.4%, range 1.0-71.0%/ 5 sites	No shrub cover description available.
12.11.23	8b	0.7m, range 0.6-0.7m/ 40.5%, range 20-60%/ 6 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 1.5-3m/ 7.7%, range 4.0-13.0%/ 6 sites	No shrub cover description available.
12.11.3b	8b	0.6m, range 0.4-1m/ 29.6%, range 10-45%/ 8 sites	No shrub cover description available.	No shrub cover description available.	2.9m, range 2-4.5m/ 16.3%, range 5.0-30.0%/ 8 sites	No shrub cover description available.
12.11.9x1	8b	0.5m/ 5%/ 1 site	No shrub cover description available.	No shrub cover description available.	4.0m/ 25%/ 1 site	No shrub cover description available.

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12.12.2	8b	0.6m, range 0.5-0.7m/ 56%, range 40-70%/ 8 sites	1.2m, range 1.2-1.2m/ 14%, range 8.0-20.0%/ 2 sites	No shrub cover description available.	2.3m, range 1.5-3.5m/ 5.5%, range 1.0-10.0%/ 8 sites	No shrub cover description available.
12.12.4	8b	0.7m, range 0.5-1m/ 47.3%, range 5-90%/ 13 sites	0.5m/ 5%/ 1 site	No shrub cover description available.	2.0m, range 0.5-3m/ 9.7%, range 1.0-41.0%/ 22 sites	No shrub cover description available.
12.12.6	8b	0.5m, range 0.5-0.5m/ 24.3%, range 2-60%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 1.2-2m/ 19%, range 0.0-47.0%/ 5 sites	No shrub cover description available.
12.2.8	8b	0.6m, range 0.5-0.8m/ 25.2%, range 2-61%/ 23 sites	0.5m, range 0.5-0.5m/ 21.1%, range 3.0-44.0%/ 18 sites	No shrub cover description available.	2.1m, range 1.5-4m/ 31%, range 2.0-80.0%/ 24 sites	No shrub cover description available.
12.5.6c	8b	0.5m, range 0.5-0.5m/ 45%, range 40-50%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.1m, range 2-2.5m, 4/ 22.5%, range 8.0-60.0%/ 4 sites	No shrub cover description available.
12.8.1	8b	0.7m, range 0.6-0.9m/ 24.8%, range 19-35%/ 4 sites	No shrub cover description available.	No shrub cover description available.	3.3m, range 3-4m/ 22.8%, range 10.0-41.0%/ 4 sites	No shrub cover description available.
12.8.12	8b	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.1a	8b	0.3m/ 30%/ 1 site	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.9-10.14	8b	0.6m, range 0.5-0.8m/ 72%, range 45-95%/ 7 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 1.5-3m, 9/ 11.2%, range 1.0-21.0%/ 9 sites	No shrub cover description available.
12.9-10.14b	8b	0.7m, range 0.5-0.8m/ 56%, range 55-57%/ 2 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 1.5-1.7m/ 23.5%, range 20.0-27.0%/ 2 sites	2.8m, range 2.5-3m/ 14%, range 13.0-15.0%/ 2 sites
12.9-10.20	8b	0.4m, range 0.3-0.5m/ 32.8%, range 5-60%/ 4 sites	1.3m, range 1-2m/ 37%, range 5.0-66.0%/ 3 sites	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.11.3	9a	0.6m, range 0.3-1.8m/ 37.7%, range 3-94%/ 31 sites	1.0m, range 0.8-1.2m/ 21%, range 12.0-30.0%/ 2 sites	No shrub cover description available.	2.2m, range 1.2-3m/ 10%, range 1.0-30.0%/ 32 sites	No shrub cover description available.
12.11.3a	9a	0.6m, range 0.3-0.7m/ 32.5%, range 15-80%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.9m, range 1-2.5m/ 15%, range 5.0-30.0%/ 4 sites	No shrub cover description available.

Regional Ecosystem	**BVG(1M) Identifier**	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.12.15	9a	0.5m, range 0.25-0.7m/ 43%, range 15-70%/ 13 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.4-3m/ 12%, range 1.0-75.0%/ 13 sites	No shrub cover description available.
12.5.6	9a	No technical description	No technical description	No technical description	No technical description	No technical description
12.5.6b	9a	0.5m/ 25%/ 1 site	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.8.8a	9a	0.5m, range 0.3-0.7m/ 14%, range 10-20%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 2-3m/ 9.7%, range 6.0-13.0%/ 3 sites	No shrub cover description available.
12.9-10.17	9a	No ground cover description available.	No shrub cover description available.	No shrub cover description available.	2.2m, range 2-2.5m/ 22.7%, range 7.0-33.0%/ 3 sites	No shrub cover description available.
12.9-10.17d	9a	0.5m, range 0.3-1m/ 54.7%, range 15-90%/ 7 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-4m/ 16.3%, range 0.0-64.0%/ 11 sites	No shrub cover description available.
12.9-10.17e	9a	No technical description	No technical description	No technical description	No technical description	No technical description
11.5.8a	9b	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.20	9c	0.4m, range 0.2-0.6m/ 50%, range 50-50%/ 2 sites	1.2m/ 5%/ 1 site	No shrub cover description available.	2.0m, range 1-3m/ 1%, range 0.0-2.0%/ 2 sites	No shrub cover description available.
12.2.11	9f	0.5m, range 0.3-0.6m/ 38.6%, range 1-93%/ 18 sites	1.0m, range 0.5-2m/ 10.8%, range 2.0-31.0%/ 6 sites	No shrub cover description available.	2.4m, range 0.5-4.5m/ 9.7%, range 1.0-62.0%/ 25 sites	No shrub cover description available.
12.2.5	9f	0.6m, range 0.3-0.9m/ 33.4%, range 4-70%/ 15 sites	0.7m, range 0.5-1.2m/ 8.8%, range 2.0-20.0%/ 11 sites	No shrub cover description available.	2.4m, range 0.9-4.8m/ 21.9%, range 1.0-60.0%/ 19 sites	No shrub cover description available.
12.3.14a	9g	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.5a	9g	0.6m, range 0.3-0.7m,/ 46.5%, range 5-75%/ 25 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 1.5-3m/ 8.1%, range 1.0-25.0%/ 26 sites	No shrub cover description available.
12.11.5j	9g	0.5m, range 0.5-0.6m/ 52.5%, range 35-90%/ 6 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1-3m/ 9.9%, range 2.0-22.0%/ 7 sites	No shrub cover description available.
12.5.12	9g	0.8m/ 54%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.4m, range 2-3m, 6/ 29.2%, range 6.0-64.0%/ 6 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.8.25	9g	0.4m/ 70%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m, range 2-2m/ 7.3%, range 4.0-13.0%/ 3 sites	No shrub cover description available.
12.9-10.12	9g	0.5m, range 0.4-0.75m/ 54%, range 45-76%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.25-2.5m/ 17%, range 5.0-35.0%/ 5 sites	No shrub cover description available.
12.9-10.12a	9g	No ground cover description available.	No shrub cover description available.	No shrub cover description available.	3.3m, range 3-3.5m/ 55%, range 50.0-60.0%/ 2 sites	No shrub cover description available.
12.9-10.17c	9g	0.8m, range 0.5-1m/ 35.5%, range 20-51%/ 2 sites	No shrub cover description available.	No shrub cover description available.	1.6m/ 26%/ 1 site	2.5m, range 2-3m/ 13.5%, range 10.0-17.0%/ 2 sites
12.9-10.4	9g	0.5m, range 0.3-1m/ 58.2%, range 24-85%/ 20 sites	1.5m, range 1-2m/ 15%, range 10.0-20.0%/ 2 sites	No shrub cover description available.	2.0m, range 1.5-2.5m/ 12.7%, range 5.0-30.0%/ 23 sites	No shrub cover description available.
12.2.6	9g	0.6m, range 0.1-1m/ 26.8%, range 1-73%/ 47 sites	0.5m, range 0.5-0.6m/ 21.1%, range 3.0-50.0%/ 41 sites	No shrub cover description available.	2.2m, range 1.5-4.3m/ 29.9%, range 5.0-80.0%/ 50 sites	No shrub cover description available.
12.5.2	9g	No technical description	No technical description	No technical description	No technical description	No technical description
12.5.2a	9g	0.8m/ 78%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m/ 30%/ 1 site	4.1m, range 2-8m/ 23.5%, range 4.0-40.0%/ 4 sites
12.5.2b	9g	0.8m, range 0.6-1m,/ 62.5%, range 45-80%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.9m, range 2-4m/ 12.5%, range 5.0-20.0%/ 4 sites	No shrub cover description available.
12.5.3	9g	0.5m, range 0.3-1m/ 56.4%, range 22-85%/ 21 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 0.8-2m/ 12.2%, range 6.0-20.0%/ 6 sites	2.4m, range 1.5-4m/ 17.4%, range 5.0-40.0%/ 21 sites
12.5.3a	9g	0.4m, range 0.4-0.5m/ 58%, range 35-80%/ 5 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.9-2m/ 14%, range 5.0-28.0%/ 5 sites	No shrub cover description available.
12.5.4	9g	0.5m, range 0.3-0.8m/ 56.5%, range 15-95%/ 26 sites	1.2m, range 0.7-2m/ 31.3%, range 5.0-80.0%/ 15 sites	No shrub cover description available.	2.3m, range 1.2-4m/ 12.4%, range 1.0-73.0%/ 59 sites	No shrub cover description available.
12.5.5	9g	0.5m, range 0.5-0.5m/ 40%, range 30-50%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.8m, range 1.5-4m/ 15%, range 3.0-40.0%/ 7 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.5.8	9g	0.5m, range 0.4-0.8m/ 58.2%, range 11-95%/ 6 sites	1.0m, range 0.8-1.2m/ 19%, range 1.0-59.0%/ 7 sites	No shrub cover description available.	2.1m, range 1.5-2.5m/ 7.8%, range 1.0-26.0%/ 13 sites	No shrub cover description available.
12.11.9	9g	0.5m, range 0.2-0.8m/ 40.6%, range 10-75%/ 7 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-3m/ 5.3%, range 0.0-15.0%/ 8 sites	No shrub cover description available.
12.12.12	9g	0.5m, range 0.5-0.6m/ 41.3%, range 20-60%/ 4 sites	0.8m/ 10%/ 1 site	No shrub cover description available.	2.4m, range 2-4m/ 7.7%, range 1.0-20.0%/ 18 sites	No shrub cover description available.
12.12.14	9g	0.5m, range 0.4-0.6m/ 35.4%, range 8-70%/ 5 sites	No shrub cover description available.	No shrub cover description available.	1.9m, range 1.5-2m/ 8.2%, range 2.0-20.0%/ 5 sites	No shrub cover description available.
12.12.23	9g	0.5m, range 0.5-0.6m/ 64.7%, range 55-74%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.7m, range 2-4.5m/ 5.2%, range 1.0-12.0%/ 5 sites	No shrub cover description available.
12.11.22	9h	0.5m, range 0.4-0.6m/ 45%, range 32-65%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.9m, range 1.5-2.5m/ 15.5%, range 4.0-30.0%/ 4 sites	No shrub cover description available.
12.11.5h	9h	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.20	9h	0.5m, range 0.4-0.6m/ 31.7%, range 10-60%/ 6 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1-3m/ 24.9%, range 2.0-60.0%/ 8 sites	No shrub cover description available.
12.8.26	9h	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.18	9h	0.4m, range 0.2-0.6m/ 34%, range 7-70%/ 12 sites	No shrub cover description available.	No shrub cover description available.	2.6m, range 1.5-4m/ 17.2%, range 5.0-38.0%/ 13 sites	No shrub cover description available.
12.9-10.18a	9h	0.4m, range 0.05-0.8m/ 48.3%, range 40-55%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-3m/ 12.3%, range 5.0-22.0%/ 3 sites	No shrub cover description available.
12.9-10.18b	9h	No ground cover description available.	1.5m/ 23%/ 1 site	No shrub cover description available.	3.5m, range 2-5m/ 41.5%, range 30.0-53.0%/ 2 sites	No shrub cover description available.
12.9-10.21	9h	0.6m, range 0.4-0.9m/ 50.8%, range 0-100%/ 12 sites	No shrub cover description available.	No shrub cover description available.	2.1m, range 1.5-4.5m/ 21.1%, range 1.0-80.0%/ 34 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.9-10.5	9h	0.4m, range 0.3-0.5m/ 30%, range 8-75%/ 7 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 1.2-3.5m/ 26.7%, range 6.0-64.0%/ 7 sites	No shrub cover description available.
12.9-10.5a	9h	0.7m, range 0.3-1m/ 51.1%, range 27-78%/ 10 sites	1.4m, range 1.2-1.5m/ 38.8%, range 18.0-79.0%/ 4 sites	No shrub cover description available.	2.4m, range 1.5-3m/ 21.3%, range 5.0-65.0%/ 11 sites	No shrub cover description available.
12.9-10.5d	9h	0.6m, range 0.5-0.6m/ 50%, range 40-60%/ 2 sites	0.8m/ 3%/ 1 site	No shrub cover description available.	3.5m, range 2-5m/ 5%, range 5.0-5.0%/ 2 sites	No shrub cover description available.
12.5.1c	9h	0.8m, range 0.5-1.2m/ 46%, range 37-60%/ 5 sites	1.4m, range 1-1.5m/ 39%, range 5.0-75.0%/ 5 sites	No shrub cover description available.	2.9m, range 2-4m/ 12%, range 2.0-25.0%/ 5 sites	No shrub cover description available.
11.12.5	9h	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.15	9h	0.6m/ 70%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.4m, range 2-2.5m/ 20.5%, range 10.0-30.0%/ 4 sites	No shrub cover description available.
12.11.17	9h	0.4m, range 0.3-0.5m/ 56.7%, range 40-70%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1-2.5m/ 9.7%, range 1.0-35.0%/ 6 sites	No shrub cover description available.
12.11.19	9h	0.4m, range 0.2-0.5m/ 33.2%, range 15-41%/ 5 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 9.5%, range 7.0-12.0%/ 6 sites	No shrub cover description available.
12.11.21	9h	0.4m/ 19%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m/ 0%/ 1 site	No shrub cover description available.
12.12.11	9h	0.5m, range 0.4-0.8m/ 48.8%, range 15-90%/ 28 sites	1.5m, range 0.5-2m/ 7.8%, range 0.0-30.0%/ 5 sites	No shrub cover description available.	2.4m, range 1.5-5m/ 6.5%, range 0.0-35.0%/ 42 sites	No shrub cover description available.
12.12.21	9h	0.5m, range 0.4-0.5m/ 72.5%, range 64-81%/ 2 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 23.3%, range 2.0-66.0%/ 3 sites	No shrub cover description available.
12.12.22	9h	0.5m, range 0.5-0.5m/ 33.5%, range 10-57%/ 2 sites	0.5m, range 0.5-0.5m/ 9.7%, range 7.0-13.0%/ 3 sites	No shrub cover description available.	2.0m, range 1.5-2.5m/ 14%, range 1.0-34.0%/ 6 sites	No shrub cover description available.
12.12.24	9h	0.5m, range 0.5-0.5m/ 53.3%, range 20-75%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.1m, range 2-2.5m/ 8.8%, range 5.0-12.0%/ 4 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.12.25	9h	0.6m, range 0.5-1m/ 33.8%, range 25-45%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 2-2m/ 17.5%, range 12.0-23.0%/ 2 sites	2.8m, range 2-4.5m/ 14.9%, range 2.0-33.0%/ 7 sites
12.12.27	9h	0.5m, range 0.5-0.5m/ 25.3%, range 15-43%/ 6 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 2-2.5m/ 6.1%, range 5.0-10.0%/ 7 sites	No shrub cover description available.
12.5.1e	9h	0.5m, range 0.4-0.5m/ 62.5%, range 60-65%/ 2 sites	No shrub cover description available.	No shrub cover description available.	3.0m/ 10%/ 1 site	No shrub cover description available.
11.10.1	10a	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.3	10a	0.3m, range 0.25-0.5m/ 39.5%, range 13-65%/ 4 sites	1.1m, range 0.9-1.4m/ 10.5%, range 2-30%/ 4 sites	No shrub cover description available.	1.6m, range 1.2-2.5m/ 4.6%, range 0-10%/ 12 sites	No shrub cover description available.
11.11.4a	10a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.6	10a	0.7m, range 0.3-1m/ 25.5%, range 16-35%/ 2 sites	1.0m, range 0.9-1m/ 7.8%, range 1-12%/ 4 sites	No shrub cover description available.	1.6m, range 0.5-3m/ 6.7%, range 0-20%/14 sites	No shrub cover description available.
11.12.6a	10a	No technical description	No technical description	No technical description	No technical description	No technical description
11.5.9d	10a	No technical description	No technical description	No technical description	No technical description	No technical description
11.7.6	10a	0.4m, range 0.2-0.5m/ 28.7%, range 10-46%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.9m, range 0.8-3m/ 7.7%, range 0-15%/ 3 sites	No shrub cover description available.
12.11.5	10b	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.5e	10b	0.6m, range 0.3-0.8m/ 33.1%, range 15-60%/ 14 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.2-3m/ 8.6%, range 1.0-24.0%/ 14 sites	No shrub cover description available.
12.11.5k	10b	0.6m, range 0.3-0.9m/ 33.7%, range 8-80%/ 12 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 1.5-3m/ 4.5%, range 1.0-15.0%/ 12 sites	No shrub cover description available.
12.11.6	10b	0.5m, range 0.3-0.8m/ 38%, range 3-93%/ 30 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1-3m, 42/ 11.2%, range 0.0-40.0%/ 42 sites	No shrub cover description available.
12.12.3	10b	0.4m, range 0.3-0.5m/ 32.5%, range 12-48%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-4.5m/ 10.8%, range 1.0-45.0%/ 13 sites	No shrub cover description available.

Regional Ecosystem	**BVG(1M) Identifier**	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.12.5	10b	0.5m, range 0.3-0.9m/ 45.4%, range 4-100%/ 23 sites	1.4m, range 0.5-2m/ 10.4%, range 2.0-37.0%/ 17 sites	No shrub cover description available.	2.5m, range 0.5-4.5m/ 8.8%, range 0.0-35.0%/ 69 sites	No shrub cover description available.
12.5.1	10b	0.5m, range 0.2-0.75m/ 22.3%, range 5-91%/ 7 sites	1.0m/ 8%/ 1 site	No shrub cover description available.	2.3m, range 2-2.5m/ 19.3%, range 3.0-35.0%/ 7 sites	No shrub cover description available.
12.5.7	10b	0.4m, range 0.2-0.8m/ 49.4%, range 18-66%/ 12 sites	No shrub cover description available.	No shrub cover description available.	2.4m, range 1.5-4m, 23/ 15.2%, range 1.0-60.0%/ 23 sites	No shrub cover description available.
12.5.7a	10b	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.24	10b	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.17b	10b	0.4m, range 0.3-0.5m/ 77.2%, range 35-98%/ 5 sites	No shrub cover description available.	No shrub cover description available.	2.8m, range 2-4.5m/ 23.8%, range 1.0-70.0%/ 11 sites	No shrub cover description available.
12.9-10.19a	10b	0.5m, range 0.3-0.5m/ 40%, range 15-60%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 1.5-2m/ 5.8%, range 0.0-15.0%/ 4 sites	No shrub cover description available.
12.9-10.2	10b	0.5m, range 0.15-0.85m/ 49.7%, range 14-90%/ 14 sites	1.2m/ 3%/ 1 site	No shrub cover description available.	2.4m, range 1.2-5m/ 19.2%, range 1.0-65.0%/ 31 sites	No shrub cover description available.
11.8.2a	11a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.4	11a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.5	11a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.5a	11a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.8	11a	No technical description	No technical description	No technical description	No technical description	No technical description
12.8.16	11a	0.5m, range 0.4-0.5m/ 32.5%, range 5-60%/ 2 sites	1.0m/ 60%/ 1 site	No shrub cover description available.	2.5m, range 2-4m/ 8.7%, range 1.0-30.0%/ 6 sites	No shrub cover description available.
12.8.17	11a	0.5m, range 0.5-0.5m/ 52.5%, range 45-60%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.7-2.5m/ 30.8%, range 9.0-63.0%/ 5 sites	No shrub cover description available.

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12.8.14	11a	0.6m, range 0.3-1.2m/ 61%, range 4-95%/ 8 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-3.5m/ 6.8%, range 1.0-23.0%/ 12 sites	No shrub cover description available.
11.10.13	12a	No technical description	No technical description	No technical description	No technical description	No technical description
11.10.4	12a	No technical description	No technical description	No technical description	No technical description	No technical description
11.10.7	12a	No technical description	No technical description	No technical description	No technical description	No technical description
11.7.4	12a	0.3m, range 0.1-1m/ 36.6%, range 1-70%/ 12 sites	1.3m, range 1-1.5m/ 13%, range 1.0-25.0%/ 4 sites	No shrub cover description available.	2.6m, range 0.8-5m/ 10.7%, range 0.0-58.0%/ 15 sites	No shrub cover description available.
11.7.4c	12a	No technical description	No technical description	No technical description	No technical description	No technical description
11.7.7	12a	0.3m, range 0.2-0.4m/ 19%, range 10-30%/ 5 sites	No shrub cover description available.	No shrub cover description available.	2.8m, range 2.5-3m/ 15.8%, range 15.0-17.0%/ 5 sites	No shrub cover description available.
12.5.1a	12a	0.5m, range 0.3-0.6m/ 26%, range 1-90%/ 5 sites	No shrub cover description available.	No shrub cover description available.	2.9m, range 1.5-4m/ 30.6%, range 5.0-50.0%/ 5 sites	No shrub cover description available.
12.5.1b	12a	No technical description	No technical description	No technical description	No technical description	No technical description
12.7.1	12a	No technical description	No technical description	No technical description	No technical description	No technical description
12.7.2	12a	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.13	12a	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.19	12a	0.5m, range 0.3-0.8m/ 32.6%, range 5-66%/ 17 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 0.6-2m/ 20.3%, range 3.0-45.0%/ 12 sites	2.3m, range 1-4.5m/ 17.6%, range 0.0-68.0%/ 49 sites
12.9-10.5b	12a	0.8m, range 0.5-1m/ 42.5%, range 25-60%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 2.5-2.5m/ 4.5%, range 4.0-5.0%/ 2 sites	No shrub cover description available.
12.9-10.5c	12a	0.7m/ 25%/ 1 site	1.5m/ 3%/ 1 site	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.9-10.7a	12a	0.6m, range 0.5-0.7m/ 46.8%, range 20-83%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 2-3m/ 13.8%, range 1.0-46.0%/ 4 sites	No shrub cover description available.
12.9-10.9	12a	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.23	12a	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.9-10.24	12a	No ground cover description available.	0.5m/ 4%/ 1 site	No shrub cover description available.	1.8m, range 1.5-2m/ 8.5%, range 6.0-11.0%/ 2 sites	No shrub cover description available.
12.12.9	12a	0.8m, range 0.7-0.8m/ 32.5%, range 25-40%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 2-2m/ 15.6%, range 2.0-35.0%/ 11 sites	No shrub cover description available.
11.11.1	13c	0.6m, range 0.25-1m/ 30%, range 5-65%/ 10 sites	No shrub cover description available.	No shrub cover description available.	2.0m/ 30%/ 1 site	2.2m, range 1-6m/ 7.2%, range 0-25%/ 14 sites
11.11.15	13c	0.7m, range 0.1-1m/ 53.3%, range 16-100%/ 15 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 9.5%, range 3-15%/ 4 sites	2.4m, range 0.6-5m/ 6%, range 0-50%/ 25 sites
11.11.15a	13c	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.4	13c	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.4b	13c	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.1	13c	0.6m, range 0.35-0.75m/ 54.4%, range 20-90%/ 14 sites	0.8m, range 0.7-1m/ 4%, range 1-8%/ 3 sites	No shrub cover description available.	2.0m, range 1-6m/ 7.4%, range 0-71%/25 sites	No shrub cover description available.
11.12.3	13c	0.5m, range 0.4-0.5m/ 56.5%, range 18-95%/ 2 sites	1.2m, range 1.1-1.2m/ 3.5%, range 3-4%/ 2 sites	No shrub cover description available.	3.0m, range 1.1-5m/ 8%, range 0-23%/ 4 sites	No shrub cover description available.
11.9.9	13c	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.14	13c	0.6m, range 0.5-0.9m/ 47.5%, range 5-95%/ 6 sites	0.6m, range 0.5-0.9m/ 47.5%, range 5-95%/ 6 sites	No shrub cover description available.	2.3m, range 1.5-3m/ 5%, range 1.0-12.0%/ 6 sites	No shrub cover description available.
12.11.7	13c	0.4m, range 0.2-0.5m/ 36.8%, range 5-64%/ 5 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.2-2m/ 5.8%, range 0.0-20.0%/ 10 sites	No shrub cover description available.
12.12.7	13c	0.5m, range 0.3-0.6m/ 56.1%, range 14-80%/ 18 sites	No shrub cover description available.	No shrub cover description available.	2.0m/ 3%/ 1 site	2.1m, range 1.2-4.5m/ 7.9%, range 0.0-35.0%/ 30 sites
12.9-10.7	13c	0.5m, range 0.3-0.7m/ 71.9%, range 60-90%/ 11 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1-3m/ 11%, range 0.0-40.0%/ 11 sites	No shrub cover description available.
11.11.10a	13d	No technical description	No technical description	No technical description	No technical description	No technical description

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11.11.3c	13d	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.4c	13d	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.2b	13d	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.26	13d	4.1m, range 0.15-30m/ 61.5%, range 20-92%/ 8 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 0.3-5m/ 3%, range 0-6%/ 7 sites	No shrub cover description available.
11.5.20	13d	No technical description	No technical description	No technical description	No technical description	No technical description
11.9.13	13d	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.18	13d	0.4m, range 0.3-0.6m/ 40.9%, range 8-70%/ 9 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.5-3m/ 11.3%, range 0.0-47.0%/ 12 sites	No shrub cover description available.
12.11.18a	13d	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.28	13d	0.3m, range 0.2-0.5m/ 36%, range 1-98%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.7m, range 1.2-2m/ 8.7%, range 4.0-12.0%/ 3 sites	2.7m, range 2-4.2m/ 13.4%, range 1.0-50.0%/ 11 sites
12.12.28x1	13d	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.3b	13d	0.4m, range 0.2-0.5m/ 60.5%, range 51-70%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.8m, range 1.5-4m/ 17%, range 4.0-30.0%/ 2 sites	No shrub cover description available.
12.3.3d	13d	0.4m, range 0.3-0.6m/ 47.5%, range 18-75%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1.5-3m/ 12.5%, range 4.0-30.0%/ 6 sites	No shrub cover description available.
12.9-10.3	13d	0.4m, range 0.3-0.5m/ 62.5%, range 29-95%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 2-2.5m/ 13.5%, range 2.0-45.0%/ 13 sites	No shrub cover description available.
12.8.14a	13d	0.8m/ 70%/ 1 site	No shrub cover description available.	No shrub cover description available.	3.0m/ 15%/ 1 site	No shrub cover description available.
11.3.23	15b	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.25	16a	0.6m, range 0.2-1.3m/ 51.7%, range 13-100%/ 19 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 0.5-6m/ 4.4%, range 0.0-30.0%/ 19 sites	No shrub cover description available.
12.3.7	16a	0.5m, range 0.3-0.8m/ 35.6%, range 10-90%/ 10 sites	No shrub cover description available.	No shrub cover description available.	2.4m, range 2-3.5m/ 18.4%, range 2.0-95.0%/ 19 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
11.3.4	16c	0.7m, range 0.2-1.1m/ 60.6%, range 12-95%/ 14 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 0.5-4m/ 2.3%, range 0.0-10.0%/ 11 sites	No shrub cover description available.
12.3.11	16c	0.6m, range 0.2-1m/ 49.3%, range 9-95%/ 16 sites	1.2m/ 0%/ 1 site	No shrub cover description available.	2.8m, range 0.8-5m/ 21.5%, range 3.0-83.0%/ 30 sites	No shrub cover description available.
12.3.11a	16c	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.3	16c	0.6m, range 0.4-0.8m/ 59.1%, range 10-90%/ 17 sites	1.1m, range 0.5-2.5m/ 2.6%, range 0.0-10.0%/ 8 sites	No shrub cover description available.	2.9m, range 1.5-5m/ 6.7%, range 0.0-25.0%/ 22 sites	No shrub cover description available.
12.3.9	16c	0.3m/ 80%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m/ 12%/ 1 site	No shrub cover description available.
12.3.7b	16d	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.9	17a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.17	17a	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.2	17a	0.4m, range 0.05-1m/ 51.1%, range 10-97%/ 19 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 1-2.2m/ 0.5%, range 0.0-1.0%/ 4 sites	2.6m, range 1.2-6m/ 4.4%, range 0.0-10.0%/ 18 sites
11.9.7	17a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.26a	17a	0.5m, range 0.5-0.5m/ 25.3%, range 15-43%/ 6 sites	No shrub cover description available.	No shrub cover description available.	2.0m/ 1%/ 1 site	No shrub cover description available.
12.3.10	17a	0.6m, range 0.5-0.6m/ 72.5%, range 70-75%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 2-2m/ 7%, range 2.0-12.0%/ 2 sites	No shrub cover description available.
11.11.10	17b	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.2	17b	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.6	17b	No technical description	No technical description	No technical description	No technical description	No technical description
11.9.2	17b	No technical description	No technical description	No technical description	No technical description	No technical description
12.11.8	17b	0.5m/ 30%/ 1 site	0.5m/ 6%/ 1 site	No shrub cover description available.	2.1m, range 2-2.5m/ 7.7%, range 0.0-30.0%/ 6 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.12.8	17b	0.5m/ 40%/ 1 site	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.8-2.5m/ 10.4%, range 2.0-35.0%/ 8 sites	No shrub cover description available.
12.9-10.8	17b	0.5m, range 0.4-0.6m/ 80%, range 75-85%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 1.5-2.5m/ 13%, range 1.0-25.0%/ 2 sites	No shrub cover description available.
11.3.29	18b	No technical description	No technical description	No technical description	No technical description	No technical description
11.5.1	18b	0.3m, range 0.1-0.6m/ 24%, range 5-65%/ 20 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 1.2-1.8m/ 9.3%, range 3.0-21.0%/ 4 sites	2.7m, range 0.4-6.5m/ 12.3%, range 1.0-40.0%/ 22 sites
11.5.2	18b	No technical description	No technical description	No technical description	No technical description	No technical description
11.5.4	18b	0.6m, range 0.1-1m/ 32.8%, range 5-70%/ 5 sites	No shrub cover description available.	No shrub cover description available.	1.8m/ 45%/ 1 site	3.6m, range 1.5-10m/ 7%, range 0.0-15.0%/ 7 sites
12.3.3a	18b	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.6b	20a	No technical description	No technical description	No technical description	No technical description	No technical description
11.10.9	20a	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.12	21a	0.5m, range 0.2-0.8m/ 59.2%, range 21-91%/ 17 sites	0.5m, range 0.5-0.5m/ 40%, range 32.0-48.0%/ 2 sites	No shrub cover description available.	2.0m, range 0.8-3m/ 8.7%, range 1.0-47.0%/ 16 sites	No shrub cover description available.
12.5.4a	21a	0.5m, range 0.4-0.5m/ 82.5%, range 70-95%/ 2 sites	No shrub cover description available.	No shrub cover description available.	2.6m, range 1.5-4m/ 16.5%, range 5.0-38.0%/ 4 sites	No shrub cover description available.
12.3.3c	21b	0.3m, range 0.2-0.5m/ 46%, range 30-54%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.9m, range 1.5-2.5m/ 2.8%, range 1.0-4.0%/ 4 sites	No shrub cover description available.
12.5.9a	21b	0.5m, range 0.5-0.6m/ 9.7%, range 7-12%/ 3 sites	1.3m, range 1-1.5m/ 7.5%, range 3.0-12.0%/ 2 sites	No shrub cover description available.	2.8m, range 2-4m/ 45%, range 40.0-50.0%/ 3 sites	No shrub cover description available.
12.9-10.11	21b	0.3m, range 0.2-0.5m/ 41%, range 37-44%/ 3 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 1%, range 1.0-1.0%/ 3 sites	No shrub cover description available.
12.9-10.11a	21b	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.2.7	22a	1.0m, range 0.5-2m/ 68.2%, range 5-100%/ 39 sites	1.5m, range 0.5-3m/ 19.2%, range 2.0-60.0%/ 13 sites	No shrub cover description available.	2.7m, range 1.2-8m/ 12.4%, range 0.0-65.0%/ 38 sites	No shrub cover description available.
12.2.7a	22a	1.6m, range 1.5-1.75m/ 95%, range 80-100%/ 4 sites	No shrub cover description available.	No shrub cover description available.	4.0m, range 2.5-7m/ 8.3%, range 5.0-10.0%/ 3 sites	No shrub cover description available.
12.2.7c	22a	2.1m, range 1.75-2.5m/ 94%, range 88-100%/ 2 sites	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.3.4	22a	1.0m, range 0.63-1.75m/ 70%, range 30-100%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.4m, range 1.5-4m/ 26.8%, range 2.0-70.0%/ 4 sites	No shrub cover description available.
12.3.4a	22a	1.0m, range 1-1m/ 85%, range 75-95%/ 2 sites	1.5m, range 1.5-1.5m/ 50%, range 30.0-70.0%/ 2 sites	No shrub cover description available.	2.5m, range 2.5-2.5m/ 17.5%, range 5.0-30.0%/ 2 sites	No shrub cover description available.
12.3.5	22a	1.0m, range 0.15-1.75m/ 65.6%, range 5-100%/ 31 sites	No shrub cover description available.	No shrub cover description available.	2.4m, range 1-3m, 20/ 11.8%, range 1.0-40.0%/ 20 sites	No shrub cover description available.
12.3.5a	22a	0.7m, range 0.1-1.5m/ 53.3%, range 2-100%/ 19 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 1.5-4m/ 19.6%, range 1.0-80.0%/ 18 sites	No shrub cover description available.
12.3.6	22a	0.6m, range 0.3-1m/ 65%, range 20-100%/ 18 sites	No shrub cover description available.	No shrub cover description available.	2.2m, range 1-4.5m/ 16.9%, range 1.0-80.0%/ 22 sites	No shrub cover description available.
12.3.7a	22c	0.7m/ 25%/ 1 site	No shrub cover description available.	No shrub cover description available.	3.0m/ 6%/ 1 site	No shrub cover description available.
11.5.2a	24a	No technical description	No technical description	No technical description	No technical description	No technical description
11.7.2	24a	No technical description	No technical description	No technical description	No technical description	No technical description
11.11.14	25a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.21	25a	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.1	25a	0.3m, range 0.07-0.5m/ 31.8%, range 3-80%/ 13 sites	No shrub cover description available.	No shrub cover description available.	2.0m, range 0.5-4m/ 12.7%, range 1.0-26.0%/ 15 sites	No shrub cover description available.
11.3.17	25a	No technical description	No technical description	No technical description	No technical description	No technical description
11.4.3	25a	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	Ground Layer Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Lower Shrub Cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher shrub cover 1 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*	Higher - shrub cover 2 Technical Description *(mean height, height range/mean FPC, FPC range/sites surveyed)*
11.9.10	25a	No technical description	No technical description	No technical description	No technical description	No technical description
11.9.5	25a	0.3m, range 0.01-0.6m/ 22.1%, range 0-70%/ 14 sites	1.3m, range 0.8-2m/ 9%, range 2.0-18.0%/ 4 sites	No shrub cover description available.	3.3m, range 1-6m/ 13.1%, range 3.0-38.0%/ 19 sites	No shrub cover description available.
11.9.5a	25a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.26	25a	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.10a	25a	0.5m, range 0.4-0.5m/ 11%, range 10-12%/ 2 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 1.8%, range 0.6-2.9%/ 2 sites	No shrub cover description available.
12.8.23	25a	0.5m/ 70%/ 1 site	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 25%, range 10.0-40.0%/ 2 sites	No shrub cover description available.
12.9-10.6	25a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.15	27c	No technical description	No technical description	No technical description	No technical description	No technical description
12.1.1	28a	0.6m, range 0.1-1.75m/ 66.3%, range 6-100%/ 23 sites	No shrub cover description available.	No shrub cover description available.	3.2m, range 1.5-9m/ 14.1%, range 4.0-40.0%/ 16 sites	No shrub cover description available.
12.2.14	28a	0.4m, range 0.3-0.5m/ 48.3%, range 30-70%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.3m, range 2-2.5m/ 8%, range 2.0-14.0%/ 2 sites	No shrub cover description available.
12.2.16	28d	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.14	28e	No technical description	No technical description	No technical description	No technical description	No technical description
12.9-10.17a	28e	No technical description	No technical description	No technical description	No technical description	No technical description
12.3.15	28e	0.6m, range 0.5-0.6m/ 40%, range 18-73%/ 4 sites	No shrub cover description available.	No shrub cover description available.	2.1m, range 2-2.5m/ 9.3%, range 3.0-14.0%/ 4 sites	No shrub cover description available.
12.12.19	29a	0.5m, range 0.3-1m/ 63%, range 2-99%/ 3 sites	0.5m/ 57%/ 1 site	No shrub cover description available.	2.0m/ 4%/ 1 site	No shrub cover description available.
12.12.19x2	29a	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.19x3	29a	No technical description	No technical description	No technical description	No technical description	No technical description
12.2.10	29a	0.5m, range 0.1-1.2m/ 23.6%, range 3-60%/ 12 sites	0.5m, range 0.5-0.5m/ 27.6%, range 9.0-78.0%/ 12 sites	No shrub cover description available.	2.2m, range 1.2-4m/ 45.5%, range 5.0-90.0%/ 12 sites	No shrub cover description available.

Regional Ecosystem	BVG(1M) Identifier	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
12.2.12	29a	0.7m, range 0.25-1m/ 23.3%, range 5-60%/ 10 sites	0.7m, range 0.5-1.1m/ 48.2%, range 2.0-81.0%/ 10 sites	1.5m, range 1-2m/ 38.2%, range 8.0-90.0%/ 13 sites	No shrub cover description available.	No shrub cover description available.
12.2.13	29a	0.6m/ 33%/ 1 site	0.5m/ 16%/ 1 site	1.5m/ 41%/ 1 site	No shrub cover description available.	No shrub cover description available.
12.2.9	29a	0.6m, range 0.1-1.2m/ 21.1%, range 0-60%/ 18 sites	0.7m, range 0.5-2m/ 35.2%, range 3.0-72.0%/ 17 sites	No shrub cover description available.	1.8m, range 0.5-4m/ 30%, range 5.0-80.0%/ 24 sites	No shrub cover description available.
12.3.13	29a	0.5m, range 0.3-0.7m/ 40%, range 10-70%/ 2 sites	1.0m, range 0.9-1.2m/ 32%, range 6.0-70.0%/ 3 sites	1.5m, range 1.2-2m/ 34.5%, range 5.0-80.0%/ 6 sites	No shrub cover description available.	No shrub cover description available.
12.3.14	29a	No ground cover description available.	No shrub cover description available.	No shrub cover description available.	2.0m/ 17%/ 1 site	No shrub cover description available.
12.5.10	29a	0.7m, range 0.5-0.8m/ 3%, range 3-3%/ 2 sites	1.0m, range 1-1m/ 48.5%, range 22.0-75.0%/ 2 sites	No shrub cover description available.	2.0m, range 1.2-3m/ 41.5%, range 3.0-95.0%/ 8 sites	No shrub cover description available.
12.5.9	29a	No technical description	No technical description	No technical description	No technical description	No technical description
11.12.18a	29b	No technical description	No technical description	No technical description	No technical description	No technical description
11.7.5	29b	0.4m, range 0.25-0.5m/ 26%, range 9-38%/ 4 sites	No shrub cover description available.	No shrub cover description available.	1.6m, range 0.9-2.8m/ 32.8%, range 9.0-60.0%/ 9 sites	No shrub cover description available.
11.7.5a	29b	No technical description	No technical description	No technical description	No technical description	No technical description
12.12.10	29b	0.6m, range 0.5-0.8m/ 13%, range 8-19%/ 4 sites	0.7m, range 0.6-0.8m/ 4%, range 2.0-6.0%/ 2 sites	No shrub cover description available.	2.4m, range 2-3m/ 9.8%, range 2.0-16.0%/ 4 sites	No shrub cover description available.
12.8.19	29b	0.5m/ 6%/ 1 site	1.1m, range 1-1.1m/ 7.5%, range 5.0-10.0%/ 2 sites	No shrub cover description available.	2.5m, range 2-3m/ 10%, range 5.0-15.0%/ 2 sites	No shrub cover description available.
11.3.21	30a	No technical description	No technical description	No technical description	No technical description	No technical description
11.3.24	30a	No technical description	No technical description	No technical description	No technical description	No technical description
11.8.11	30b	0.6m, range 0.4-1m/ 67.8%, range 65-73%/ 4 sites	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.	No shrub cover description available.
12.8.15	32b	No technical description	No technical description	No technical description	No technical description	No technical description

Regional Ecosystem	BVG(1M) Identifier	**Ground Layer Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Lower Shrub Cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher shrub cover 1 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*	**Higher - shrub cover 2 Technical Description** *(mean height, height range/mean FPC, FPC range/sites surveyed)*
11.5.17	34b	No technical description	No technical description	No technical description	No technical description	No technical description
12.2.15	34c	1.3m, range 0.7-2m/ 96.3%, range 80-100%/ 9 sites	No shrub cover description available.	No shrub cover description available.	1.8m, range 1.5-2m/ 32.7%, range 20.0-53.0%/ 3 sites	No shrub cover description available.
12.3.8	34c	1.1m, range 0.5-2m/ 97.7%, range 93-100%/ 3 sites	No shrub cover description available.	No shrub cover description available.	2.5m, range 2-3m/ 7%, range 4.0-10.0%/ 2 sites	No shrub cover description available.
12.9-10.22	34f	No technical description	No technical description	No technical description	No technical description	No technical description

Appendix D: Regional Ecosystems, Ground and Low Shrub Layer Cover Categories and combined Low Undergrowth Category

Appendix D: Regional Ecosystems, Ground and Shrub Layer Cover Categories and Combined Low Undergrowth Category

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.11.10	2a	Sparse	Sparse	2
12.12.13	2a	Sparse	Sparse	2
12.12.16	2a	Sparse	Sparse	2
12.8.3	2a	Sparse	Sparse	2
12.8.4	2a	Sparse	Sparse	2
11.2.3	3a	Sparse	Very sparse	1
12.2.2	3a	Sparse	Very sparse	1
12.2.3	3a	Very sparse	Very sparse	1
12.11.1	4a	Mid-Dense	Very sparse	2
12.12.1	4a	Mid-Dense	Very sparse	2
12.2.1	4a	Very sparse	Very sparse	1
12.3.1	4b	Sparse	Very sparse	1
12.11.11	5a	Very sparse	Very sparse	1
12.11.12	5a	Very sparse	Very sparse	1
12.5.13	5a	Very sparse	Very sparse	1
12.5.13a	5a	Very sparse	Very sparse	1
12.5.13b	5a	Very sparse	Very sparse	1
12.8.13	5a	Very sparse	Very sparse	1
12.9-10.16	5a	Very sparse	Very sparse	1
12.8.18	6a	Mid-dense	Sparse	2
12.8.5	6a	Mid-dense	Sparse	2
12.8.6	6a	Mid-dense	Sparse	2
12.8.7	6a	Mid-dense	Sparse	2
12.11.4	7a	Sparse	Sparse	2
11.10.8	7a	Sparse	Sparse	2
11.11.18	7a	Sparse	Sparse	2
11.11.5	7a	Sparse	Sparse	2
11.11.5a	7a	Sparse	Sparse	2
11.12.4	7a	Sparse	Sparse	2
11.3.11	7a	Sparse	Sparse	2
11.5.15	7a	Sparse	Sparse	2
11.8.13	7a	Sparse	Sparse	2
11.8.3	7a	Sparse	Sparse	2
11.9.4a	7a	Sparse	Sparse	2
11.9.4c	7a	Sparse	Sparse	2
12.11.13	7a	Sparse	Sparse	2
12.12.17	7a	Sparse	Sparse	2
12.12.18	7a	Sparse	Sparse	2
12.5.13c	7a	Sparse	Sparse	2
12.8.21	7a	Sparse	Sparse	2

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.8.22	7a	Sparse	Sparse	2
12.9-10.15	7a	Sparse	Sparse	2
12.11.16x1	8a	Dense/closed	Very sparse	3
12.11.2	8a	Dense/closed	Very sparse	3
12.12.15a	8a	Dense/closed	Very sparse	3
12.12.15b	8a	Dense/closed	Very sparse	3
12.12.20	8a	Dense/closed	Very sparse	3
12.12.2a	8a	Dense/closed	Very sparse	3
12.12.2b	8a	Dense/closed	Very sparse	3
12.12.3a	8a	Dense/closed	Very sparse	3
12.3.2	8a	Dense/closed	Very sparse	3
12.5.11	8a	Dense/closed	Very sparse	3
12.5.6a	8a	Dense/closed	Very sparse	3
12.8.10	8a	Dense/closed	Very sparse	3
12.8.11	8a	Dense/closed	Very sparse	3
12.8.14x1	8a	Dense/closed	Very sparse	3
12.8.2	8a	Dense/closed	Very sparse	3
12.8.8	8a	Dense/closed	Very sparse	3
12.8.9	8a	Dense/closed	Very sparse	3
12.9-10.1	8a	Dense/closed	Very sparse	3
12.9-10.14a	8a	Dense/closed	Very sparse	3
12.2.4	8a	Dense/closed	Very sparse	3
12.9-10.1x1	8a	Dense/closed	Very sparse	3
12.11.16	8b	Mid-dense	Very sparse	2
12.11.23	8b	Mid-dense	Very sparse	2
12.11.3b	8b	Mid-dense	Very sparse	2
12.11.9x1	8b	Mid-dense	Very sparse	2
12.12.2	8b	Mid-dense	Very sparse	2
12.12.4	8b	Mid-dense	Very sparse	2
12.12.6	8b	Mid-dense	Very sparse	2
12.2.8	8b	Mid-dense	Very sparse	2
12.5.6c	8b	Mid-dense	Very sparse	2
12.8.1	8b	Mid-dense	Very sparse	2
12.8.12	8b	Mid-dense	Very sparse	2
12.8.1a	8b	Mid-dense	Very sparse	2
12.9-10.14	8b	Mid-dense	Very sparse	2
12.9-10.14b	8b	Mid-dense	Very sparse	2
12.9-10.20	8b	Mid-dense	Very sparse	2
12.11.3	9a	Mid-dense	Very sparse	2
12.11.3a	9a	Mid-dense	Very sparse	2
12.12.15	9a	Mid-dense	Very sparse	2
12.5.6	9a	Mid-dense	Very sparse	2
12.5.6b	9a	Mid-dense	Very sparse	2
12.8.8a	9a	Mid-dense	Very sparse	2

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.9-10.17	9a	Mid-dense	Very sparse	2
12.9-10.17d	9a	Mid-dense	Very sparse	2
12.9-10.17e	9a	Mid-dense	Very sparse	2
11.5.8a	9b	Mid-dense	Very sparse	2
12.11.20	9c	Mid-dense	Very sparse	2
12.2.11	9f	Mid-dense	Very sparse	2
12.2.5	9f	Mid-dense	Very sparse	2
12.3.14a	9g	Mid-dense	Very sparse	2
12.11.5a	9g	Mid-dense	Very sparse	2
12.11.5j	9g	Mid-dense	Very sparse	2
12.5.12	9g	Mid-dense	Very sparse	2
12.8.25	9g	Mid-dense	Very sparse	2
12.9-10.12	9g	Mid-dense	Very sparse	2
12.9-10.12a	9g	Mid-dense	Very sparse	2
12.9-10.17c	9g	Mid-dense	Very sparse	2
12.9-10.4	9g	Mid-dense	Very sparse	2
12.2.6	9g	Mid-dense	Very sparse	2
12.5.2	9g	Mid-dense	Very sparse	2
12.5.2a	9g	Mid-dense	Very sparse	2
12.5.2b	9g	Mid-dense	Very sparse	2
12.5.3	9g	Mid-dense	Very sparse	2
12.5.3a	9g	Mid-dense	Very sparse	2
12.5.4	9g	Mid-dense	Very sparse	2
12.5.5	9g	Mid-dense	Very sparse	2
12.5.8	9g	Mid-dense	Very sparse	2
12.11.9	9g	Mid-dense	Very sparse	2
12.12.12	9g	Mid-dense	Very sparse	2
12.12.14	9g	Mid-dense	Very sparse	2
12.12.23	9g	Mid-dense	Very sparse	2
12.11.22	9h	Mid-dense	Very sparse	2
12.11.5h	9h	Mid-dense	Very sparse	2
12.8.20	9h	Mid-dense	Very sparse	2
12.8.26	9h	Mid-dense	Very sparse	2
12.9-10.18	9h	Mid-dense	Very sparse	2
12.9-10.18a	9h	Mid-dense	Very sparse	2
12.9-10.18b	9h	Mid-dense	Very sparse	2
12.9-10.21	9h	Mid-dense	Very sparse	2
12.9-10.5	9h	Mid-dense	Very sparse	2
12.9-10.5a	9h	Mid-dense	Very sparse	2
12.9-10.5d	9h	Mid-dense	Very sparse	2
12.5.1c	9h	Mid-dense	Very sparse	2
11.12.5	9h	Mid-dense	Very sparse	2
12.11.15	9h	Mid-dense	Very sparse	2
12.11.17	9h	Mid-dense	Very sparse	2

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.11.19	9h	Mid-dense	Very sparse	2
12.11.21	9h	Mid-dense	Very sparse	2
12.12.11	9h	Mid-dense	Very sparse	2
12.12.21	9h	Mid-dense	Very sparse	2
12.12.22	9h	Mid-dense	Very sparse	2
12.12.24	9h	Mid-dense	Very sparse	2
12.12.25	9h	Mid-dense	Very sparse	2
12.12.27	9h	Mid-dense	Very sparse	2
12.5.1e	9h	Mid-dense	Very sparse	2
11.10.1	10a	Sparse	Very sparse	1
11.11.3	10a	Sparse	Very sparse	1
11.11.4a	10a	Sparse	Very sparse	1
11.12.6	10a	Sparse	Very sparse	1
11.12.6a	10a	Sparse	Very sparse	1
11.5.9d	10a	Sparse	Very sparse	1
11.7.6	10a	Sparse	Very sparse	1
12.11.5	10b	Sparse	Very sparse	1
12.11.5e	10b	Sparse	Very sparse	1
12.11.5k	10b	Sparse	Very sparse	1
12.11.6	10b	Sparse	Very sparse	1
12.12.3	10b	Sparse	Very sparse	1
12.12.5	10b	Sparse	Very sparse	1
12.5.1	10b	Sparse	Very sparse	1
12.5.7	10b	Sparse	Very sparse	1
12.5.7a	10b	Sparse	Very sparse	1
12.8.24	10b	Sparse	Very sparse	1
12.9-10.17b	10b	Sparse	Very sparse	1
12.9-10.19a	10b	Sparse	Very sparse	1
12.9-10.2	10b	Sparse	Very sparse	1
11.8.2a	11a	Mid-dense	Very Sparse	2
11.8.4	11a	Mid-dense	Very Sparse	2
11.8.5	11a	Mid-dense	Very Sparse	2
11.8.5a	11a	Mid-dense	Very Sparse	2
11.8.8	11a	Mid-dense	Very Sparse	2
12.8.16	11a	Mid-dense	Very Sparse	2
12.8.17	11a	Mid-dense	Very Sparse	2
12.8.14	11a	Mid-dense	Very sparse	2
11.10.13	12a	Very sparse	Very sparse	1
11.10.4	12a	Very sparse	Very sparse	1
11.10.7	12a	Very sparse	Very sparse	1
11.7.4	12a	Very sparse	Very sparse	1
11.7.4c	12a	Very sparse	Very sparse	1
11.7.7	12a	Very sparse	Very sparse	1
12.5.1a	12a	Very sparse	Very sparse	1

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.5.1b	12a	Very sparse	Very sparse	1
12.7.1	12a	Very sparse	Very sparse	1
12.7.2	12a	Very sparse	Very sparse	1
12.9-10.13	12a	Very sparse	Very sparse	1
12.9-10.19	12a	Very sparse	Very sparse	1
12.9-10.5b	12a	Very sparse	Very sparse	1
12.9-10.5c	12a	Very sparse	Very sparse	1
12.9-10.7a	12a	Very sparse	Very sparse	1
12.9-10.9	12a	Very sparse	Very sparse	1
12.9-10.23	12a	Very sparse	Very sparse	1
12.9-10.24	12a	Very sparse	Very sparse	1
12.12.9	12a	Very sparse	Very sparse	1
11.11.1	13c	Dense/closed	Very sparse	3
11.11.15	13c	Dense/closed	Very sparse	3
11.11.15a	13c	Dense/closed	Very sparse	3
11.11.4	13c	Dense/closed	Very sparse	3
11.11.4b	13c	Dense/closed	Very sparse	3
11.12.1	13c	Dense/closed	Very sparse	3
11.12.3	13c	Dense/closed	Very sparse	3
11.9.9	13c	Dense/closed	Very sparse	3
12.11.14	13c	Dense/closed	Very sparse	3
12.11.7	13c	Dense/closed	Very sparse	3
12.12.7	13c	Dense/closed	Very sparse	3
12.9-10.7	13c	Dense/closed	Very sparse	3
11.11.10a	13d	Mid-dense	Very sparse	2
11.11.3c	13d	Mid-dense	Very sparse	2
11.11.4c	13d	Mid-dense	Very sparse	2
11.12.2b	13d	Mid-dense	Very sparse	2
11.3.26	13d	Mid-dense	Very sparse	2
11.5.20	13d	Mid-dense	Very sparse	2
11.9.13	13d	Mid-dense	Very sparse	2
12.11.18	13d	Mid-dense	Very sparse	2
12.11.18a	13d	Mid-dense	Very sparse	2
12.12.28	13d	Mid-dense	Very sparse	2
12.12.28x1	13d	Mid-dense	Very sparse	2
12.3.3b	13d	Mid-dense	Very sparse	2
12.3.3d	13d	Mid-dense	Very sparse	2
12.9-10.3	13d	Mid-dense	Very sparse	2
12.8.14a	13d	Mid-dense	Very sparse	2
11.3.23	15b	Sparse	Very sparse	1
11.3.25	16a	Mid-dense	Very sparse	2
12.3.7	16a	Mid-dense	Very sparse	2
11.3.4	16c	Mid-dense	Very sparse	2
12.3.11	16c	Mid-dense	Very sparse	2

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
12.3.11a	16c	Mid-dense	Very sparse	2
12.3.3	16c	Mid-dense	Very sparse	2
12.3.9	16c	Mid-dense	Very sparse	2
12.3.7b	16d	Very sparse	Very sparse	1
11.11.9	17a	Mid-dense	Very sparse	2
11.12.17	17a	Mid-dense	Very sparse	2
11.3.2	17a	Mid-dense	Very sparse	2
11.9.7	17a	Mid-dense	Very sparse	2
12.12.26a	17a	Mid-dense	Very sparse	2
12.3.10	17a	Mid-dense	Very sparse	2
11.11.10	17b	Mid-dense	Very sparse	2
11.12.2	17b	Mid-dense	Very sparse	2
11.3.6	17b	Mid-dense	Very sparse	2
11.9.2	17b	Mid-dense	Very sparse	2
12.11.8	17b	Mid-dense	Very sparse	2
12.12.8	17b	Mid-dense	Very sparse	2
12.9-10.8	17b	Mid-dense	Very sparse	2
11.3.29	18b	Mid-dense	Very sparse	2
11.5.1	18b	Mid-dense	Very sparse	2
11.5.2	18b	Mid-dense	Very sparse	2
11.5.4	18b	Mid-dense	Very sparse	2
12.3.3a	18b	Mid-dense	Very sparse	2
11.12.6b	20a	Sparse	Very sparse	1
11.10.9	20a	Sparse	Very sparse	1
12.3.12	21a	Mid-dense	Very sparse	2
12.5.4a	21a	Mid-dense	Very sparse	2
12.3.3c	21b	Sparse	Very sparse	1
12.5.9a	21b	Sparse	Very sparse	1
12.9-10.11	21b	Sparse	Very sparse	1
12.9-10.11a	21b	Sparse	Very sparse	1
12.2.7	22a	Mid-dense	Very sparse	2
12.2.7a	22a	Mid-dense	Very sparse	2
12.2.7c	22a	Mid-dense	Very sparse	2
12.3.4	22a	Mid-dense	Very sparse	2
12.3.4a	22a	Mid-dense	Very sparse	2
12.3.5	22a	Mid-dense	Very sparse	2
12.3.5a	22a	Mid-dense	Very sparse	2
12.3.6	22a	Mid-dense	Very sparse	2
12.3.7a	22c	Mid-dense	Very sparse	2
11.5.2a	24a	Very sparse	Very sparse	1
11.7.2	24a	Very sparse	Very sparse	1
11.11.14	25a	Sparse	Very sparse	1
11.12.21	25a	Sparse	Very sparse	1
11.3.1	25a	Sparse	Very sparse	1

Regional Ecosystem	BVG(1M) Identifier	Ground cover Density	Lower Shrub Cover Density	Low Undergrowth Density Category
11.3.17	25a	Sparse	Very sparse	1
11.4.3	25a	Sparse	Very sparse	1
11.9.10	25a	Sparse	Very sparse	1
11.9.5	25a	Sparse	Very sparse	1
11.9.5a	25a	Sparse	Very sparse	1
12.12.26	25a	Sparse	Very sparse	1
12.3.10a	25a	Sparse	Very sparse	1
12.8.23	25a	Sparse	Very sparse	1
12.9-10.6	25a	Sparse	Very sparse	1
11.12.15	27c	Sparse	Very sparse	1
12.1.1	28a	Mid-dense	Very sparse	2
12.2.14	28a	Mid-dense	Very sparse	2
12.2.16	28d	Very sparse	Very sparse	1
12.9-10.17a	28e	Mid-dense	Very sparse	2
12.3.15	28e	Mid-dense	Very sparse	2
11.12.14	28e	Very sparse	Very sparse	1
12.12.19	29a	Sparse	Sparse	2
12.12.19x2	29a	Sparse	Sparse	2
12.12.19x3	29a	Sparse	Sparse	2
12.2.10	29a	Sparse	Sparse	2
12.2.12	29a	Sparse	Sparse	2
12.2.13	29a	Sparse	Sparse	2
12.2.9	29a	Sparse	Sparse	2
12.3.13	29a	Sparse	Sparse	2
12.3.14	29a	Sparse	Sparse	2
12.5.10	29a	Sparse	Sparse	2
12.5.9	29a	Sparse	Sparse	2
11.12.18a	29b	Sparse	Sparse	2
11.7.5	29b	Sparse	Sparse	2
11.7.5a	29b	Sparse	Sparse	2
12.12.10	29b	Sparse	Sparse	2
12.8.19	29b	Sparse	Sparse	2
11.3.21	30a	Mid-Dense	Very sparse	2
11.3.24	30a	Mid-Dense	Very sparse	2
11.8.11	30b	Mid-Dense	Very sparse	2
12.8.15	32b	Mid-dense	Very sparse	2
11.5.17	34b	Sparse	Very sparse	1
12.2.15	34c	Dense/closed	Very sparse	3
12.3.8	34c	Dense/closed	Very sparse	3
12.9-10.22	34f	Dense/closed	Dense/closed	3

Appendix E: Metadata Extracts

Appendix E: Metadata Extracts

Metadata Extract: Biodiversity status of pre-clearing and remnant regional ecosystems - version 9.0 - 2013 - South East Qld

Identification

Title: Biodiversity status of pre-clearing and remnant regional ecosystems - version 9.0 - 2013 - South East Qld.

Alternative title: DP_VegVSE_DCDB_A.zip.

Date: 2015-05-08 (publication).

Presentation form code: mapDigital.

Description

The pre-clearing mapping is based on aerial photography and field survey of vegetation communities. Regional ecosystem linework reproduced at a scale greater than 1:100,000, except in designated areas, should be used as a guide only. The positional accuracy of RE data, mapped at a scale of 1:100,000, is 100 metres. The map scale of 1:50,000 applies to the Wet Tropics and part of Southeastern Queensland and map amendments areas.

The remnant extent is based on mapping derived from the standard state-wide coverage of dry season (around September) Landsat imagery

Purpose

Pre-clearing regional ecosystems mapping at a map scale of 1:100,000 and 1:50,000 in part, based on surveys of vegetation communities and related landform, soils and geology and on 1:80,000 B&W 1960's aerial photography. Version 9.0 regional ecosystem descriptions, as originally described in Sattler & Williams (ed.) (1999) are available for download on the Queensland government website (search on: Regional Ecosystem Description Database). The survey and mapping of regional ecosystems of Queensland provides information for regional groups, non-government organisations, government departments, local government and industry, for planning and management purposes. (Dataset for Queensland incomplete).

Spatial Data Information

Spatial representation type: vector

Coordinate Reference System EPSG code: EPSG: 4283

Contacts

Organisation: Department of Science, Information Technology and Innovation

Status

Progress status: completed

Maintenance and update frequency: irregular

Data / Resource Constraints

Resource Access Level: -->

Security classification (ISO 19115): unclassified

Use limitation: Public

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Temporal and Spatial extents:

Bounding box: West bounding longitude: 148.81308, East bounding longitude: 153.577908, South bounding latitude: -29.17956, North bounding latitude: -23.184751.

Temporal extent:

Start: 2012-09-26 End: 2012-09-26

Data Quality

Completeness (omission): Pre-clearing and remnant regional ecosystem mapping over the majority of Queensland is produced at a scale of 1:100,000. At this scale, the minimum remnant polygon area is 5 hectares or minimum remnant width of 75 metres. For the Wet Tropics and part of South-eastern Queensland, the mapping is produced at a scale of 1:50,000 allows a 1 hectare minimum remnant area and a 35 metre width limit.

Consistency (conceptual): Logical consistency has been determined through the following: All polygons visually checked at 1:100,000 scale and by topological consistency checks. A test of consistency for regional ecosystem unit values (RE and PERCENT) between the pre-clearing and remnant coverages.

Positional accuracy (external, absolute): Polygons 100m; Sites +/- 10m. Positional accuracy of polygons is noted in the field 'L', which is a reliability code and given as either A, B or C for high, moderate and low confidence in accuracy of polygon boundaries. The level is determined on the basis of the reliability of interpretation of photopattern /reflectance of remotely sensed data (aerial photographs and rectified Landsat TM imagery) and on the positioning and frequency of sites and traverses.

Reliability code is contained in the field 'V' which refer to vegetation attributes - RE (regional ecosystem) and PERCENT accuracy and given as either A, B or C for high, moderate and low confidence in accuracy of polygon attributes.

Attribute accuracy (non quantitative): Reliability code is contained in the field 'V' which refer to vegetation attributes - RE (regional ecosystem) and PERCENT accuracy and given as either A, B or C for high, moderate and low confidence in accuracy of polygon attributes.

History:

Lineage statement: Related polygon coverages include: pre-clearing vegetation communities and regional ecosystems, 1997, 1999, 2000, 2001, 2003, 2005, 2006, 2006b, 2007, , 2011 remnant regional ecosystems and, for areas where regional ecosystem coverages have not been completed, a separate polygon layer, remnant vegetation cover (e.g.: remcov11).

Process step: The pre-clearing vegetation is simply the vegetation before clearing. Mapping of pre-clearing vegetation is based on the interpretation of landscape as depicted on aerial photos or satellite imagery (Landsat, Spot), and ground truthed on a limited sample of known points. The Queensland Herbarium uses the 1:80,000 black and white 1960's photos as the standard imagery for mapping pre-clearing vegetation. The structural classification system is based on Walker and Hopkins (1990). Where vegetation has already been cleared on these aerial photographs, the pre-clearing vegetation is reconstructed by the botanist using available information, including landform, soils, geology, field data (remnant roadside trees) and ecological knowledge. In addition, historical survey records of vegetation types and older aerial photos (if they exist) are used extensively in this reconstruction. The 2011 extent is based on the 2011 extent mapping that was derived from the standard state-wide coverage of dry season (around September) 2011. Technical processes: Vegetation boundaries are drawn on aerial photographs and manually digitised. Boundaries are referenced primarily to rectified Landsat imagery supplied by the State Land and Trees Study (SLATS, DSITIA) and to orthophotos if available. Field survey provided partial verification of boundaries. Pre-clearing vegetation is delineated using above resource material. Remnant vegetation boundaries derived by intersecting the 'vegetation cover' with the pre-clear coverage and altering attributes to reflect the remaining vegetation components of each polygon. The vegetation cover data is generated from Landsat imagery, using change detection data &/or Foliage Protection Cover (woody cover) from SLATS, DSITIA, as additional indicators of remnant, cleared or disturbed areas.

Source: General Source Data: 1:80,000 B&W 1960's aerial photography, Landsat TM imagery rectified to 1:100,000 topographic maps, geology, soils and land systems data, topographic maps, field survey, existing field site data and existing mapped data (digital and hard-copy). Other reference data: National Estates (QLD), DCDB. Primary data source for the Wet Tropics bioregion 1:50,000 scale regional ecosystem mapping: • Vegetation of the Wet Tropics of Queensland bioregion. Wet Tropics Management Authority, Cairns, Stanton J.P. and Stanton, D.J. (2005). Additional Source Data for SEQ 1:50,000 scale mapping: 1:100,000 scale geological mapping NR&M (2002) and extensive field data for all revisions. • Ipswich, Mt Lindesay, Esk & Helidon sheets revised (2000-2001) using 1:25,000 colour aerial photography (1994-1997). • Gatton Shire revision using 1:25,000 colour aerial photography (1997) and Gatton Shire Remnant vegetation mapping, QPWS, Grimshaw (2001). • Crows Nest Shire revision using 1:25,000 colour aerial photography (2000). • Boonah Shire revision using 1:25,000 vegetation survey, Olsen (2001). • Laidley Shire revision using 1:25,000 colour aerial photography (1997) and 1:50,000 vegetation survey, Lockyer Landcare (1997). • Noosa Shire revision using 1:25,000 colour aerial photography (1997 & 2000) and Noosa Shire 1:25,000 vegetation survey, Burrows (2000). • Pine Rivers Shire revision using 1:25,000 colour aerial photography (1997), Pine Rivers Shire regional ecosystem database (2001) and the Brisbane Forest Park, 1:25,000 vegetation survey, Young (1996). • Logan City revision using 1:25,000 Logan City vegetation survey, Ecograph (2000). • Redland Shire revision using 1:25,000 Redland Shire vegetation survey, Olsen (2001). • Gold Coast City Council revision using 1:10,000 digital ortho-photography (2001) and QPWS Fire Management Strategy (2001). • Beaudesert Shire revision using 1:25,000 colour aerial photography (1997) and Beaudesert Shire vegetation survey, Chenoweth EPLA (2002) and QPWS Fire Management Strategy (2001). • Cooloola Shire revision using 1:40,000 colour aerial photography (1996) and Cooloola Shire vegetation survey, Lowe (2002). • Maroochy Shire revision using 1:25,000 colour aerial photography (1997) and

Maroochy Shire vegetation survey, MSC (2002). • Caloundra City Council revision using 1:25,000 colour aerial photography (1997).

Metadata Extract: Wooded extent and foliage projective cover - Queensland 2013

Identification

Title: Wooded extent and foliage projective cover - Queensland 2013

Alternative title: DP_QLD_FPC2013_WOODED_VEG.zip

Date: 2015-01-23 (publication)

Description

Foliage Projective Cover (FPC) is the percentage of ground area occupied by the vertical projection of foliage. The Remote Sensing Centre FPC mapping is based on an automated decision tree classification technique applied to dry season (May to October) Landsat-5 TM, Landsat-7 ETM+ and Landsat-8 OLI imagery for the period 1988-2013. The wooded extent product has a nominal accuracy of 85%. The field data used to calibrate the imagery/FPC relationship was mostly collected over the period 1996-1999. Corrections have been applied to remove errors due to topographic effects, cloud, cloud shadow, water, cropping, and regrowth following clearing. Some errors may remain. The product was generated from WRS-2 path/row scenes obtained from the United States Geological Survey (USGS). While some land cover change may be detected in the FPC processing, this product is not designed to generate clearing or regrowth following clearing layers, and should not be used to assess clearing or be compared with previous years for change monitoring. The Statewide Landcover and Trees Study (SLATS) produces accurate clearing layers for this purpose.

Additional Information:

FPC is the percentage of ground area occupied by the vertical projection of foliage. Image value = FPC + 100 (i.e. FPC of 5% = image value of 105). The pixel values in the QLD_FPC_WOODED_VEGETATION_X data set represent the predicted FPC values. Range is 100-200 which is equivalent to 0-100% FPC. Values erroneously predicted above 100% or below 0% have been classed as 200 and 100 respectively. Zero values indicate null data. A number of datasets have been used to mask out certain features from the FPC dataset:

- Cropping and plantation areas have been masked using the 1999 Queensland Land Use Mapping Program (QLUMP) dataset (http://www.derm.qld.gov.au/science/lump/).

- A Landsat-derived water index was used to mask water bodies from each individual FPC image (Danaher and Collett 2006). An additional mask is applied for areas with persistent inundation based on multi-temporal analysis of the water index.
- A topographic correction based on the 1 second SRTM derived Digital Surface Model, Version 1.0, was applied to misclassified steep east-facing slopes. The SRTM data consisted of a DEM and slope layer as processed by Geosciences Australia.

Spatial Data Information

Spatial representation type: grid

Projection: EPSG:3577

Horizontal Datum: GDA94

Spatial resolution: Ground sample distance: *30 (meters)*

Contacts

Organisation: Department of Science, Information Technology and Innovation

Status

Progress status: ongoing

Maintenance and update frequency: annually

Data / Resource Constraints

Resource Access Level: -->

Security classification (ISO 19115): unclassified

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Temporal and Spatial extents:

Bounding box: West bounding longitude: 137.372, East bounding longitude: 154.419, South bounding latitude: -29.346, North bounding latitude: -8.967.

Temporal extent:

Start: 1988-01-01 End: 2013-12-31

Data Quality

Completeness (omission): Areas of deep shadow on the south-eastern sides of land of high relief were unclassified. Some offshore islands including Torres Strait islands have not been included.

Positional accuracy (external, absolute): All the data described here has been generated from the analysis of Landsat Thematic Mapper (TM) data, which has a resampled spatial resolution of 25m. The imagery is rectified using control points measured with a differential GPS ensuring a maximum root mean square (RMS) error of 20 metres at these control points. However, it is possible that errors up to ±50 meters occur between these control points. The imagery has been corrected for height displacement using a digital elevation model (DEM) from the Shuttle Radar. It is not recommended that these data sets be used at scales more detailed than 1:100,000.

Attribute accuracy (non quantitative): The final wooded extent classification model had a Kappa statistic of 85.12%. Comparison of overstorey FPC estimates with independent field estimates of perennial FPC acquired for a range of vegetation types over Queensland, show very good agreement (r2=0.84). Further independent quantitative validation of the final FPC product showed good agreement with field sites (r2 0.78) and lidar data (r2 0.93) estimates of FPC (Kitchen et al., 2010).

History:

Lineage statement: Armston, J.D., Denham, R.J., Danaher, T.J., Scarth, P.F. and Moffiet, T., 2008, Prediction and validation of foliage projective cover from Landsat-5 TM and Landsat-7 ETM+ imagery for Queensland, Australia. Journal of Applied Remote Sensing, 3: 033540-28.

Kitchen, J., Armston, J., Clark, A., Danaher, T., and Scarth, P., 2010, Operational use of annual Landsat-5 TM and Landsat-7 ETM+ image time-series for mapping wooded extent and foliage projective cover in north-eastern Australia. Proceedings of the 15th Australasian Remote Sensing and Photogrammetry Conference, Alice Springs, Australia, 13 -17 September 2010.

Metadata Extract: Soil and Landscape Grid National Soil Attribute Maps - Soil Depth (3" resolution) - Release 1

Data Collection Description:

This is Version 1 of the Soil Depth product of the Soil and Landscape Grid of Australia. The Soil and Landscape Grid of Australia has produced a range of digital soil attribute products. This depth product estimates the depth of soil down to 2 metres. The digital soil attribute maps are in raster format at a resolution of 3 arc sec (~90 x 90 m pixels). The soil attribute products are provided as continuous maps that represent each of six depth intervals to a maximum depth of 2 metres. We acknowledge that soil depth is variable across Australia, and in some landscapes there might be no soil or soil might be shallower than 2 metres. We have provided continuous maps because of the relative unavailability of data on soil depth. Further, existing data on depth is biased to near surface layers and there are few records that extend beyond 1.5m. Therefore, we provide here, our best estimate of soil depth to allow users to generate masks, which might be used together with the attribute maps to approximate the presence of areas with no soil or areas with shallow soil. We encourage users to draw on local data and expertise for such assessments. Attribute Definition: Depth of soil profile (A & B horizons); Units: metres; Period (temporal coverage; approximately): 1950-2013; Spatial resolution: 3 arc seconds (approx 90m); Total number of gridded maps for this attribute: 3; Number of pixels with coverage per layer: 2007M (49200 * 40800); Total size before compression: about 8GB; Total size after compression: about 4GB;

Data license:

Creative Commons Attribution 3.0 (CC By);

Target data standard:

GlobalSoilMap specifications;

Format:

GeoTIFF.

Data Start Date:

01 Jan 1950

Data End Date:

31 Dec 2013

Contact:

CSIRO Enquiries
enquiries@csiro.au
1300 363 400

Lineage:

The National Soil Attribute Maps are generated by combining the best available digital soil mapping to calculate a variance weighted mean for each pixel. For this soil attribute the Australia-wide three-dimensional Digital Soil Property Maps are the only maps available. Thus the modelling for this soil attribute only used Decision trees with piecewise linear models with kriging of residuals developed from soil site data across Australia. (Viscarra Rossel et al., 2015a).

Credit:

Development of and access to the data has been made possible by CSIRO, and the Terrestrial Ecosystem Research Network (TERN), with support from the Australian Government through the National Collaborative Research Infrastructure Strategy and the Super Science Initiative, and with agreement from the custodians of the soil site data of each state and territory. All of the organisations listed as collaborating agencies have contributed significantly to the project and the final products.

Licence:

Creative Commons Attribution Licence

Organisations:

CSIRO Australia, Geoscience Australia, NSW Office of Environment and Heritage, Northern Territory Department of Land Resource Management, Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA), South Australia Department of Environment, Water and Natural Resources, Tasmania Department Primary Industries, Parks, Water and Environment, University of Sydney, Victoria Department of Environment and Primary Industries, Western Australia Department of Agriculture and Food

Attribution Statement:

Raphael Viscarra Rossel; Charlie Chen; Mike Grundy; Ross Searle; David Clifford; Nathan Odgers; et al. (2014): Soil and Landscape Grid National Soil Attribute Maps - Soil Depth (3" resolution) - Release 1. v2. CSIRO. Data Collection. 10.4225/08/546F540FE10AA

Rights Statement:

All Rights (including copyright) CSIRO Australia 2014.

Access:

The metadata and data are available to the public.

Metadata Extract: Queensland Bioclimatic Parameter (BIOCLIM) Surfaces

Abstract

These raster datasets comprise 27 bioclimatic parameters for Queensland derived using the Anuclim/Bioclim program Version 5.1. Each of the bioclimatic parameters relates to one of the following climatic variables: temperature, rainfall, and radiation. All the bioclimatic parameters have been interpolated from surface coefficient files, which have been produced from irregular networks of actual meteorological variables. The bioclimatic paramenters listed below weredeveloped running Anuclim/Bioclim using a weekly time step:

1. Annual Mean Temperature. The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.
2. Mean Diurnal Range (Mean (period max-min)). The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.
3. Isothermality 2/7. The mean diurnal range (parameter 2) divided by the Annual Temperature Range (parameter 7).
4. Temperature Seasonality (C of V) The temperature Coefficient of Variation (C of V) is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in degrees Kelvin is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small.
5. Max Temperature of Warmest Period. The highest temperature of any weekly maximum temperature.
6. Min Temperature of Coldest Period. The lowest temperature of any weekly minimum temperature.
7. Temperature Annual Range (5-6). The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period.
8. Mean Temperature of Wettest Quarter. The wettest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
9. Mean Temperature of Driest Quarter. The driest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

10. Mean Temperature of Warmest Quarter. The warmest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

11. Mean Temperature of Coldest Quarter. The coldest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.

12. Annual Precipitation. The sum of all the monthly precipitation estimates.

13. Precipitation of Wettest Period. The precipitation of the wettest week or month, depending on the time step.

14. Precipitation of Driest Period. The precipitation of the driest week or month, depending on the time step.

15. Precipitation Seasonality(C of V). The Coefficient of Variation (C of V) is the standard deviation of the weekly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).

16. Precipitation of Wettest Quarter. The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

17. Precipitation of Driest Quarter. The driest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

18. Precipitation of Warmest Quarter. The warmest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

19. Precipitation of Coldest Quarter. The coldest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.

20. Annual Mean Radiation. The mean of all the weekly radiation estimates.

21. Highest Period Radiation. The largest radiation estimate for all weeks.

22. Lowest Period Radiation. The lowest radiation estimate for all weeks.

23. Radiation Seasonality (C of V). The Coefficient of Variation (C of V) is the standard deviation of the weekly radiation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).

24. Radiation of Wettest Quarter. The wettest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.

25. Radiation of Driest Quarter. The driest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.

26. Radiation of Warmest Quarter. The warmest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.

27. Radiation of Coldest Quarter. The coldest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.

Spatial Domain: Geographic Extent Name: Queensland

Data Currency:

Beginning Date: Not Known

Ending Date: Current

Jurisdiction: Queensland

Dataset Status

Progress: Complete

Maintenance and Update Frequency: These raster datasets were derived using the Anuclim/Bioclim program Version 5.1. With the release of new version Anuclim/Bioclim the data will be derived with the current version.

Spatial Reference

Datum: GDA94

Projection: Geographics

Spheroid: GRS1980

Stored Data Format: Digital Arc/Info

Available Format Type: Digital Arc/Info Export;

Access Constraints

The conditions of use are detailed in the data usage agreement, signed between the Custodian and the Recipient. No third party usage is permitted other than indicated in the agreement.

Lineage

The Anuclim/Bioclim software requires the input of a Digital Elevation Model for the area of interest. The Queensland GEODATA 9 SECOND DEM VERSION 2 (Code: ANZQL0132000766; Id: 17526) was used to build all bioclimatic parameter files. Anuclim/Bioclim produces a standard set of 35 bioclimatic parameters, however 8 of these are related to a moisture index that requires input of maximum available soil water and soil type. This data was not available Queensland wide and the moisture index related bioclimatic parameters were not calculated. The result of running Bioclim with the QLD 9 second DEM produced the following ArcInfo Grids:

1. qld_1_amt Annual Mean Temperature

2. qld_2_mdr Mean Diurnal Range(Mean(period max-min))
3. qld_3_iso Isothermality 2/7
4. qld_4_ts Temperature Seasonality (C of V)
5. qld_5_mtwp Max Temperature of Warmest Period
6. qld_6_mtcp Min Temperature of Coldest Period
7. qld_7_tar Temperature Annual Range (5-6)
8. qld_8_mtwq Mean Temperature of Wettest Quarter
9. qld_9_mtdq Mean Temperature of Driest Quarter
10. qld_10_mtwq Mean Temperature of Warmest Quarter
11. qld_11_mtcq Mean Temperature of Coldest Quarter
12. qld_12_ap Annual Precipitation
13. qld_13_pwp Precipitation of Wettest Period
14. qld_14_pdp Precipitation of Driest Period
15. qld_15_ps Precipitation Seasonality(C of V)
16. qld_16_pwq Precipitation of Wettest Quarter
17. qld_17_pdq Precipitation of Driest Quarter
18. qld_18_pwq Precipitation of Warmest Quarter
19. qld_19_pcq Precipitation of Coldest Quarter
20. qld_20_amr Annual Mean Radiation
21. qld_21_hpr Highest Period Radiation
22. qld_22_lpr Lowest Period Radiation
23. qld_23_rs Radiation Seasonality (Cof V)
24. qld_24_rwq Radiation of Wettest Quarter
25. qld_25_rdq Radiation of Driest Quarter
26. qld_26_rwq Radiation of Warmest Quarter
27. qld_27_rcq Radiation of Coldest Quarter

Attribute Accuracy

Attribute accuracy depends on the interpolation algorithm of Anuclim and the original meteorological source data.

Logical Consistency

Logical consistency depends on the accuracy of source data for the Digital Elevation Model used.

Completeness

Complete

Originator

Custodian: Department of Science, Information Technology and Innovation

Appendix F: Digital Data

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