Assessment of Bangalay Sand Forest TEC on NSW Crown Forest Estate

Survey, Classification and Mapping Completed for the NSW Environment Protection Authority

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1 Overview

Bangalay Sand Forest is a threatened ecological community (TEC) associated with coastal sand plains found in the Sydney Basin and South East Corner bioregions. The most common tree species are *Eucalyptus botryoides* (bangalay) and *Banksia integrifolia* (coast banksia). The understorey is characterised by a mix of sclerophyll and mesophyll species.

In this report, we focus on the distribution of this TEC in the NSW South Coast region, an area that extends from Sydney to the Victorian border. This study assesses whether Bangalay Sand Forest is located within the 350,000 hectares of state forest found in our southern study area.

Our interpretation of Bangalay Sand Forest (BASF) was informed by the six previously described vegetation communities cited in the final determination that were relevant to the South Coast region. Four are eucalypt-dominated forests and one a coastal scrub dominated by *Banksia integrifolia* and *Leptospermum* species. An additional community has a mixed canopy composition for which the final determination includes a qualifying statement to exclude stands dominated by Casuarina glauca.

Initially we examined existing maps of coastal sand landforms and geology along with available vegetation maps to determine the likely extent of habitats suitable to support the presence of the TEC within state forest. We reviewed candidate areas that were within or proximate to state forests using interpretation of high-resolution digital aerial imagery as a basis for planning field surveys. We identified a small number of areas in Termeil and East Boyd State Forests that were plausible locations for BASF and an additional two areas in Nullica and Mogo State Forests identified from existing vegetation mapping. Sites that had not already been subject to field survey were visited and were either systematically sampled or were rejected on site where the species composition and landform were clearly mapping inaccuracies (e.g. estuarine mudflat)

Our analyses of plot data assigned 66 plots (out of 8452) to Bangalay Sand Forest, based on allocation to a previously defined community cited in the final determination and agreed substrate qualifiers. We used plot data and a selection of environmental and remote-sensing variables to develop a Random Forest (RF) presence-absence model of the probability of occurrence of Bangalay Sand Forest across the study area. We used the RF model and the locations of plot data to further assess whether Bangalay Sand Forest occurred on state forest.

We found no evidence of Bangalay Sand Forest occurring on any state forest within our study area based on the results of our field surveys, analysis of plot data, review of existing map data and predictive models.

2 Introduction

2.1 Project rationale

This project was initiated by the NSW Environment Protection Authority (EPA) and Forestry Corporation of NSW (FCNSW) as a coordinated approach to resolve long-standing issues surrounding the identification, extent and location of priority NSW Threatened Ecological Communities (TECs) that occur on the NSW State Forest estate included within eastern Regional Forest Agreements.

2.2 Final determination

Bangalay Sand Forest of the Sydney Basin and South East Corner bioregions (BASF) was first gazetted as an Endangered Ecological Community on 21 October 2005.

Paragraph 4 of the final determination (NSW Scientific Committee 2011) provides an overview of the structure and floristic composition of BASF. It ‘typically has a dense to open tree canopy, approximately 5 - 20 metres tall, depending on exposure and disturbance history. The most common tree species include *Eucalyptus botryoides* (Bangalay) and *Banksia integrifolia* subsp. *integrifolia* (Coast Banksia), while *Eucalyptus pilularis* (Blackbutt) and *Acmena smithii* (Lilly Pilly) may occur in more sheltered situations. *Casuarina glauca* (Swamp Oak) may occur on dunes exposed to salt-bearing sea breezes or where Bangalay Sand Forest adjoins Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner bioregions, as listed under the *Threatened Species Conservation Act* (TSC ACT) 1995.’

Paragraph 6 of the final determination (NSW Scientific Committee 2011) cites several vegetation communities as included within the definition of the TEC including: 'Ecotonal Coastal Hind Dune Swamp Oak-Bangalay Shrub Forest' (ecosystem 27) excluding those stands that are dominated by *Casuarina glauca* and 'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000); 'Littoral Thicket' (map unit 63) and part of 'Coastal Sand Forest' (map unit 64) of Tindall et al. (2004); 'Coastal Sand Bangalay-Blackbutt Forest' (map unit 25) of NPWS (2002); and 'Dry Dune Shrub Forest' of Keith and Bedward (1999).

Paragraphs 7 and 8 of the final determination (NSW Scientific Committee 2011) refers to other Endangered Ecological Communities (Umina Sand Plain Woodland and Kurnell Dune Forest) which may adjoin or intergrade with BASF and states that these collectively cover all intergrades where they occur. However, both are not relevant to our study as they are located within the Southern Sydney and Central Coast areas only.

2.3 Initial TEC Reference Panel Interpretation

Under the TSC Act 1995, TECs are defined by two characteristics: an assemblage of species and a particular location. The TEC Panel agreed that the occurrence of BASF is constrained to the IBRA bioregions stated in the final determination. The panel agreed that BASF is a TEC that has been defined primarily from previous quantitative floristic analyses. Accordingly, the assemblage of species is interpreted by reference to vegetation communities which have been previously described from quantitative floristic analysis and which have been explicitly listed in the final determination. From the final determination, one of the defined assemblages are only partially included in BASF depending on dominant species. The panel noted that these qualifiers should be considered in assessing BASF. From the final determination for BASF, Table 1 summarises the key determining features of BASF and how they have been used in the assessment reported here, based on the interpretation of the features by the Panel. Numbers in the left-hand column refer to paragraph numbers in the final determination.

Table 1: Key features of Bangalay Sand Forest of potential diagnostic value.

	Feature	Diagnostic value and use for this assessment
1	NSW occurrences fall within Sydney Basin and South East Corner bioregions	Explicitly diagnostic. This assessment focuses on the region south of Sydney and as a result only the Sydney Basin (in part) and South East Corner bioregions are considered
1	Occurs on deep, freely draining to damp sandy soils on flat to moderate slopes within a few kilometres of the sea	Indicative and used to construct substrate maps to assist with identifying potential occurrence but 'a few kilometres' is not precisely defined
1	Found at altitudes below 100 m	Potentially diagnostic, not used
1, 4	Typically comprises a relatively dense or open tree canopy, an understorey of mesophyllous and/or sclerophyllous small trees and shrubs, and a variable groundcover dominated by sedges, grasses or ferns	Indicative, not used
1	Characterised by the listed 50 plant species	Potentially diagnostic, in the context of previously described communities cited in the determination in Paragraph 6
5	Currently known from parts of the Local Government Areas of Sutherland, Wollongong, Shellharbour, Kiama, Shoalhaven, Eurobodalla and Bega Valley	Indicative, not used
4	Typically has a dense to open tree canopy, approximately 5 - 20 m tall, depending on exposure and disturbance history. The most common tree species include Eucalyptus botryoides (Bangalay) and Banksia integrifolia subsp. integrifolia (Coast Banksia), while Eucalyptus pilularis (Blackbutt) and Acmena smithii (Lilly Pilly) may occur in more sheltered situations, and Casuarina glauca (Swamp Oak) may occur on dunes exposed to salt-bearing sea breezes or where Bangalay Sand Forest adjoins Swamp Oak Floodplain Forest	Potentially diagnostic, used to distinguish parts of communities not wholly included in BASF.
4	Description of understorey, listing 5 shrub species and 11 ground cover species and 5 vine species which may be present	Indicative, not used
7, 8	Description of differences in tree species composition and environmental differences from other TECs on coastal floodplains	Indicative, but used to distinguish areas which are floristically similar to two or more TECs
6	In the Sydney-South Coast region, this community includes 'Ecotonal Coastal Hind Dune Swamp Oak-Bangalay Shrub Forest' (ecosystem 27) excluding those stands that are dominated by *Casuarina glauca* and 'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000); 'Littoral Thicket' (map unit 63) and part of 'Coastal Sand Forest' (map unit 64) of Tindall et al. (2004); 'Coastal Sand Bangalay-Blackbutt Forest' (map unit 25) of NPWS (2002); and 'Dry Dune Shrub Forest' of Keith and Bedward (1999). Bangalay Sand Forest of the Sydney Basin and South East Corner bioregions is included within the 'South Coast Sands Dry Sclerophyll Forests' vegetation class of Keith (2002, 2004)	Used as the main comparative diagnostic feature, including explicit qualifications of individual communities relating to tree species composition. The panel noted that only 'part' of map unit 64 of Tindall et al. (2004) was included and no guidance is provided on which part. For the purposes of this project the panel included all of map unit 64 as conforming to the TEC

2.4 Assessment Area

2.4.1 Location and study area boundaries

Our South Coast study area is shown in Figure 1. This area includes all of the South East Corner bioregion, all IBRA subregions south from the Hawkesbury River in Sydney Basin bioregion, a five-kilometre wide perimeter zone on these areas, and areas below 250 metres elevation in river valleys in South East Highlands bioregion. We considered that this would include all vegetation relevant to any TEC likely to occur in state forests on the NSW South Coast, from Sydney down to the Victorian border. Within our South Coast study area, there are no lowland state forests north of Nowra and our assessment concentrated on the area south of Nowra. Figure 2 also illustrates the distribution of the primary substrate associated with this TEC.

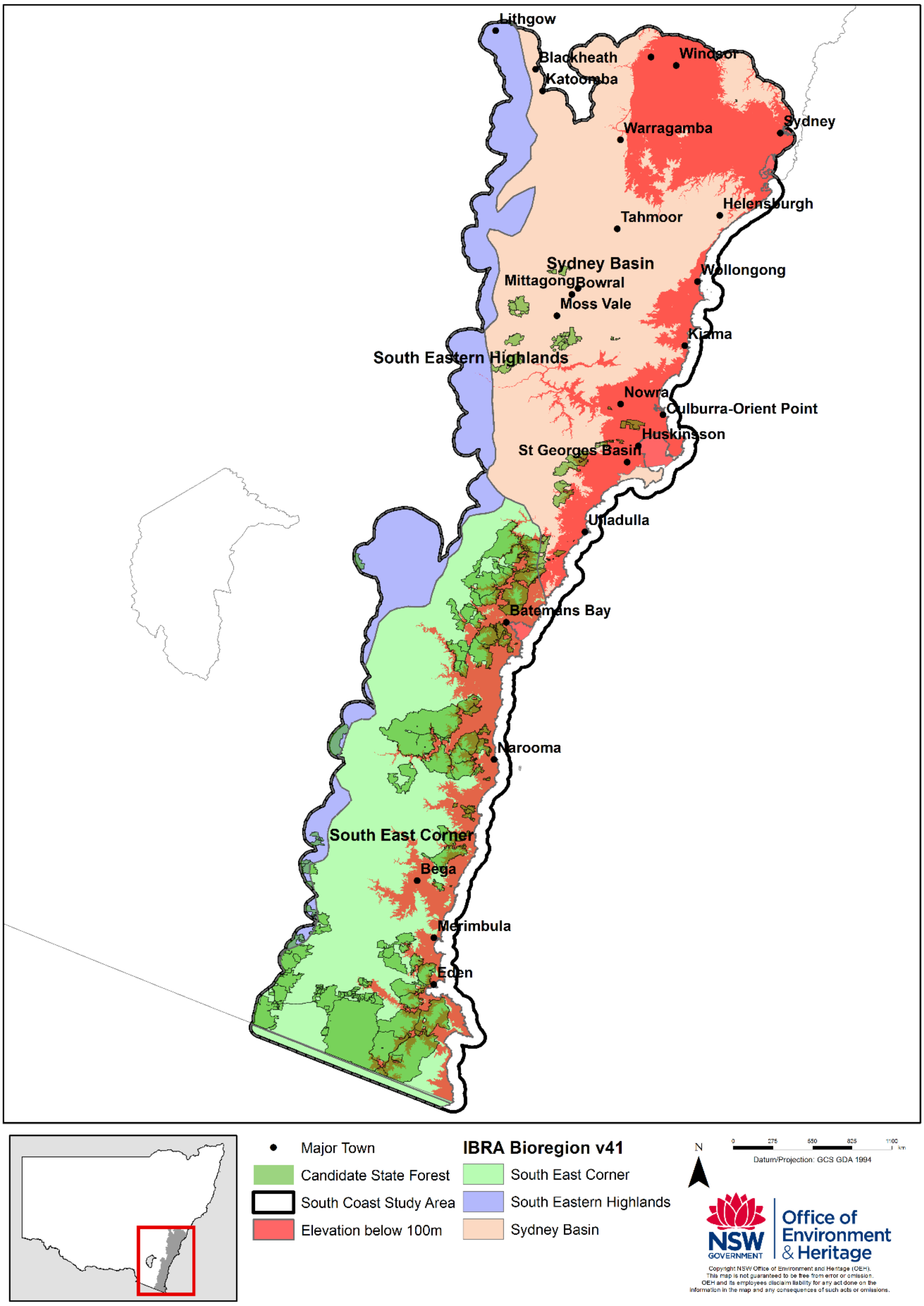

Figure 1: Assessment area showing bioregions and elevation thresholds (<100m) cited in the BASF final determination

2.4.2 State forests subject to assessment

The project study area includes Crown forest estate situated within Southern and Eden Integrated Forestry Operations Approval (IFOA) regions. A total of 61 state forests were included in this assessment (Table 2). State forests excluded from the assessment include those areas defined as Forest Management Zones 5 (Hardwood Plantations) and Zone 6 (Softwood Plantations). Small areas of native forest wholly enclosed or adjoining Forest Management Zone 6 (Softwoods) are also excluded from the assessment as they are considered to be outside of the authority of the IFOA.

Table 2: List of candidate state forests assessed for Bangalay Sand Forest.

State Forest	Area (Ha)	State Forest	Area (Ha)
Badja State Forest	4839	Moruya State Forest	4059
Bateman State Forest	1	Mumbulla State Forest	6137
Belanglo State Forest	3891	Murrah State Forest	4215
Benandarah State Forest	2761	Nadgee State Forest	20537
Bermagui State Forest	1861	Nalbaugh State Forest	4396
Bodalla State Forest	24079	Newnes State Forest	281
Bolaro State Forest	1779	North Brooman State Forest	3631
Bombala State Forest	620	Nowra State Forest	521
Bondi State Forest	12742	Nullica State Forest	18298
Boyne State Forest	6161	Nungatta State Forest	887
Broadwater State Forest	167	Penrose State Forest	1986
Bruces Creek State Forest	791	Shallow Crossing State Forest	3855
Buckenbowra State Forest	5193	Shoalhaven State Forest	104
Cathcart State Forest	1735	South Brooman State Forest	5587
Clyde State Forest	3587	Tallaganda State Forest	1363
Coolangubra State Forest	8489	Tanja State Forest	867
Corunna State Forest	183	Tantawangalo State Forest	2466
Currambene State Forest	1695	Termeil State Forest	698
Currowan State Forest	11977	Timbillica State Forest	9144
Dampier State Forest	33746	Tomerong State Forest	212
East Boyd State Forest	21010	Towamba State Forest	5471
Flat Rock State Forest	4896	Wandella State Forest	5492
Glenbog State Forest	4641	Wandera State Forest	5198
Gnupa State Forest	1318	Wingello State Forest	3975
Jellore State Forest	1411	Woodburn State Forest	10
Jerrawangala State Forest	268	Yadboro State Forest	10750
Kioloa State Forest	171	Yambulla State Forest	47108
Mcdonald State Forest	3684	Yarrawa State Forest	179
Meryla State Forest	4554	Yerriyong State Forest	6604
Mogo State Forest	15498	Yurammie State Forest	4050
		Total	352931

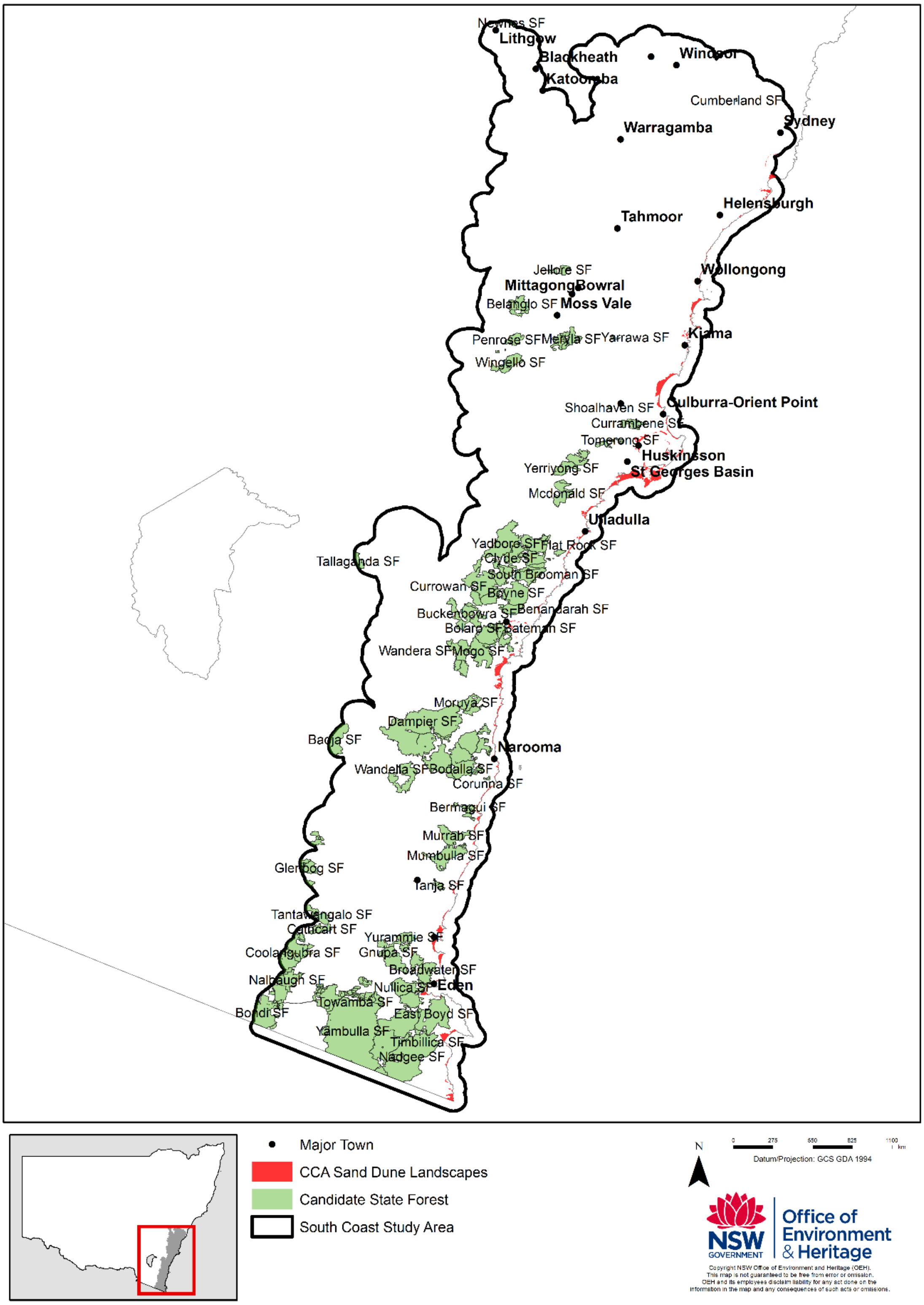

Figure 2: Existing comprehensive coastal assessment (CCA) coastal sand landscapes

2.5 Project Team

This project was completed by the Ecology and Classification Team in the OEH Native Vegetation Information Science Branch. It was initiated and funded by the NSW Environment Protection Authority under the oversight of the Director Forestry.

The project was managed by Daniel Connolly. Doug Binns undertook the floristic analysis of survey plots, and has interpreted the relationships and relatedness between relevant vegetation communities. Allen McIlwee performed the spatial analysis and broad scale predictive distribution modelling. Owen Maguire undertook API mapping using 3D stereo imagery across the study area. Flora survey plots were completed by Jackie Miles and Paul McPherson (Eden area), with additional samples completed by Ken Turner, Jedda Lemmon and Doug Binns. Field assistance was provided by Paula Pollock (EPA), Alex Waterworth (EPA), Ken Turner, Daniel Connolly and Philip Gleeson. Dan Bowles provided GIS, mapping and technical support.

3 Methodology

3.1 Approach

Analysis and mapping was guided by the general principles and particular interpretation of Bangalay Sand Forest (BASF) adopted by the TEC Reference Panel (the Panel), described in Section 2.3. For the purpose of this project, BASF is interpreted to be defined primarily by floristic plot data as allocated to vegetation communities which have been previously described from quantitative floristic analysis, and, which have been explicitly listed in the final determination. The following statements from the final determination provide the basis for comparative analysis: in the Sydney-South Coast region, this community includes 'Ecotonal Coastal Hind Dune Swamp Oak-Bangalay Shrub Forest' (ecosystem 27) excluding those stands that are dominated by *Casuarina glauca* and 'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000); 'Littoral Thicket' (map unit 63) and part of 'Coastal Sand Forest' (map unit 64) of Tindall et al. (2004); 'Coastal Sand Bangalay-Blackbutt Forest' (map unit 25) of NPWS (2002); and 'Dry Dune Shrub Forest' of Keith and Bedward (1999).

Plots in which standard floristic data had been collected were compared with plots previously allocated to the communities' equivalent to those listed in the BASF final determination, (as described in Section 3.3.1 below). These plots comprised data already held in the OEH VIS flora survey database over all tenures, together with data collected specifically for this project in state forests.

We used dissimilarity-based methods to assess the likelihood that plots in state forests belonged to one or more of the communities listed in the final determination. There is no single preferred method of making these comparisons and no objective threshold to determine whether or not a plot belongs to a community (and thus BASF). Options for different methods and thresholds represent narrower or broader interpretations of BASF, but this approach using plot-based floristic comparison provides a means of consistently allocating plots to being either BASF, or not, for a range of interpretation options.

3.2 Identifying Coastal Sandplain Landforms

3.2.1 Coastal comprehensive assessment maps

Troedson and Hashimoto (2008) describe a series of maps of Quaternary geology and related features, used for a comprehensive coastal assessment. We selected the units from these maps that identify the provenance of the substrate material as marine sand, in whole or in part, irrespective of the age of the deposit. These are shown in Figure 2.

3.3 Existing Vegetation Data

3.3.1 Existing vegetation classifications

The three classifications cited in the final determination that are most relevant to BASF in the South Coast region are those of Keith and Bedward (1999), Thomas et al. (2000) and Tindall et al. (2004). Subsequent to the final determination, each of these studies has been superseded by more recent studies (Gellie 2005 in place of Thomas et al. 2000, and Tozer et al. 2010 in place of Keith and Bedward 1999 and Tindall et al. 2004) using a larger pool of data. Previously defined communities cited in the final determination can be traced to equivalent communities in the more recent classifications, so plot allocations for the latter are used in this project for floristic comparison. The relevant communities from the final determination and their more recent equivalents are listed in Table 3.

Table 3: Communities defined from recent analyses that are equivalent to those cited in the final determination.

Community listed in final determination	Recent equivalent	Qualifier as Bangalay Sand Forest (BASF)
FE27 'Ecotonal Coastal Hind Dune Swamp Oak-Bangalay Shrub Forest'	VG 27: Ecotonal Coastal Swamp Forest - *Casuarina glauca / E. botryoides - Angophora floribunda / E. elata / Acacia mearnsii* (Gellie 2005)	Excludes stands dominated by *Casuarina glauca*
'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000)	'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000)	None, all included
'Littoral Thicket' (map unit 63) (Tindall et al. 2004)	S_HL63 Littoral Thicket (Tozer et al. 2010)	None, all included
'Coastal Sand Forest' (map unit 64) of Tindall et al. (2004)	S_DSF64 Coastal Sand Forest (Tozer et al. 2010)	Part only but further information on which part is not provided in the determination. For the purposes of this analysis we adopted all map unit 64 as meeting the determination
'Coastal Sand Bangalay-Blackbutt Forest' (map unit 25) of NPWS (2002)	N/A	None, all included and plots describing this unit are wholly included within S_DSF64 of Tozer et al. (2010)
'Dry Dune Shrub Forest' of Keith and Bedward (1999)	N/A	None, all included and plots describing this unit are wholly included within S_DSF64 of Tozer et al. (2010)

3.3.2 Existing vegetation data

A recent review of OEH systematic flora survey data holdings in eastern NSW (OEH in prep) was available for the project. The review identified a subset of data suitable for use in quantitative vegetation classification on the basis that it met a set of predefined criteria, namely that plot:

- provided location co-ordinates with a stated precision of less than 100 m in accuracy
- covered a fixed survey search area of approximately 0.04 hectares
- supported an inventory of all vascular plants
- provided a documented method that assigns a quantitative and/or semi quantitative measure of the cover and abundance of each species recorded

A total of 15,487 plots within the study area, including 184 plots surveyed specifically for our project, were in the OEH VIS Flora Survey Database at 22 July 2015. 11,558 of these had floristic data suitable for analysis.

3.3.3 Analysis data set

We chose our pool of data to ensure that it included all plots that had previously been allocated to any community that we considered relevant to BASF, or to any of the other coastal TECs covered by our broader project, and all other plots that had not previously been analysed or allocated to a community in a regional study. Plots were omitted which had previously been allocated to communities which we considered not relevant to the group of TECs under consideration in our study area.

Communities were assessed as not relevant for one of the following reasons: tablelands communities occurring on ridges or slopes mostly above 600 metres; ridgetop dry shrubby forests; heaths with few species in common with communities of interest; communities recorded only north of the Illawarra area and not listed in any of the relevant determinations; communities which were clearly floristically and environmentally distinct from communities of interest. Appendix A indicates all communities from which plot data were included. We also included all plots for which no previous community allocations were available and all plots that had not previously been classified or allocated to a community.

3.3.4 Data preparation and taxonomic review

All species in the pooled dataset was standardised for analysis using a review completed for all flora survey data compiled for the Eastern NSW Classification (OEH in prep). Nomenclature was standardised to follow Harden (1990, 2002) and updated to reflect currently accepted revisions using the PlantNETWebsite (Royal Botanic Gardens 2002). The data was amended to:

- exclude exotic species
- exclude species identified to genus level only
- improve consistency in assignment of subspecies or varieties to species.

Cover and abundance score data extracted from the pooled data set was standardised to a six class modified braun-blanquet score. The transformation algorithm available within the OEH VIS Flora Survey data analysis module was applied to the analysis dataset.

3.4 New Survey Effort

3.4.1 Survey stratification and design

We identified an initial list of state forests that may support candidate areas of Bangalay Sand Forest by selecting those that fell below an elevation threshold of 120 metres above sea level, were situated within the nominated bioregions, and were within five kilometres of the coastline. We refined potential areas for survey by overlaying a range of substrate maps (Troedson & Hashimoto (2008); 1:250 000 geological mapping (Lewis & Glen 1995; McIlveen 1973; Rose 1966a, 1966b) and the nominated vegetation map units cited in the final determination. Forest type (RN17, Baur 1989) was added to identify those types (and their subtype/ composites) commonly associated with sand deposits (107, 108, 41, 233 and 224).

Given the small and patchy distribution of candidate areas, individual mapped polygons of potential Bangalay Sand Forest were assessed using recent stereoscopic digital aerial imagery and available environmental data. Several areas were identified as mapping inaccuracies based on the conflict between map label, topographic position and relief, image pattern and mapped geology data. To address issues associated with map scale, any state forest located within 500 metres of a polygon identifying marine sand deposits or selected vegetation map units, were visually assessed to identify potential related vegetation patterns not discriminated by available mapping.

A small number of areas were identified in Mogo, Nullica, Nowra, Termeil and East Boyd State Forests, with the latter two forests requiring targeted field surveys. Field surveys applied systematic techniques to assess forests and woodlands associated with marine sand masses (or not easily determined) and rapid assessment techniques where vegetation could be immediately resolved by obvious conflicts between the substrate and vegetation and the TEC determination.

3.4.2 Survey method

Systematic surveys

Systematic flora survey were conducted in accordance with OEH standard methods (Sivertsen 2009). Preselected sample points were located in the field using a global positioning system (GPS). In the field, plots were assessed for the presence of heavy disturbance (such as severe disturbance through clearing or weed infestation) and were either abandoned or moved to an adjoining location in matching vegetation.

Systematic floristic sample plots were fixed to 0.04 hectares in size. The area was marked out using a 20 by 20 metre tape, although in some communities (such as riparian vegetation) a rectangular configuration of the plot (e.g. 10 by 40 metres) was required. Within each sample plot all vascular plant species were recorded and assigned estimates for foliage cover and number of individuals. Raw scores were later converted to a modified 1-8 braun-blanquet scale (Poore 1955) as shown in Table 4.

Table 4: Braun-blanquet-to-cover abundance conversion table.

Modified braun-blanquet 6 point scale	Raw Cover Score	Raw Abundance Score
1 (<5% and few)	<5%	≤3
2(<5% and many)	<5%	≥3
3 (5-25%)	≥5 and <25%	any
4 (25%-50%)	≥25% and <50%	any
5 (50%-75%)	≥50% and <75%	any
6 (75%-100%)	≥75%	any

Species that could not be identified in the field were recorded to the nearest possible family or genus and collected for later identification. Species that could not be identified confidently were lodged with the NSW Herbarium for identification. At each plot, estimates were made of the height range, projected foliage cover and dominant species of each vegetation stratum recognisable at the plot. Measurements of slope and aspect were taken. Notes on topographic position, geology, soil type and depth were also compiled. Evidence of recent fire, erosion, clearing, grazing, weed invasion or soil disturbance was recorded. The location of the plot was determined using a hand held GPS or a topographic map where a reliable reading could not be taken. Digital photographs were also taken at each plot.

Non-systematic surveys

Non-systematic survey techniques were employed by survey teams to record observations of flora species present in likely habitat. Survey observations were made against a standard proforma which recorded a minimum of three dominant species in each of the upper, middle and ground stratum.

These partial floristic plots were identified as rapid field plots. No fixed assessment area was used and the number of species recorded was subject to time and visibility constraints. Observations were supported by a georeferenced position and a digital photograph. In addition, brief descriptions of vegetation composition and pattern were also made intermittently by field crews to identify vegetation patterns of interest. These were retained as free text descriptors attached to a georeferenced point and are known as ‘Field Note Points’.

3.5 Classification Analyses

3.5.1 Clustering

There is a range of methods available for quantitative classification of vegetation communities. Results may vary depending on which method is used and which parameters are chosen for a particular method. There is no single best method, but the most widely used method is clustering of plots based on pairwise dissimilarities. As results vary with varying dissimilarity measures, comparisons with previous classification require use of the same measures. Relationships among plots vary depending on the data pool used, so that introducing additional data may change the composition of previously defined groups.

Most clustering methods result in a plot being allocated to a single vegetation community. A plot may also be related to other communities, but these interrelationships are not evident from allocations. As an alternative, fuzzy clustering methods assign a membership value to each plot for each community, which provides a measure of the likelihood that a plot belongs to any particular community. For this project, Noise Clustering (De Cáceres, Font, & Oliva 2010; Wiser & De Cáceres 2013) was selected as the most appropriate fuzzy clustering method for three reasons: it allows specification of fixed clusters defined from previously described groups and provides direct allocations to those groups; it is relatively robust to outliers (which have a large difference from all previously defined groups or communities) and allows clustering into new groups; and it is robust to the prevalence of transitional plots with relationships to two or more previously defined communities. The latter are both characteristic of data for the study area. Noise Clustering requires specification of a fuzziness coefficient (where a coefficient of 1 is equivalent to hard clustering which allocates each plot to only one community) and a threshold distance for outliers. Following a number of trial runs with different subsets of data, different fixed groups and different parameters, we chose a fuzziness coefficient of 1.1 and an outlier threshold of 0.85. These parameters resulted in results which were relatively robust to different sets of data and which had a high degree of consistency with previous classifications. Analyses were done using functions in the ‘vegclust’ package in R 3.1.1.

We conducted a number of analyses using different subsets of data and different sets of previously defined communities, as follows:

1. A subset of 1345 plots which comprised all plots previously allocated to a relevant vegetation group by Gellie (2005) plus previously unallocated plots in state forest or surveyed for this project. Relevant vegetation groups are listed in Appendix A. This provided an assessment of the membership of all state forest plots to communities that could be related to those defined by Thomas et al. (2010) which were explicitly listed in the final determination.
2. A subset of 2708 plots which comprised all plots previously allocated to a relevant vegetation community by Tozer et al. (2010) plus previously unallocated plots in state forest or surveyed for this project. Relevant vegetation communities are listed in Appendix A. This provided an assessment of the membership of all state forest plots to communities that could be related to those defined by Tindall et al. (2004) and Keith & Bedward (1999) which were explicitly listed in the final determination.
3. A subset of 8452 plots comprising all suitable plots available in VIS up to 15 June 2016 which either previously had been allocated to a relevant community by either Gellie (2005) or Tozer et al. (2010), or had not previously been allocated. This subset included all previously unallocated plots regardless of occurrence in state forests and included all plots in both subsets 1 and 2. Two fuzzy clustering analyses were applied to this subset, one using Gellie (2005) allocations as fixed groups and the other using Tozer et al. (2010). These analyses were designed to investigate allocations in a broader context.

3.5.2 Allocation of standard floristic plots to BASF and other communities

We assessed plots as being BASF if their membership of any floristic community defined by Gellie (2005) or Tozer et al. (2010) and equivalent to a community cited in the final determination (we will refer to these as BASF communities) was 0.5 or above and they met the qualifying condition, if any, for that community. In the case where a plot belonged to one qualified community and one unqualified, but did not meet the qualifying condition, we assessed the plot on the basis of its membership of the unqualified community. We considered that plots which belonged to a BASF community with primary membership <0.5 were potentially BASF (no plot had a primary membership <0.1). If these potential BASF plots had a strong membership (>0.75) of a non-BASF community in an alternative classification (Gellie 2005 or Tozer et al. 2010, as appropriate), we assessed them as not BASF. If their memberships were weak in both classifications or they most strongly belonged to a community that had not been previously described, we considered that they could be treated as BASF for management purposes, using a precautionary approach to assessment.

3.6 Indicative EEC Distribution Map

3.6.1 Background

A niche modelling approach (also known as species or habitat distribution modelling) was used to create indicative potential distribution map for BASF. This approach attempts to extrapolate the fundamental niche of the TEC outside the locations where it is known to be present (its realised niche), by relating known occurrence and absence to environmental predictors.

Modelling the distribution of a TEC requires the characterisation of environmental conditions that are suitable for the community to exist. The inclusion of the absence data from the plot allocation allows us to constrain the potential distribution model to a narrow set of favourable environmental conditions that are not occupied by other vegetation communities. Nonetheless, without API and associated on-ground validation, it is difficult to determine the extent to which potentially suitable habitat is actually occupied by the TEC.

Ecological niche modelling involves the use of environmental data describing factors that are known to have either a direct (proximal) or indirect (distal) impact on a species or ecological community. Proximal variables directly affect the distribution of the biotic entity, while distal variables are correlated to varying degrees with the causal ones (Austin 2002). Austin and Smith (1990) differentiate between indirect gradients, which have no physiological effects on plants, and direct or resource gradients, which directly influence plant growth or distribution. Direct or resource gradients mainly concern light, temperature, water and nutrients, whereas the main indirect gradients are altitude, topography and geology (Austin & Van Niel 2011). An environmental variable may act both as a resource that provides building blocks for growth processes and as a condition that fulfils the requirements for physiological processes to function effectively.

Figure 3 provides a basic conceptual framework for how plant communities are likely to respond to their environment. Arrows in the figure show how particular indirect variables interact to generate more direct environmental drivers through biophysical processes. It should be noted that plant distributions are also influenced by stochastic processes such as extreme heat or cold, landslip or erosion, high winds, drought, flood and fire. However, in niche modelling, we assume that the composition of vegetation is primarily determined by environment rather than successional status or by time since last disturbance (Franklin 1995). It is also assumed that vegetation is in equilibrium with the environment, or at least a quasi-equilibrium where change is slow relative to the life span of the biota.

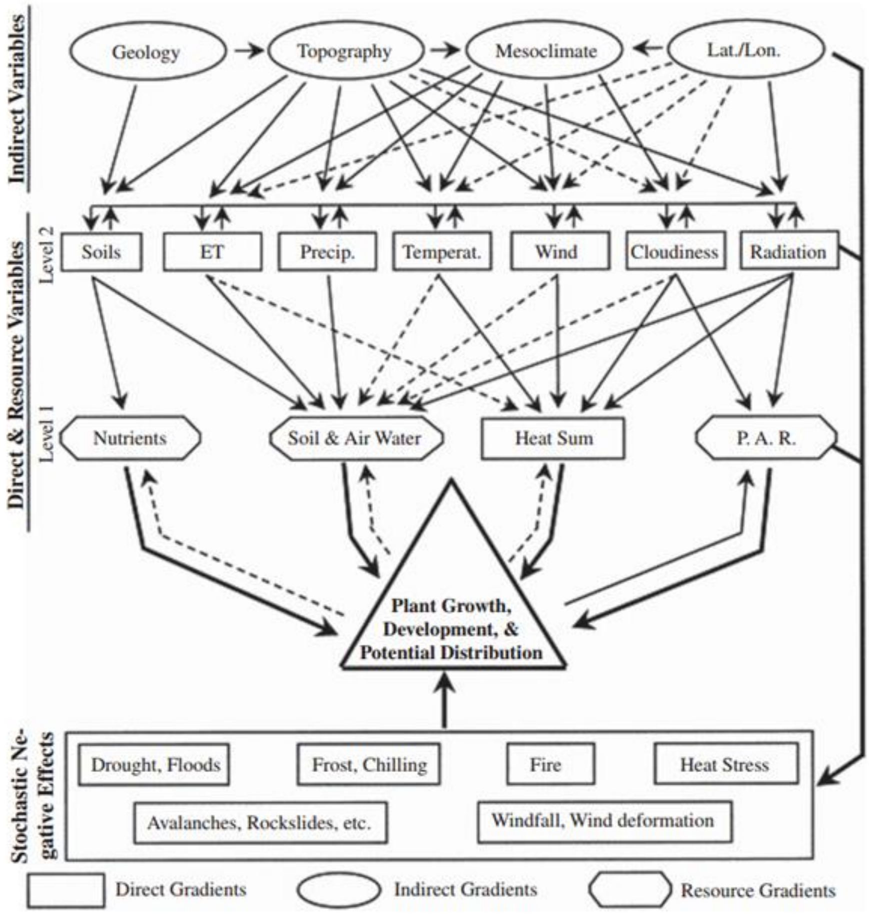

Figure 3: Conceptual model of relationships between resources, direct and indirect environmental gradients and their influence on growth, performance and geographical distribution of plants and vegetation communities in general.

Source: Guisan and Zimmermann (2000; Figure 3).

Figure 4 provides an overview of the step-by-step modelling process, which involves a 'classification-then-modelling' approach (Ferrier et al. 2002) with two distinct stages. In the first stage, the biological survey data are subjected to a vegetation classification and full-floristic vegetation plots are allocated to presence/absence category for the TEC. This classification is run without any reference to the environmental data. In the second stage, the TEC entity as defined by the classification are modelled as a function of environmental predictors.

The statistical model refers to the choice of (i) a suitable machine learning algorithm for predicting a presence-absence response variable and its associated theoretical probability distribution, and (ii) choice of an appropriate variable selection procedure that either has the goal of optimising prediction accuracy or interpretability.

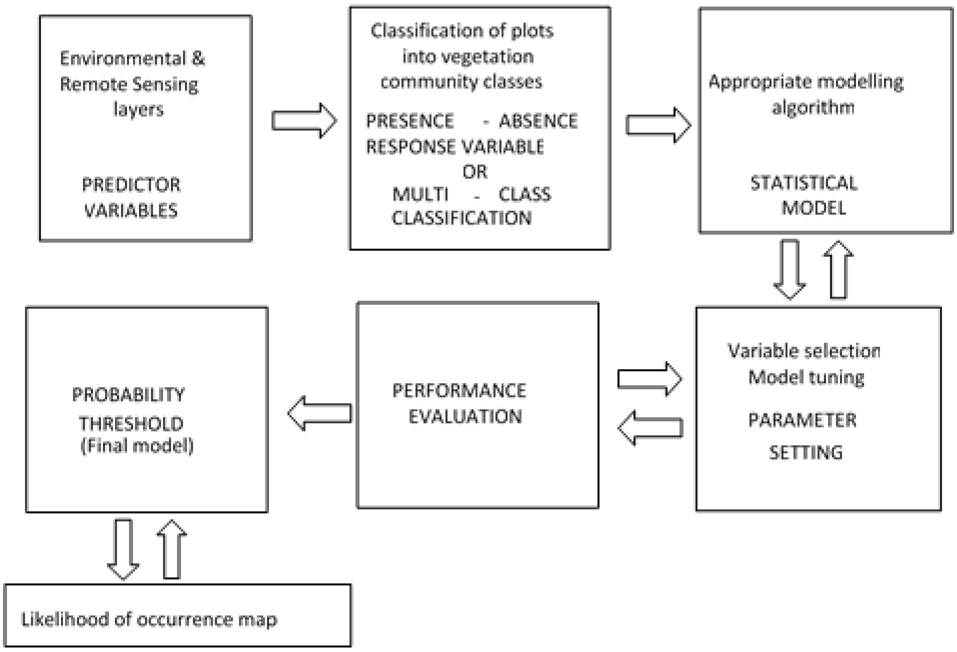

Figure 4 Process for creating indicative TEC distribution maps.

3.6.2 Modelling complex ecological systems

The niche modelling community has made considerable headway in developing machine learning algorithms to predict the occurrence of species and communities using presence-absence data (Evans & Crushman 2009). The methods model vegetation patterns as continuous measures of site suitability or probability of occupancy. Non-parametric approaches such as Classification and Regression Trees (CART) have gained widespread use in ecological studies (De´ath & Fabricius 2000). However, CART suffers from problems such as over-fitting and difficulty in parameter selection. Solutions to deal with these issues have been proposed that incorporate iterative approaches (Breiman 1996). One approach, Random Forests (Brieman 2001), has risen to prominence due to its ability to handle large numbers of predictors and find signal in noisy data (Cutler et al. 2007). Another advantage of Random Forests is that, by permutation of independent variables, it provides local and global measures of variable importance.

Random Forests is an algorithm that developed out of CART and bagging approaches. By generating a set of weak-learners based on a bootstrap of the data, the algorithm converges on an optimal solution while avoiding issues related to CARTs and parametric statistics (Cutler et al. 2007). Ensemble-based weak learning hinges on diversity and minimal correlation between learners. Diversity in Random Forest is obtained through a Bootstrap of training, randomly drawing selection of M (independent variables) at each node (defined as m), and retaining the variable that provides the most information content. To calculate variable importance, improvement in the error is calculated at each node for each randomly selected variable and a ratio is calculated across all nodes in the forest.

The algorithm can be explained by:

1. Iteratively construct N Bootstraps (with replacement) of size n (36%) sampled from Z, where N is number of Bootstrap replicates (trees to grow) and Z is the population to draw a Bootstrap sample from.
2. Grow a random-forest tree T_b at each node randomly select m variables from M to permute through each node to find best split by using the Gini entropy index to

assess information content and purity. Grow each tree to full extent with no pruning (e.g., no complexity parameter).

3. Using withheld data (OOB, out-of-bag) to validate each random tree T_b (for classification
4. OOB Error; for regression pseudo R^2 and mean squared error).
5. Output ensemble of random-forest trees

$$\{T_b\}\frac{B}{1}$$

To make a prediction for a new observation x_i:
Regression:

$$\hat{f}_{\mathrm{rf}}^{B}(x) = \frac{1}{B}\sum_{b=1}^{B} T_b(x)$$

Classification: Let $\hat{C}_b\,(x)$ be the class prediction of the *B*th random-forests tree then

$$\hat{C}_{rf}^{B}(x) = \text{majorityvote}\left\{\hat{C}_b(x)\right\}\frac{1}{B}$$

Commonly, the optimal *m* is defined for classification problems as sqrt (*M*); and for regression *M*/3, where *M* is a pool of independent variables. It has been demonstrated that Random Forest is robust to noise even given a very large number of independent variables (Breiman 2001a; Hastie et al. 2009).

All modelling was performed in the statistical software package R version 3.3.0

3.6.3 Spatial data and the variable selection process

A set of 175 variables were available for modelling. These include a set of 1) 130 continuous environmental variables relating to climate, topography and Euclidean distance to features such as the coastline, permanent water bodies and various stream orders, 2) 32 variables derived from Landsat and Spot 5 imagery, and 3) 13 categorical variables such as great soil group and single dominant lithology type, which were extracted from statewide corporate GIS layers. All variables were in the form of gridded Erdas Imagine rasters (*.img), with exactly the same cell size (30 x 30 m) and extent.

The raster layers were stacked in R using the Raster Package (Hijmans & van Etten 2014). The grid cell values for each of the 175 potential predictor variables were extracted for each site in the allocation file using a customised script in R, and the resulting csv file loaded into R. To improve model fit we tested for multicollinearity between the site values across the predictors using the ‘multicollinear’ function in the rfUtilities library using a significance value of 0.001. To check whether the collinear variables were in fact redundant, we performed a ‘leave one out’ test that identifies whether any variables are forcing other variables to appear multicollinear.

Random Forest models are a good starting point for making inferences about the factors driving the distribution of a plant species or ecological community. However, they are data driven models, whose purpose is to give the best possible predicted extent for the data available, and the complexity of spatial pattern. Variable selection is a crucial step in the modelling process. We used a variable selection procedure developed by Murphy et al. (2010) which standardises the relative importance values of predictors to a ratio and iteratively subsets variables within a given ratio, running a new model for each subset of variables. Each resulting model is compared with the original model, which is held fixed. Model selection is achieved by optimising model performance based on a minimisation of both 'out-of-bag' error and largest 'within-class' error for classification. There is also a penalty for the number of variables selected in a model, resulting in a preference for the lowest number of predictors from closely competing models.

For the BASF model, we also checked whether the shape of the fitted functions made sense based on our knowledge of the types of coastal environments that the TEC is constrained to. In the past, in cases where a TEC did not model well into the environments we expected it to occur, we went back and re-examined the site allocation data, and made a decision on whether to split the TEC into different communities or sub-types, that each may respond to different environmental drivers.

We ran preliminary Random Forest models using three types of predictor sets. The first used the full set of continuous environmental variables, with the aim of predicting the potential distribution (realised niche) of the TEC in its broadest sense. The second used a combination of continuous environmental and remote sensing variables. The inclusion of remote sensing variables added information about the spectral characteristics of vegetation at a site, and its dynamics through time, giving a better reflection of the actual as opposed to potential distribution of the TEC. Categorical variables were not incorporated into the models directly, but the data were occasionally used to compare frequency histograms across presence and absence sites to see if a distinct preference for a particular soil type or fertility class existed. However, given that the number of absence sites greatly outnumbered the presences, there was generally insufficient data to draw conclusions about preferences for one group of soil classes over another.

Through a series of initial trials, we found a third hybrid approach produced the best set of predictors for modelling. Here we used the variable selection process described above to identify a subset of 30 environmental predictors out of the 130 available. We then added the 32 remote sensing variables and reran the same variable selection process, selecting out two subsets, one with 15 and the other with 30 predictors. These numbers were set *a priori* since previous modelling had suggested that a minimum of around 12 predictors (those with the highest relative influence values) was generally needed to get a levelling out of the performance curves (see below). Beyond this stabilisation point, one could double or triple the number of predictors in a model, but this would have little effect on overall performance since the new predictors tended to have a very small influence on the model.

3.6.4 Model performance and TEC-habitat relationships

As a means to assess model performance, we plotted the predicted probability of occurrence (PO) values for all plots allocated to a TEC (in descending order) against the same number of highest ranked absence plots. A good model was defined as having high PO values across the majority of TEC presence sites, with a possible drop sharply at the end for those plots that occupy marginal environmental space (and could potentially be misclassified false positives). If there was no overlap in PO values for the lowest ranked presence sites and the highest ranked absence sites, performing a classification using any number between these two values would result in the correct prediction of 100% of presence and absence sites. In such a case, there was no need to present a confusion matrix describing the percentage of sites correctly classified.

In most cases, environmental variables were found to strongly dominate the set of 15 predictors, although occasionally one or two remote sensing variables were selected. However, in the set of 30 predictors, it was common for a number of the original environmental variables to drop out and be replaced with remote sensing variables. We found that models with 15 predictors generally had very good performance with 100% of sites allocated to the TEC and 100% of absence sites correctly classified. However, we also found that doubling the number of predictors generally resulted in a better model. Although a tighter fitting, finer threaded potential distribution map was produced, it was sometimes unclear as to whether the additional variables picked up important variation not captured in the main set of 15 predictors, or whether they simply account for noise in the dataset.

To understand and evaluate the habitat relationships for BASF, we used a combination of the scaled variable importance values for predictors and shape of the response functions in partial plots as a measure of the strength and nature of interactions. From this, we assessed whether the models were likely to predict onto coastal sand plains, as we expected them to.

3.6.5 Spatial interpolation

We used the Random Forest models with 15 and 30 variables to create two 30 x 30 metre BASF probability of occurrence maps covering the Upper North Coast study area. Using the performance plots described above, we selected a single threshold just below the maximum PO across all absence sites to represent the cut of above which the TEC has the potential to occur, and below which, we assumed the TEC is absent. Setting the threshold at the high end of probability of occurrence values for absence sites resulted in a relatively narrow predicted extent. This created a model that matched finer habitat characteristics around known presences but was often a constrained model that also failed to capture some areas we considered likely to include presences in locations with limited survey data. To capture the broader extent, we also created a probability of occurrence map with a threshold 0.05 below the first. This had the effect of selectively extending the model out to cover a larger area (onto a number of sites classified in the site allocation as absent). However, at the slightly lower threshold, we felt more confident that we were capturing the broadest possible extent of the BASF, allowing us to make the decision as to which state forests had the potential to support the TEC, and which did not.

3.7 Aerial Photograph Interpretation

The mapped extent of coastal sand masses by the comprehensive coastal assessment were used as starting point for mapping the distribution of BASF on state forest. Aerial photograph interpretation (API) was used to assess the underlying environmental attributes of the forest by inferring relationships between forest structure and overstorey composition with image patterns associated with known sand deposits.

API technicians, experienced in interpretation of NSW forest and vegetation types, used recent high-resolution (50cm GSD) stereo digital imagery, in a digital 3D GIS environment, to delineate observable pattern in canopy species dominance, understorey characteristics and landform elements. Interpreters adopted a viewing scale between 1:1000 and 1:3000 to assess canopy species composition and/or understorey composition.

A minimum map polygon size of 0.25 hectares was used to inform the detection and delineation of image patterns. Interpreters were supplied with a range of environmental variables to accompany interpretation including existing vegetation community maps including (RN17), substrate maps, roads and trails and tenure boundaries. All relevant georeferenced floristic data held in OEH databases was extracted and supplied to aid interpretation. Floristic data was supplemented by interpreter field traverse using an iterative process to boost interpretation confidence by relating field observations to image patterns.

The API layer was then cross-checked against the derived spatial model of BASF. Any areas of high probability of occurrence within or adjoining the spatial model not already included within the existing API layer were identified and later assessed using the mapping protocols.

4 Results

4.1 Survey Effort

Within our study area there were 8452 standard full-floristic plots in the OEH VIS database that we used for our initial analysis, 832 of which are in state forest. All plots are shown in Figure 5. This includes 285 plots that were surveyed specifically for our TEC project. In addition, we collected partial floristic data and other observations for TEC assessment at a further 342 sample points in state forests. Table 5 summarises samples referable to BASF communities that we included in our analysis.

Table 5: Distribution of samples in state forest using existing reference maps identifying candidate areas of Bangalay Sand Forest.

Mapping Type	State Forest	Hectares	Full floristic sample	Rapid Sample
CCA coastal sand maps	East Boyd	1	0	1
Map Unit 64 Coastal Dune Forest (Tozer et al. 2010)	East Boyd Nullica	0.6 0.8	0	1
Map Unit 63 Littoral Thicket (Tozer et al. 2010)	Termeil	2	1	0
G27	Mogo	22.7	0	3
G28	N/A	3	1	5
Assembled Forest Types (RN17)	Termeil	2	2	1

4.2 Classification Analyses

4.2.1 Relationships to existing classifications

Of the 8452 plots analysed, 4232 (51%) could be allocated with a high degree of confidence to an existing community described either by Gellie (2005) or Tozer et al. (2010) ('SCIVI' community). A further 989 (11%) were not closely related to any of the Tozer et al. 2010 communities selected for inclusion in the analysis, but formed additional floristic groups. In some cases, these were groups corresponding to communities that have been described elsewhere, but which we chose to not include in analysis because they were not relevant to any TEC in our study area. In other cases, they may represent previously undescribed communities. The remaining 1387 plots (22%) are not readily allocated to any single community and show a degree of relationship to two or more. Some of these may represent undescribed communities but many are likely to represent transitional vegetation or vegetation that belongs to communities not included in our analysis.

Table 6 and 7 summarises the assignment of plots to cited classifications in the BASF final determination. Table 6 shows there is significant overlap between the classifications with SCIVI map unit 64 sharing a high number of plots with both g28, g29 in the Gellie (2005) classification. Notably, g29 is implicitly excluded from the final determination, as it is not cited. SCIVI Map Unit 63 includes over 10 sites that are also allocated to g27 in the Gellie (2005) unit, but there are indications that the Gellie (2005) classification does not cover all the floristic variation described by Map Unit 63 and hence a new group is identified (M17).

Table 6; Distribution of plots >= 0.5 membership to cited Tozer et al. (2010) communities (Columns) compared to strongest membership to a community either from Gellie (2005) (prefix g) or Keith and Bedward (1999) (prefix E).

Prefix M indicates a new community against either of the latter classifications.

Classification Units (Gellie)	p63 Littoral Thicket	p64 Coastal Dune Forest	Total Plots
E37		1	1
E61	1		1
g11		1	1
g136		1	1
g22	1		1
g27	11		11
g28	6	33	39
g29		12	12
M17	10	1	11
M18	1		1
M3	1		1
M9		2	2
Total Plots	31	51	82

Table 7: Distribution of plots >= 0.5 membership to cited Gellie (2005) communities (Columns) compared to strongest membership to a community from Tozer et al. (2010) (rows).

Classification Units (Tozer et al.)	g27 (Gellie)	g28(Gellie)	Grand Total
M3	1		1
p105	1		1
p3	1		1
p30	2		2
p434	5	1	6
p63	4	1	5
p64		26	26

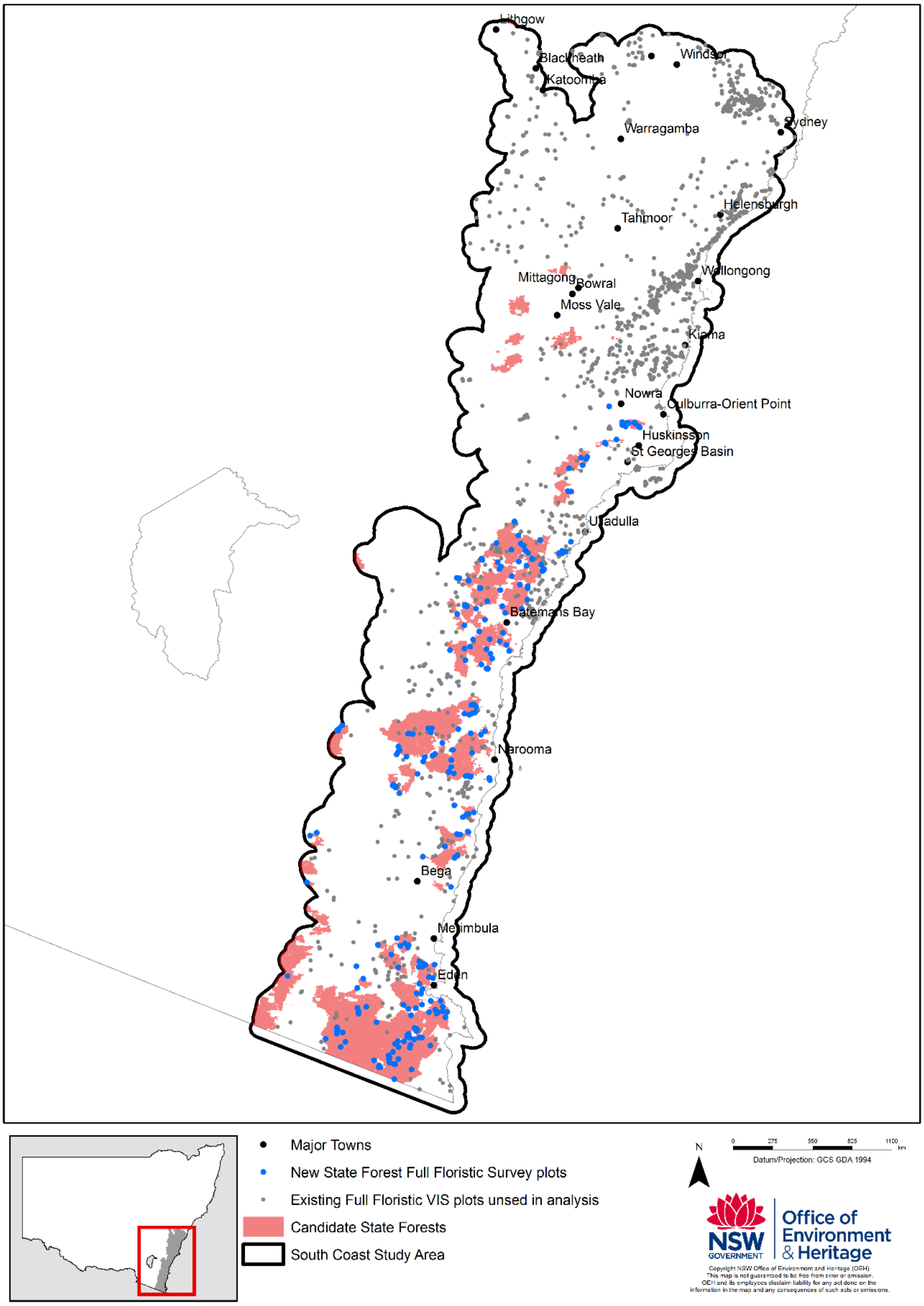

Figure 5 : Distribution of new full-floristic and rapid surveys on state forest in the South Coast study area.

4.2.2 Assessment of plots and communities as Bangalay Sand Forest other TECs

In total, we assessed 82 plots as BASF TEC. From our floristic analysis we regard as BASF all plots with a membership >=0.5 of any of the communities listed in Table 3 and meeting the qualifying condition of the particular community (where such a condition is stated). We excluded 13 plots from those assigned as they failed to meet the qualifying condition, that they occur on sand or that they cannot be dominated by *Casuarina glauca*. As a result plots that met the membership threshold for Gellie units g27 or g28 were excluded if they also had a strong relationship to vegetation not associated with sand masses (p30, p3, p434), or were dominated by *Casuarina glauca* (p105). We also excluded those plots that met the membership threshold for p63 and p64 that were not situated on sand masses based on site descriptions or mapped substrate information.

We regarded 66 plots with a high membership of a community cited in the final determination, as reference plots for BASF (Appendix D, subset headed ‘Reference plots’), (see Figure 6).

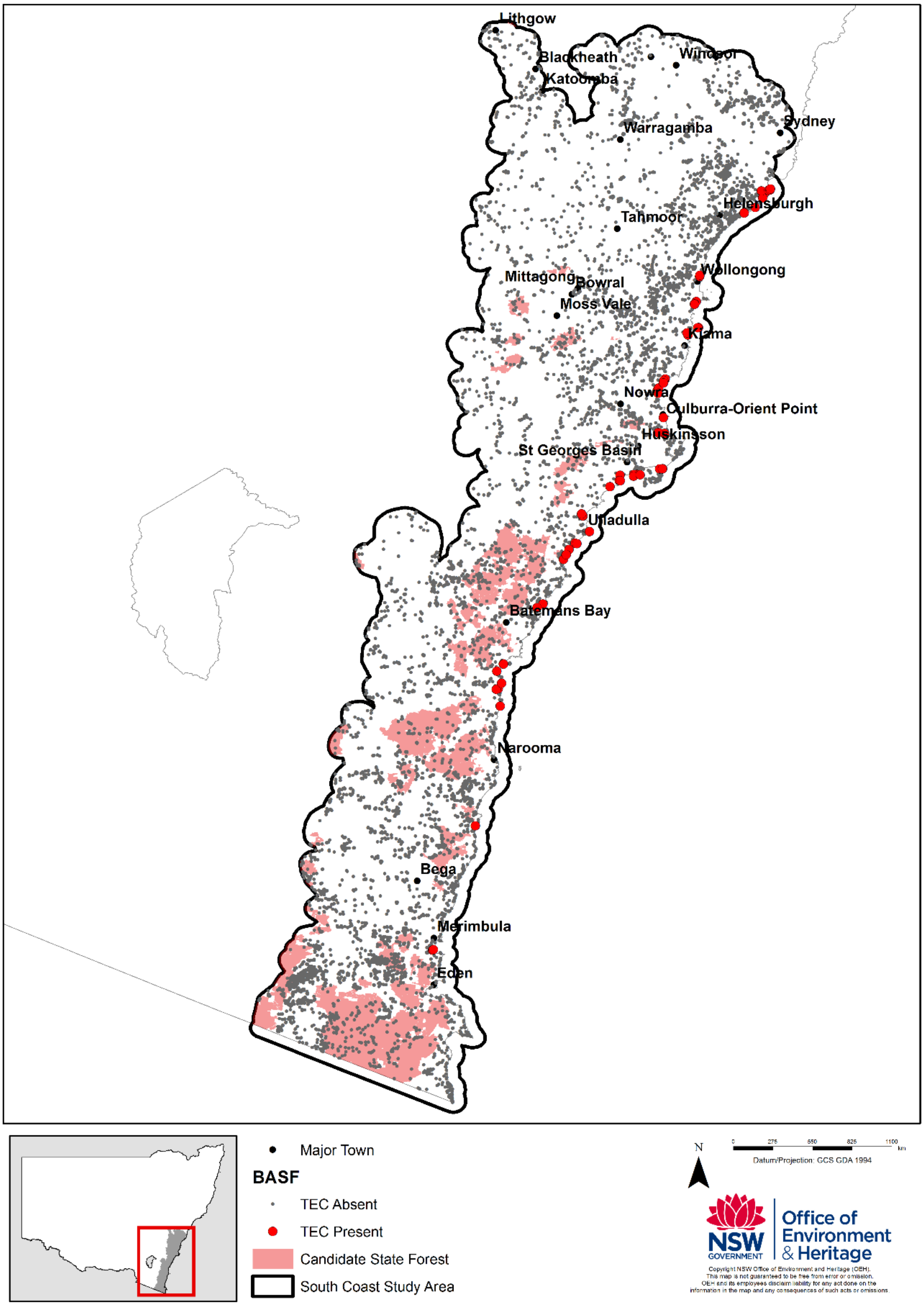

Figure 6: Standard floristic plots allocated to bangalay sand forest (basf).

4.3 Indicative TEC Mapping

4.3.1 Model performance

A Random Forest presence-absence model was used to predict the distribution of BASF across its range using the site allocation results described above. We developed a model using a subset of 31 of the original 175 predictors, as well as a narrower subset of only 16 predictors.

Figure 7 shows plots of the predicted probability of occurrence for sites allocated to BASF (in order of descending probability) plotted against the same number of highest ranked absence plots. There is no overlap between the lowest probability of occurrence value for a BASF present site and the highest probability of occurrence for a BASF absent site. Thus choosing any threshold between these two values results in 100% of all present and absent sites being correctly classified.

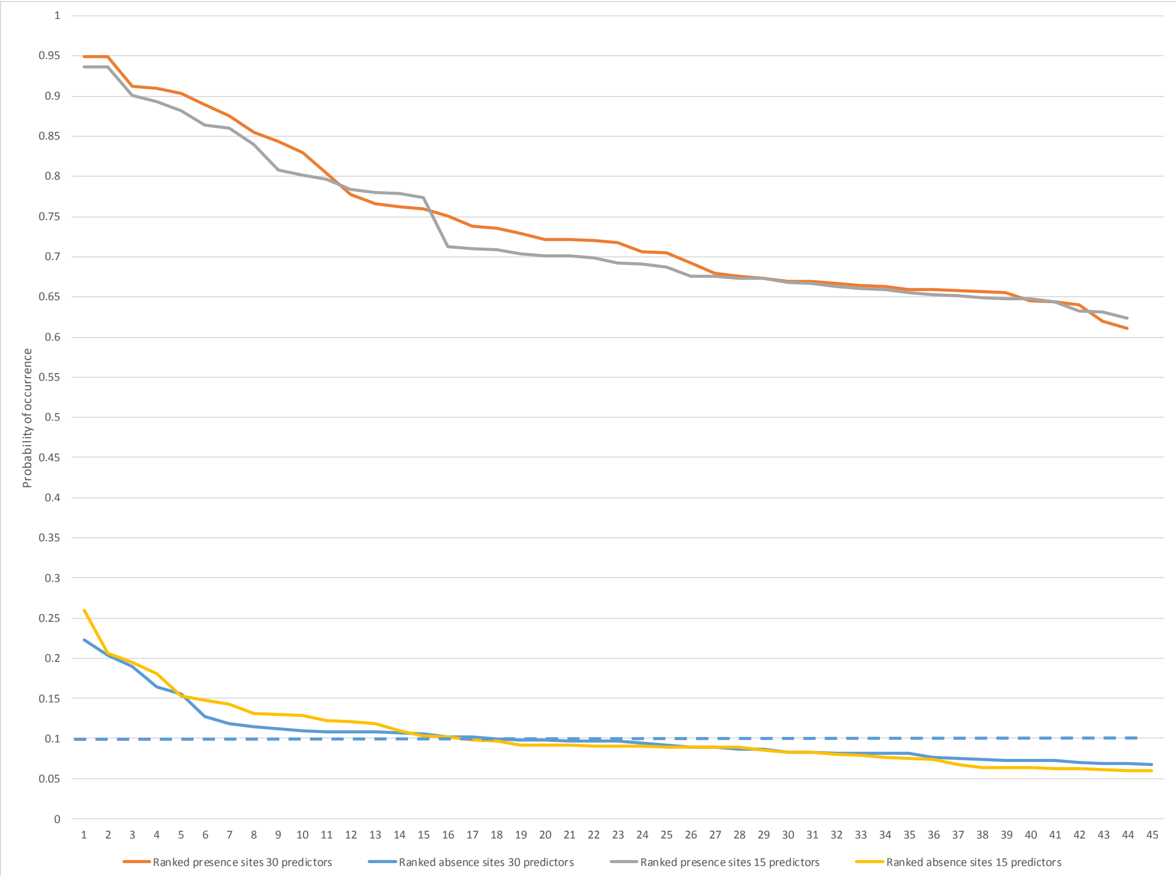

Figure 7: Predicted probability of occurrence values for sites allocated to BASF (in order of descending probability) plotted against the same number of highest ranked absence plots.

4.3.2 TEC indicative maps

The indicative maps predict the distribution of a TEC based on the probability of occurrence values above a particular threshold. From the modelling, we identified two possible indicative maps for each TEC based on the models with 16 and 31 predictors. Using a threshold of 0.1, we accept a small level of misclassification of absence sites (only 14 sites out of more than 7400). This has the effect of expanding out the model just enough to account for spatial inaccuracies that may exist in the site data.

Both sets of predicted occurrence maps were examined in ArcGIS using ADS40 imagery as the backdrop, and an assessment made as to which model/threshold best discriminated the underlying habitat features and our understanding of the vegetation patterns. In this case, the model with 31 predictors better aligned with our knowledge of the distribution of coastal sandplains. Figures 8 and 9 show the predicted distribution of BASF across all tenure. Based on a threshold of 0.1, we predict the BASF does not occur on any state forests across the South Coast study area (Figure 8), although the model does extend close to Termeil State Forest (Figure 9).

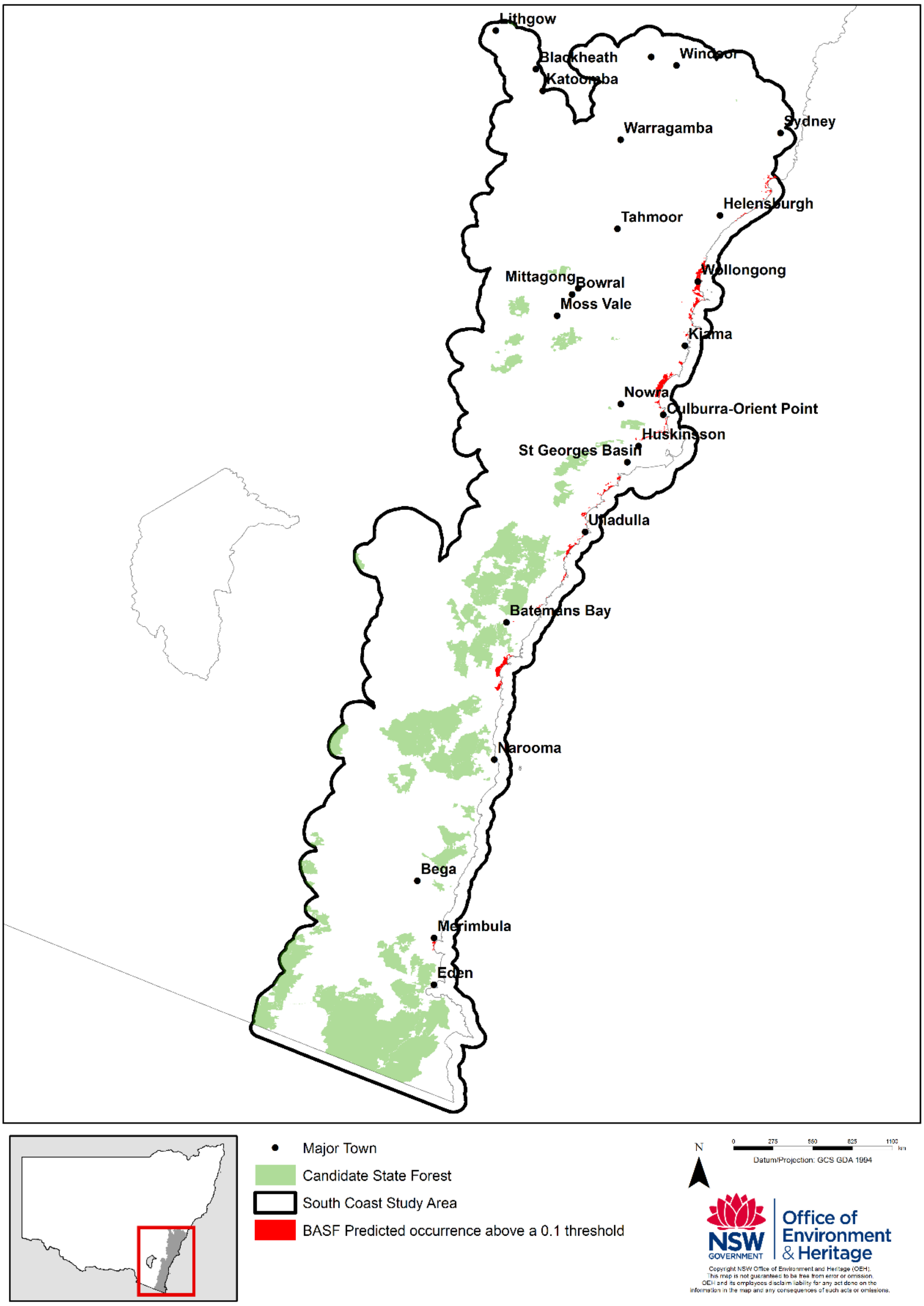

Figure 8: Predicted distribution of BASF as defined by the area with a probability of occurrence value of 0.1 and greater.

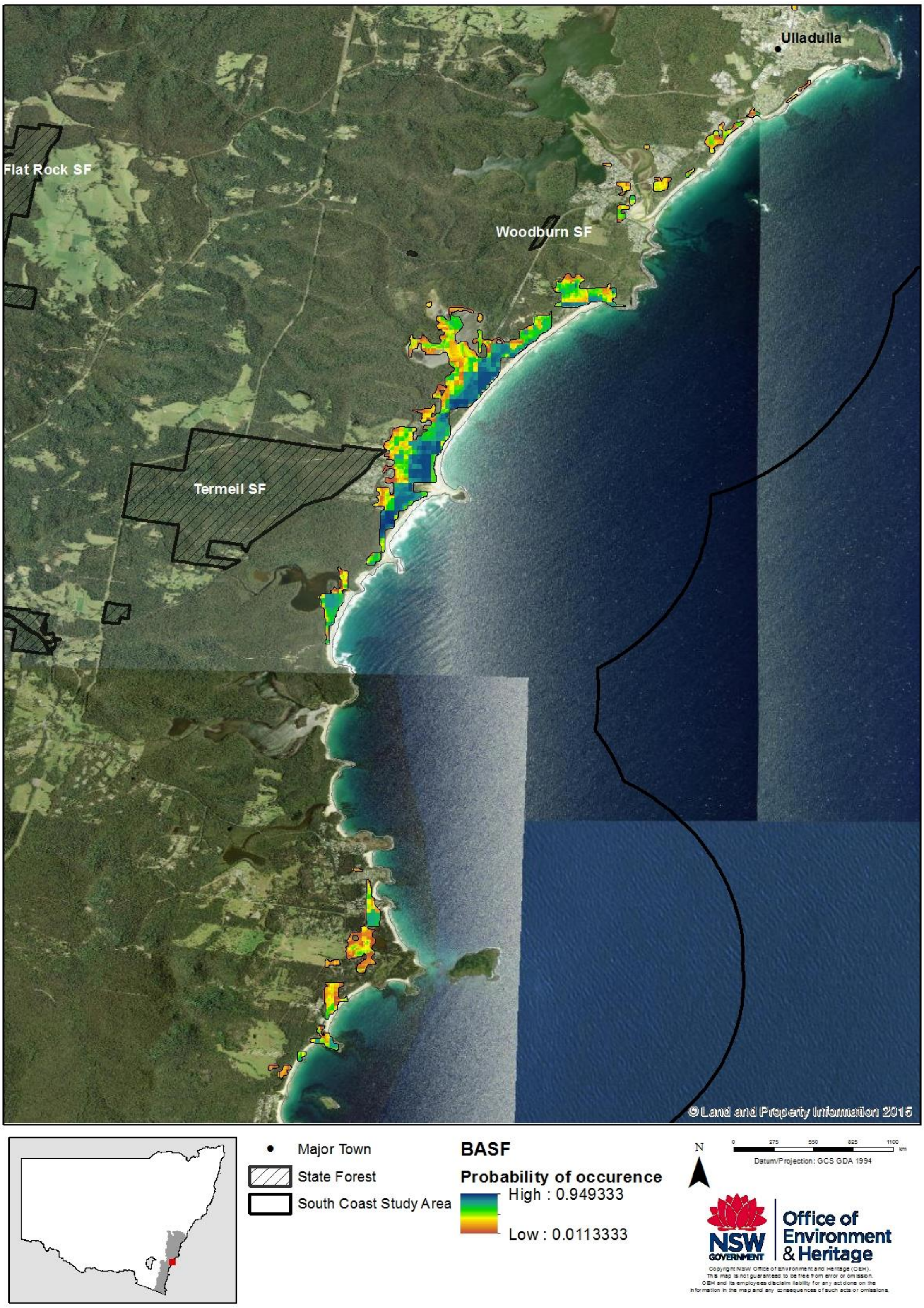

Figure 9: Close up view of the model around Termeil State Forest showing graduated probability of occurrence values above a 0.1 probability of occurrence threshold.

4.3.3 Environmental relationships

Individual fitted functions for variables in the Random Forest models are useful for determining whether a model matches what we know about the broad distribution and habitat requirements of a TEC. For example, we know from the final determination that BASF is '*associated with coastal sand plains of marine or aeolian origin. It occurs on deep, freely draining to damp sandy soils on flat to moderate slopes within a few km of the sea and at altitudes below 100 m.*'

Table 7 lists the variables that were selected in models with 16 and 31 predictors (p16 and p31). The scaled variable importance values for the final p31 model are also provided (Fig. 2). These give a measure of the relative contribution each variable has on the overall model, with low standardised variable importance values having relatively little impact on the probability of occurrence values.

Elevation and silt content at a range of depths in the soil profile are two most important factors driving the distribution of BASF. The TEC has a high probability of occurrence on soils with low silt content (inversely related to sand content), and is restricted to very low elevations along the coast. A range of climatic variables and distance to the coast also influence the broad distribution of the TEC. The shape of the fitted functions match that expected for a vegetation community that is restricted to a narrow band along the coast (Figure 11).

Table 8: List of variables selected in the BASF Random Forest models with 16 and 31 predictors.

Code	Description	In model with 16 predictors
ce_radhp_f	Highest Period Radiation (bio21)	
ce_radlp_f	Lowest Period Radiation (bio22)	Yes
ce_radseas_f	Radiation of Seasonality: Coefficient of Variation (bio23)	Yes
ct_temp_maxann_f	Average daily max temperature - Annual	
ct_temp_maxsum_f	Average daily max temperature - Summer	Yes
ct_temp_maxwin_f	Average daily max temperature - Winter	
ct_temp_minann_f	Average daily min temperature - Annual	
ct_temp_minwin_f	Average daily max temperature - Winter	yes
ct_tempannrnge_f	Temperature Annual Range: difference between bio5 and bio6 (bio7)	yes
ct_tempdiurn_f	Mean Diurnal Range (Mean(period max-min)) (bio2)	yes
ct_tempiso_f	Isothermality 2/7 (bio3)	yes
ct_tempmtcp_f	Min Temperature of Coldest Period (bio6)	yes
ct_tempseas_f	Temperature Seasonality: Coefficient of Variation (bio4)	yes
cw_prescott_f	Prescott Index	
cw_rainspr_f	Average Rainfall - Spring	
cw_rainsum_f	Average Rainfall - Summer	
d_coast_disa_f	Distance from NSW East Coast (Euclidian)	yes
d_permwater	Distance (Euclidean) from permanent water bodies	yes
gp_grav_bougb2	Bouguer gravity - band 2	

gp_grav_bougb3	Bouguer gravity - band 3	
lf_dems1s_f	Elevation from 1 sec SRTM smoothed DEM (DEM-S)	yes
lf_rough0500_f	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 500 m neighbourhood. Derived from DEM-S	
lf_rough1000_f	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 1000 m neighbourhood. Derived from DEM-S	
sp_ece_060	Effective Cation Exchange Capacity (%) (30 - 60cm)	
sp_ece_100	Effective Cation Exchange Capacity (%) (60 - 100cm)	
sp_slt_005	Silt content (%) (0 - 5cm)	yes
sp_slt_015	Silt content (%) (5 - 15cm)	yes
sp_slt_100	Silt content (%) (60 - 100cm)	yes
sp_slt_200	Silt content (%) (100 - 200cm)	yes
xrs88_sspr_g_50p	Landsat 25-year seasonal greenness in spring (50th percentile)	
xrs88_ssum_g_50p	Landsat 25-year seasonal greenness in summer (50th percentile)	

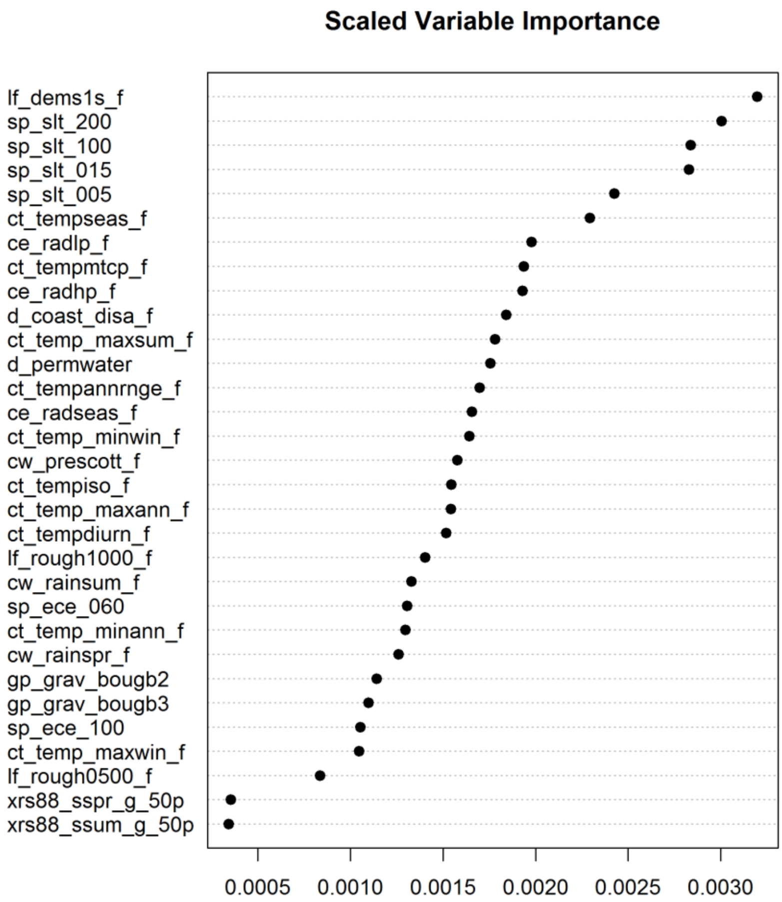

Figure 10: Scaled variable importance values in relation to the model with 31 predictors.

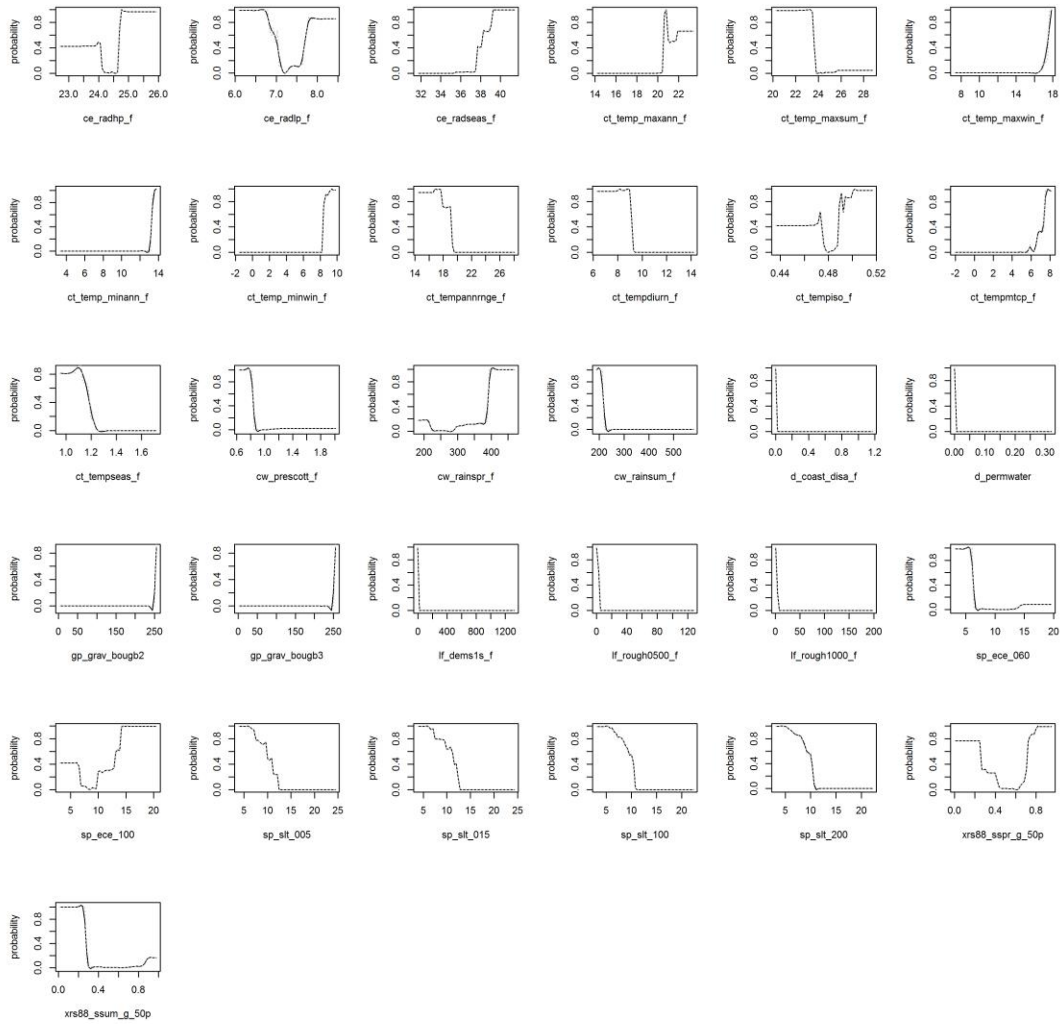

Figure 11: Shape of individual fitted functions in relation to models with 31 predictors.

4.4 Aerial Photograph Interpretation

A total of two hectares of possible BASF forest was identified within two state forests, East Boyd and Termeil.

4.5 Evidence of Occurrence on State Forest

Our analysis of plot data obtained no evidence of any BASF located on any state forest in the South Coast study area. Candidate areas identified from API were rejected on the basis of weak relationships to any of the communities cited in the final determination. In the case of Termeil State Forest, plots were more closely related to Swamp Sclerophyll Forest on floodplain and have been assigned Swamp Sclerophyll Forest TEC (OEH 2016). Areas in East Boyd were rejected either because existing mapped areas were clearly an estuarine wetland community or were identified vegetation on unrelated substrates.

5 Discussion

5.1 Summary

5.1.1 Cited vegetation communities and determination species assemblage list

The application of TEC Reference Panel principles to the floristic attributes of Bangalay Sand Forest TEC in the south coast region was simplified by the availability of sample data previously allocated to existing vegetation classifications cited in the final determination.

The project did rely on several assumptions to provide some certainty with the interpretation of the TEC. Two of the cited communities apply qualifiers that guide the inclusion or exclusion of components of the community. Only 'part' of map unit 64 Coastal Sand Forest of Tozer et al. (2010) is included and no guidance is provided as to which part. We overcame this uncertainty by including all plots assigned to map unit 64. However, our decision to include all of map unit 64 introduced a conflict with the cited Gellie (2005) classification, as more than 10 plots have been assigned to g29 'Northern Dune Forest', a unit from that classification that is omitted from the Bangalay Sand Forest determination. As a result, our interpretation is likely to produce a broader representation of BASF across all land tenures.

We also identified a conflict between the floristic and environmental attributes associated with inclusion of map unit 63 'Littoral Thicket'. Plots allocated to this community and its mapped distribution extend beyond coastal sand masses and onto sandstone bedrock found in the littoral zone or areas of maritime influence. We excluded sites situated on sandstone to avoid conflict with the primary habitat descriptor used to circumscribe the extent of the TEC.

Paragraph 8 of the final determination identifies differences that separate Bangalay Sand Forest from a related TEC, Umina Sandplain Coastal Woodland (Scientific Committee 2011). While not relevant to the assessment of state forest tenures, our floristic analysis identified very strong floristic relationships between plots located within stands of Umina Sandplain Coastal Woodland at Umina and plots defining Bangalay Sand Forest on the South Coast.

5.1.2 Distribution and habitat descriptors

The final determination includes a set of environmental descriptors that assist in locating Bangalay Sand Forest on the South Coast. We found agreement with the identified elevation parameter used in the final determination and no predicted or observed BASF was situated above 100 metres above sea level. We also found that all BASF on the south coast was recorded less than five kilometres from the coastline, which broadly concurs with the stated distribution.

5.2 TEC Panel Review and Assessment

5.2.1 Summary of discussions

The results of the community analysis and map products were subject to a review process by the TEC Panel. Table 9 presents the summary of the findings.

Table 9 Summary of issues and Panel review of BASF, meeting held 14 October 2015.

Final Determination	TEC Panel Principles	Our Project	TEC Panel Review
Occurs in '….Sydney Basin, South East Corner Bioregions'	Accept Bioregional Qualifiers	Adopted	Agreed
Occurs on deep, freely draining to damp sandy soils on flat to moderate slopes within a few km of the sea	Assess habitat descriptors and whether these constrain or define the limits of the TEC which otherwise may have a broader distribution	Coastal marine sand landforms extracted from Troedson and Hashimoto (2008); assessed other potential areas using API	Noted
Found at altitudes below 100 m		We did not restrict or assessment based on elevation	Noted
In the Sydney-South Coast region, this community includes 'Ecotonal Coastal Hind Dune Swamp Oak-Bangalay Shrub Forest' (ecosystem 27) excluding those stands that are dominated by Casuarina glauca and 'Coastal Sands Shrub/Fern Forest' (ecosystem 28) of Thomas et al. (2000); 'Littoral Thicket' (map unit 63) and part of 'Coastal Sand Forest' (map unit 64) of Tindall et al. (2004); 'Coastal Sand Bangalay-Blackbutt Forest' (map unit 25) of NPWS (2002); and 'Dry Dune Shrub Forest' of Keith and Bedward (1999)	Assess references to existing vegetation classification sources in the determination. The panel will note whether the existing classifications are 'included within' are 'part of' or 'component of' the determination Classifications developed using traceable quantitative data will be recognised as primary data upon which to assess floristic, habitat and distributional characteristics. Where data has been sourced and used in alternate regional or local classification studies the results will be considered by the panel to assist in the development of the TEC definitional attributes	We analysed relationships between new samples collected on state forest and samples used to define source classifications. We found no evidence of plots related to any source classifications located in any SF in our region	Agreed
Characterised by the list of 86 plant species	Be guided by the species lists presented in the determination	We relied on the comparative analysis with source classifications to define the TEC in the South Coast region	Noted

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Appendix A.

Communities for which all previously allocated plots were included in one or more analyses.

Table A1: Vegetation groups described by Gellie (2005).

vg	VEG_GROUP
VG 1	Southern Coastal Foothills Dry Shrub Forest
VG 2	Coastal Lowland Dry Shrub Forest
VG 3	Northern Hinterland Dry Shrub Forest
VG 5	Jervis Bay Lowlands Dry Shrub-Grass Forest
VG 6	Southern Coastal Lowlands Shrub/Tussock Grass Dry Forest
VG 7	Southern Coastal Hinterland Dry Shrub-Tussock Grass Forest
VG 8	Far Southern Coastal Dry Shrub Forest
VG 9	Coastal Lowlands Cycad Dry Shrub Dry Forest
VG 10	Southern Coastal Lowlands Shrub-Grass Dry Forest
VG 11	Coastal Shrub/Grass Dry Forest
VG 12	Coastal Hinterland (Buckenbowra) Dry Shrub-Cycad Forest
VG 13	Deua-Belowra Rainshadow Dry Shrub-Tussock Grass Forest
VG 18	Southern Coastal Hinterland Moist Shrub-Vine-Grass Forest
VG 19	Coastal Escarpment and Hinterland Dry Shrub-Fern Forest
VG 20	Coastal Hinterland Ecotonal Gully Rainforest
VG 21	South Coast Foothills Moist Shrub Forest
VG 24	Coastal Wet Heath Swamp Forest
VG 25	South Coast Swamp Forest Complex
VG 26	Coastal Dune Herb/Swamp Complex
VG 27	Ecotonal Coastal Swamp Forest
VG 28	Coastal Sands Shrub-Fern Forest
VG 29	Northern Coastal Sands Shrub-Fern Forest
VG 30	Jervis Bay Moist Shrub-Palm Forest
VG 33	South Coast Hinterland Gully Head Shrub Forest
VG 35	South Coast and Byadbo Acacia Scrubs
VG 47	Southern Escarpment Herb - Grass Moist Forest
VG 48	Coastal Lowlands Riparian Herb-Grass Forest
VG 49	South Coast Hinterland Shrub-Herb-Grass Riparian Forest
VG 50	South Coast Escarpment DryHerb-Grass Forest
VG 51	Araluen Acacia Dry Herb-Grass Forest
VG 52	Bega Valley Shrub/Grass Forest
VG 53	Riparian Acacia Shrub-Grass-Herb Forest
VG 54	Far Southern Dry Grass-Herb Forest-Woodland (171)
VG 56	Tableland and Escarpment Moist Herb-Fern Grass Forest
VG 57	Southern Escarpment Shrub-Fern-Herb Moist Forest

vg	VEG_GROUP
VG 58	Tableland and Escarpment Wet Layered Shrub Forest
VG 59	Eastern Tableland and Escarpment Shrub-Fern Dry Forest
VG 61	Southern Escarpment Edge Moist Shrub Forest
VG 62	Southern Escarpment Edge Moist Shrub-Fern Forest
VG 64	Southern East Tableland Edge Shrub-Grass Dry Forest
VG 136	08a Sandstone Plateau Heath Forests
VG 137	08a Sandstone Plateau Heath Forests
VG 138	08a Sandstone Plateau Heath Forests
VG 139	08a Sandstone Plateau Heath Forests
VG 143	08b South Coast/Hinterland Heathlands/Tall Shrublands
VG 165	Southern Escarpment Cool-Warm Temperate Rainforest
VG 166	Central Coastal Hinterland and Lowland Warm Temperate Rainforest
VG 167	Coastal Lowland Sub Tropical-Littoral Rainforest
VG 168	Araluen Ecotonal Granite Dry Rainforest
VG 169	Coastal Hinterland Sub Tropical Warm Temperate Rainforest
VG 170	Southern Coastal Hinterland Dry Gully Rainforest
VG 171	Coastal Shrub/Grass Forest
VG 179	Eastern Deua Dry Shrub Forest:

Table A2: Communities described by Tozer et al. (2010).

SCIVI_ALLO	MAPUNIT
e1	Southeast Dry Rainforest
e13	Southeast Hinterland Wet Fern Forest
e14	Southeast Hinterland Wet Shrub Forest
e15	Southeast Mountain Wet Herb Forest
e17	Southeast Flats Swamp Forest
e18	Brogo Wet Vine Forest
e19	Bega Wet Shrub Forest
e20p229	Southeast Lowland Grassy Woodland
e25	Southeast Sandstone Dry Shrub Forest
e26	Southeast Tableland Dry Shrub Forest
e27	Waalimma Dry Grass Forest
e28	Wog Wog Dry Grass Forest
e29	Nalbaugh Dry Grass Forest
e3	Rocky Tops Dry Scrub Forest
e30	Wallagaraugh Dry Grass Forest
e31	Southeast Hinterland Dry Grass Forest
e32a	Deua-Brogo Foothills Dry Shrub Forest
e32b	Far South Coastal Foothills Dry Shrub Forest
e33	Southeast Coastal Range Dry Shrub Forest

SCIVI_ALLO	MAPUNIT
e34	Southeast Coastal Gully Shrub Forest
e35	Southeast Escarpment Dry Grass Forest
e37	Southeast Lowland Gully Shrub Forest
e38	Far Southeast Riparian Scrub
e39	Bega-Towamba Riparian Scrub
e4	Brogo Shrub Forest
e42	Southeast Inland Intermediate Shrub Forest
e43	Southeast Mountain Sandstone Shrub Forest
e44	Southeast Foothills Dry Shrub Forest
e46b	Southeast Lowland Dry Shrub Forest
e47	Eden Dry Shrub Forest
e48	Mumbulla Dry Shrub Forest
e49	Southeast Coastal Dry Shrub Forest
e50	Genoa Dry Shrub Forest
e52	Southeast Mountain Rock Scrub
e57	Southeast Lowland Swamp
e60	Southeast Floodplain Wetlands
e6e7	Southeast Warm Temperate Rainforest
m15	Eden Shrubby Swamp Woodland
n183	South Coast Hinterland Wet Forest
n184	Clyde-Tuross Hinterland Forest
n185	Wadbilliga Dry Gorge Forest
p100	Escarpment Foothills Wet Forest
p103	Clyde Gully Wet Forest
p104	Southern Lowland Wet Forest
p105	Floodplain Swamp Forest
p106	Estuarine Fringe Forest
p107	Estuarine Creekflat Scrub
p110	Warm Temperate Layered Forest
p111	Subtropical Dry Rainforest
p112	Subtropical Complex Rainforest
p113	Coastal Warm Temperate Rainforest
p114	Sandstone Scarp Warm Temperate Rainforest
p116	Intermediate Temperate Rainforest
p148	Shoalhaven Sandstone Forest
p3	South Coast Lowland Swamp Woodland
p30	South Coast River Flat Forest
p31	Burragorang River Flat Forest
p32	Riverbank Forest
p33	Cumberland River Flat Forest

SCIVI_ALLO	MAPUNIT
p34	South Coast Grassy Woodland
p38	Grey Myrtle Dry Rainforest
p40	Temperate Dry Rainforest
p44	Sydney Swamp Forest
p45	Coastal Sand Swamp Forest
p58	Sandstone Riparian Scrub
p63	Littoral Thicket
p64	Coastal Sand Forest
p85	Currambene-Batemans Lowlands Forest
p86	Murramarang-Bega Lowlands Forest
p89	Batemans Bay Foothills Forest
p90	Batemans Bay Cycad Forest
p91	Clyde-Deua Open Forest
p95	Southern Turpentine Forest
p99	Illawarra Gully Wet Forest

Appendix B.

Plots assessed as Bangalay Sand Forest

Reference plots are those that are strongly matched floristically to a community cited in the final determination and for which habitat features match environmental descriptors in the final determination. We have a high degree of confidence that these belong to BASF.

SurveyID	Sitename	latitude	longitude	SCIVI	SCIVI memb	Gellie	Gellie memb
P5MA	ALB001CS	-34.596898	150.897425	p63	0.65	g28	0.11
KILLALEA20	ALB22Q4S	-34.624954	150.858186	p63	0.72	g28	0.19
ILLAWARRA	ALP20Q8U	-34.499727	150.889175	p64	0.91	g28	0.72
ILLAWARRA	ALP21Q5F	-34.508365	150.882967	p64	0.9	g29	0.31
ILLAWARRA	ALP25A0F	-34.508509	150.882996	p64	0.84	g29	0.37
ILLAWARRA	ALP29Q7M	-34.509435	150.882809	p64	0.73	g29	0.35
EA_BOOD	BD0000F1	-35.148286	150.666584	p64	0.77	g29	0.99
EA_BOOD	BD0000F2	-35.148691	150.654894	p64	0.99	g28	0.99
EA_BOOD	BD0000F3	-35.154927	150.654309	p64	0.98	g28	1
EA_BOOD	BD0000F4	-35.127767	150.751825	p64	0.76	g28	0.99
EA_BOOD	BD0000F9	-35.126523	150.762546	p64	0.97	g28	1
EA_BOOD	BD000F10	-35.127177	150.762342	p64	0.65	g136	0.48
EA_BOOD	BD000F12	-35.149313	150.678255	p64	0.62	g29	1
EA_BOOD	BD000F18	-35.150883	150.602949	p64	0.99	g28	1
EA_BOOD	BD000F19	-35.171387	150.600020	p64	0.98	g28	1
EA_BOOD	BD000F20	-35.171650	150.603745	p64	0.96	g28	1
P5MA	BRY002CS	-34.833348	150.743243	p64	0.99	g28	0.98
P5MA	BRY003CS	-34.824247	150.747887	p64	0.93	g28	0.48
P5MA	BRY004CS	-34.843395	150.745921	p64	0.96	g28	0.7
NOWRA2011	CRO11M2	-34.993962	150.769779	p64	1	g29	0.8
ELA_GARRAD	ELAGAR05	-35.304231	150.464084	p64	0.96	g28	0.25
NP_EURO	EP008F	-35.952180	150.146159	p64	0.79	g28	0.78
NP_EURODB3	EURJM06P	-35.886699	150.140649	p64	0.97	g28	0.96
P5MA	GER002CS	-34.789809	150.772854	p64	0.76	g28	0.54
ROYAL	HSFL101	-34.088446	151.148704	p64	0.81	M9	0.21
V_BENBOFB4	JMBEN71	-36.933610	149.899400	p64	0.59	M9	0.34
V_BENBOFB4	JMBEN72	-36.931236	149.902498	p64	0.88	g28	0.75
V_BIAMAFB4	JMBIA22	-36.466722	150.060421	p64	0.99	g28	0.98
ROYAL	LGFL107	-34.109932	151.138479	p63	0.59	M3	0.22
P5MA	MIL006CS	-35.362941	150.488655	p64	0.97	g28	0.43
P5MA	MIL022CS	-35.303904	150.462585	p64	0.64	E37	0.19
EURO_CSU	MOR35Q3D	-35.954688	150.138309	p64	0.68	g11	0.84
EURO_CSU	MOR54Q3D	-35.931649	150.158655	p63	0.78	g22	0.33

SurveyID	Sitename	latitude	longitude	SCIVI	SCIVI memb	Gellie	Gellie memb
P5MA	NOW019CS	-34.991408	150.746535	p64	0.99	g28	0.98
Kiama_Shel	SD004	-34.597669	150.894779	p63	0.77	g28	0.74
Kiama_Shel	SD007	-34.617135	150.854984	p63	0.98	g27	0.54
ROYAL	SDES101	-34.082331	151.161841	p64	0.8	g28	0.22
ROYAL	SDES102	-34.146475	151.110565	p63	0.98	g27	0.47
ROYAL	SDFL105	-34.078791	151.166252	p63	0.69	M17	0.23
ROYAL	SDFL106	-34.084611	151.133615	p64	0.51	M17	0.37
ROYAL	SDMA101	-34.081462	151.164027	p63	1	g27	0.37
ROYAL	SDMA102	-34.081414	151.160777	p63	0.99	g27	0.26
ROYAL	SDMA103	-34.166565	151.068896	p63	0.99	g28	0.31
ROYAL	SDMA104	-34.167466	151.068876	p63	1	g27	0.25
ROYAL	SDMA105	-34.080586	151.165726	p63	0.99	g27	0.3
NOWRA_DIST	SMB01	-34.805201	150.766123	p64	0.99	g29	0.88
NOWRA_DIST	SMB02	-34.796208	150.767338	p64	0.95	g28	0.41
V_COAST_1F	SPOTLR11	-36.017678	150.153149	p63	0.83	g27	0.59
ROYAL	SSMA105	-34.077004	151.167375	p63	0.63	g28	0.19
P5MA	SUS003CS	-35.193980	150.565423	p64	0.72	g28	0.95
NP_SCRA	SZ22072F	-35.859347	150.165004	p64	0.99	g28	0.94
NP_SCRA	SZ22073F	-35.859823	150.166083	p64	0.88	g28	0.97
NP_SCRA	SZ23006	-34.796155	150.767427	p64	0.98	g29	0.96
NP_SCRA	SZ23011	-34.805155	150.766091	p63	0.99	g27	0.63
NP_SCRA	SZ23081	-35.296256	150.458547	p64	0.77	g29	0.71
ILLAWARRA	WLL20Q5S	-34.405191	150.902105	p63	1	g27	0.42
ILLAWARRA	WLL99Q0F	-34.401240	150.903074	p63	0.95	E61	0.28
ShoalVeg15	SCCJB34	-34.935246	150.765810	p63	0.86	M17	0.26
FSCRESFM	JMBARN04	-35.406571	150.434773	p64	0.99	g28	0.91
FSCRESFM	JMBARN06	-35.407837	150.441361	p64	0.61	g28	0.45
FSCRESFM	JMMER08	-35.450591	150.399689	p64	0.99	g28	1
FSCRESFM	JMMER23	-35.430235	150.411688	p64	0.92	g28	0.56
FSCRESFM	JMMER26	-35.467235	150.390714	p64	0.99	g28	0.99
FSCRESFM	JMMER31	-35.449457	150.401455	p63	0.68	g28	0.39
FSCRESFM	JMMUR24	-35.634111	150.313642	p63	0.6	M17	0.12
FSCRESFM	JMMUR27	-35.648509	150.291285	p64	0.81	g28	0.49