

Using environmental variables and multivariate analysis to delineate preferred habitat for *Cryptostylis hunteriana*, the Leafless Tongue Orchid, in the Shoalhaven Local Government Area, NSW

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Abstract: An improved approach to predicting preferred habitat and targeting survey effort for threatened plant species is needed to aid discovery and conservation of new populations. This study employs several approaches to aid in the delineation of preferred habitat for the Leafless Tongue Orchid, *Cryptostylis hunteriana* Nicholls. BIOCLIM, a bioclimatic analysis and prediction system, is used initially to generate a bioclimatic habitat envelope within which the species can be expected to occur, based on all known sites in the Shoalhaven Local Government Area. Within the BIOCLIM envelope it is possible to further investigate the extent to which the species exhibits preferences for other habitat factors such as geology, soil landscapes and forest ecosystems. Multivariate techniques are used to compare floristic data from sites where *Cryptostylis hunteriana* is present, and sites from forest ecosystems where it has not been recorded historically. These techniques are also used to identify species which are diagnostic of each of these sets of sites. All 25 sites with *Cryptostylis hunteriana* populations are restricted to six forest ecosystems having a total area of 15% of the Shoalhaven Local Government Area and 47% of the BIOCLIM envelope. Within these forest ecosystems, ten plant species deemed indicative of the possible presence of the *Cryptostylis hunteriana* are identified.

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Introduction

Cryptostylis hunteriana Nicholls (family Orchidaceae), the Leafless Tongue Orchid (Fig. 1), is a rare, leafless saprophytic terrestrial orchid listed as Vulnerable on Schedule 2, of the NSW *Threatened Species Conservation Act, 1995* (TSC Act). It is also listed as Vulnerable under the provisions of the *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act) and has a RoTAP coding (Briggs & Leigh 1996) of (3VC-), indicating that the species is vulnerable, and has a geographic range greater than 100km, with at least one population (population size unknown) occurring in a conservation reserve.

There is an increasing need to improve our understanding of preferred habitat for rare plant species, particularly for those species regarded as cryptic. *Cryptostylis hunteriana* can be particularly hard to detect beyond its short-lived flowering event, as a consequence of its limited flowering period and the lack of above-ground parts. It is often the case for geophytic orchid species that little is known of their distribution and habitat preferences at the time of their listing on schedules of State and Commonwealth legislation, with the consequence that effective recovery planning may either be delayed or be ineffectual.

Lack of knowledge of preferred habitat can also place species at risk in areas undergoing rapid and intensive development. Section 79C(1)(b) of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) requires consideration of ‘...the likely impacts of that development,



Fig. 1. Leafless Tongue Orchid, *Cryptostylis hunteriana*, at Callala, Jervis Bay (Photo: Claire deLacey).

including environmental impacts on both the natural and built environments...'. Particularly relevant in this regard is the '8-part test' under s5A of the EP&A Act in relation to threatened species, whose points are designed to determine '...whether there is likely to be a significant effect on threatened species, populations or ecological communities, or their habitats...'. A better understanding of what constitutes preferred habitat for such species can improve our ability to meet conservation objectives for threatened species and their habitats. Any refinement in the delineation of habitat preferences for threatened species can also save time and resources, as it makes it possible to concentrate survey effort in those areas where the species is more likely to occur.

Cryptostylis hunteriana has been selected for this investigation on the basis that its distribution is incompletely known at present, and it is a species under threat from development, both within the Shoalhaven City Council area and in other parts of its known range. The species is amenable to study, as a sufficient number of sites have been identified (at least within the Shoalhaven region) to make an analysis of habitat preferences possible.

Our objective is to investigate the extent to which an existing dataset can be used to refine our understanding of habitat preferences for a threatened species with a limited number of known occurrences. It is often a characteristic of rare (and particularly cryptic) plant species that to find additional populations, expensive and time consuming field work is required, but that formal survey approaches, such as stratified random sampling (Austin & Heyligers, 1989), have very limited application. It is also the case that some of the modelling approaches, such as Generalized Linear Models (GLMs) and Generalized Additive Models (GAMs), that have been developed in recent years (Yee & Mitchell, 1991) require more data than are typically available for such species. For example, Elith (2003) using GLMs and GAMs found that the rarity of *Westringia davidii* placed severe restrictions on the number of variables that could be used, and that the explanatory power of the model developed in that study was limited.

The approach taken in this paper belongs to the category of environmental envelopes discussed by Guisan and Zimmermann (2000). In this approach, an initial envelope is divided into sub-envelopes with varying probabilities of occurrence of the species under consideration within each sub-envelope. In this study, BIOCLIM is used to identify the initial environmental envelope which constitutes the study area. Within this study area, we have made use of indirect parameters (geology, soil landscapes and vegetation), since we are interested primarily in the prediction of preferred habitat, rather than attempting to identify specific physiologically relevant factors. As Guisan and Zimmermann (2000) observe, there is often good correlation between such variables and observed species patterns. This is because they serve to integrate several different kinds of ecologically relevant information.

The ecological literature recognises that there is what may be termed a hierarchy of environmental influences, which relates broadly to scale (Mackey & Lindenmayer 2001, Davey & Stockwell 1991) on the distribution of many plant species. At a regional scale, differences in climate influence both the occurrence (presence/absence) and population parameters (abundance) of a given species. At a more local scale, differences in geology, soils and vegetation (each in turn dependent to some degree on the other) are also known to exert a significant influence. In considering geology, soil landscapes and vegetation, two alternative approaches were available:

- (i) investigation of each of the three parameters independently in order to assess their comparative value in determining preferred habitat and;
- (ii) adoption of a tiered or nested system in which the habitat identified by each variable formed a sub-envelope in which the next variable was assessed.

In this paper, the former approach is taken, recognising Mackey and Lindenmayer's (2001) assertion that while each variable constrains the next (e.g. lithology constrains soil landscape), it does not necessarily wholly contain it. Given our present limited understanding of how various factors interact to influence the distribution of *Cryptostylis hunteriana*, it was considered advisable to take the more inclusive approach of considering each parameter separately.

Indirect parameters are most useful within a geographically limited area. This is due to a tendency of species to compensate for regional differences in climate by utilising locally different aspect or elevation (Guisan & Zimmermann 2000, Prober & Austin 1991). For this reason we have restricted this investigation to the Shoalhaven LGA, although *Cryptostylis hunteriana* does occur more widely. In effect, the trade-off between precision and generality has been resolved in favour of precision.

No attempt has been made to evaluate the predictions of preferred habitat proposed in this paper. Such evaluation is usually effected by means of an independent dataset, or by dividing the existing dataset into two parts; one to generate a set of predictions and the second to test their predictive ability. The difficulty of implementing a formal systematic survey (the best way of acquiring an independent dataset) to establish where *Cryptostylis hunteriana* does and does not occur has already been mentioned above. The second option of dividing the existing dataset into two parts is obviously not suitable for the small datasets which are typically all that are available for rare species.

The approach taken here has the considerable advantage that it can be easily appreciated and understood by non-specialists, such as local government environmental assessment officers. It can also be readily applied in field situations where rapid and straightforward assessments of the likelihood of a rare species being present, must be made; this is particularly important when the species is only observable during a restricted time of the year.

Cryptostylis hunteriana

The Leafless Tongue Orchid, *Cryptostylis hunteriana* Nicholls (family Orchidaceae) (Fig. 1) is a rare, leafless saprophytic terrestrial orchid; based on current information, it appears to be most common in the Shoalhaven area, where the greatest number of populations (25) and the largest population (150+) occur. Other populations in New South Wales are known from the North Coast, Northern Tablelands and Central Coast (Bell 2001). It is also present at three localities in Victoria (Backhouse & Jeanes 1995) and has been recorded from south-east Queensland (Logan 1998). Bell (2001) provides further details on the biology of the species and its habitat preferences on the NSW Central Coast. Two of the three sites described by Bell were considered to belong to the Coastal Plains Scribbly Gum Woodland type (NPWS 2000), while the third was assigned to the Coastal Plains Smooth-barked Apple Woodland type.

Methods

Bioclimatic analysis

The BIOCLIM bioclimatic analysis and prediction system (Nix 1986) has been used to define the study area. The version employed (Chapman 1999) makes use of 16 temperature and rainfall parameters to build a climatic profile for the species based on all the sites where it is known to occur. This profile in turn generates a potential bioclimatic habitat envelope for the Shoalhaven Local Government Area within which the species can be expected to occur, at least in so far as its temperature and rainfall requirements are met.

While BIOCLIM analysis has been used for a wide variety of purposes (Chapman 1999, Lindenmayer Mackey & Nix, 1997, Claridge 2002), it is used here as the first step in a process of identifying preferred habitat for a species. This is based on the recognition that climate is an important determinant of plant species distribution at a broader, regional scale (Prober & Austin 1991, Mackey & Lindenmayer 2001). It is a helpful way of defining a 'study area' within which it is possible to investigate the extent to which other factors, geology and soils, vegetation communities, and species associations influence or reflect the distribution of the species.

Geology and soils

Geological maps of the study area (at a scale of 1:250 000, Geological Survey NSW 1966a, b) were used to determine the geology at each of the 25 sites with known populations of *Cryptostylis hunteriana*. Similarly, soil landscapes were determined from soil landscape mapping (at 1:100 000 scale) carried out as a part of the NSW Comprehensive Regional Assessments Project (Southern Region) (Joint Commonwealth NSW Regional Forest Agreement Steering Committee 1999).

Forest ecosystems

Vegetation mapping was also carried out as a part of the CRA Project (Southern Region) (Thomas, Gellie & Harrison 2000).

A combination of aerial photo interpretation (API), validation fieldwork and PATN analysis was used to produce a set of consistent 1:100 000 scale vegetation mapping units (Forest Ecosystems). More recent and detailed vegetation mapping was available for part of the study area (Graham-Higgs 2002a, 2002b) and was used in preference to the earlier CRA mapping, resulting in a few sites being assigned to more appropriate Forest Ecosystems (FEs).

Field sampling procedures

A 400 m² (20 × 20 metre) plot was used at each of the validated *Cryptostylis hunteriana* sites, and all vascular plant species recorded: plant species identification and nomenclature follows Harden (1990–1993, 2002) and Harden & Murray (2000), and recent name changes in *Cunninghamia* and *Telopea*.

For the purposes of comparison in the multivariate analyses, a comparable subset of 25 (400 m²) plots collected during the CRA from FEs (within the BIOCLIM envelope) in which *Cryptostylis hunteriana* has not been recorded historically was used. The classification dendrogram for the CRA data enabled us to select sample plot data for FEs that were separate from (but related to) those FEs with known occurrences of *Cryptostylis hunteriana*. The decision was made to compare the floristics of the known *Cryptostylis hunteriana* sites with a sub-set of the FEs where it has never been found, rather than with the full range of FEs within the BIOCLIM envelope. This comparison was likely to be more informative if it were limited to floristically related FEs: for this reason, vegetation types such as rainforest, wet gully forest and wetlands were not considered. The intention of these comparisons was to explore the detailed differences in floristics between FEs in which *Cryptostylis hunteriana* is known to occur and FEs in which the species has never been recorded.

Multivariate analyses

Two routines in PRIMER (Plymouth Routines in Multivariate Ecological Research) (Clarke & Gorley 2001) have been used to elucidate differences between the species composition of sites with known populations of *Cryptostylis hunteriana* and that of sites from FEs where the species has not been recorded. Ordination by non-metric multidimensional scaling (MDS) provides a two-dimensional spatial model based on species composition. The similarity percentages routine (SIMPER) was used in order to rank the importance of particular species in discriminating between sample sites in which *Cryptostylis hunteriana* was present and those sites in which it had never been recorded.

Results

BIOCLIM analysis

The bioclimatic envelope (Fig. 2) produced from an analysis of the temperature and rainfall variables at all 25 known sites for *Cryptostylis hunteriana* represents an area with the same

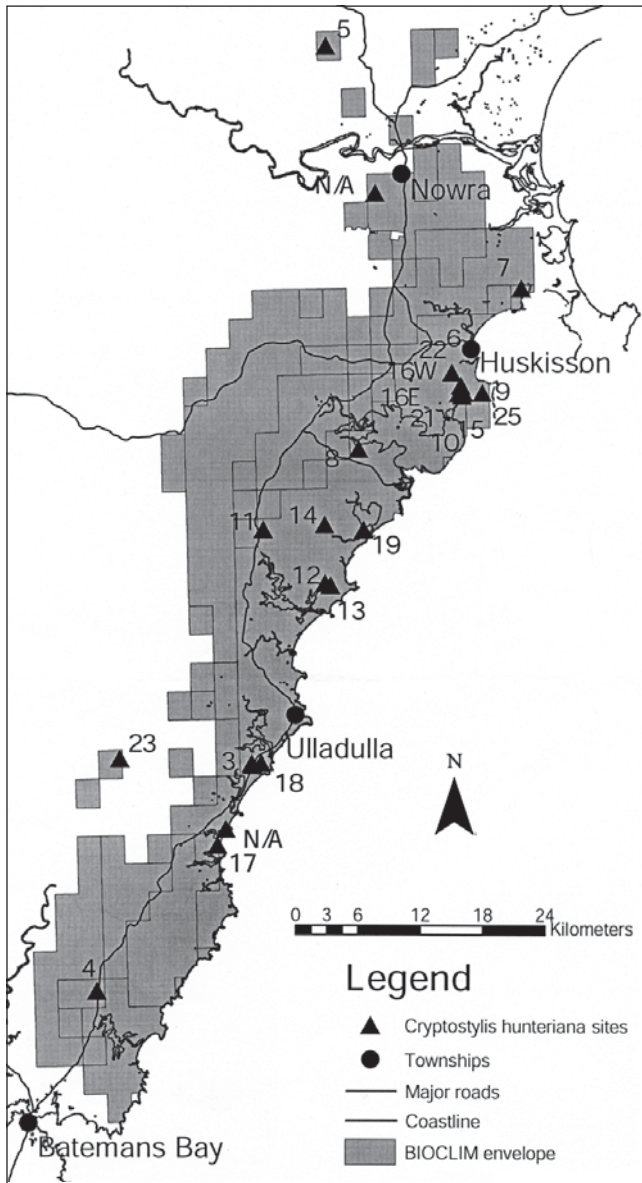


Fig. 2. BIOCLIM potential bioclimatic habitat envelope derived from the climatic profiles at the twenty-five *Cryptostylis hunteriana* sites shown (black triangles).

temperature and rainfall characteristics as the sites with known occurrences of the species. The total area of this envelope is 146 065 ha, representing 31% of the area of the Shoalhaven Local Government Area (468 536 ha).

Correlations with geology and soils

The 25 known occurrences of the *Cryptostylis hunteriana* within the Shoalhaven LGA occur on seven geological units — the Berry, Hawkesbury Sandstone, Conjola and Wandrawandian Formations, as well as areas mapped as Ordovician Sediments, Quaternary Sands and Undifferentiated Sediments (Geological Survey NSW 1966a, 1966b). All of these geological units must be considered to reflect potential habitat for the species.

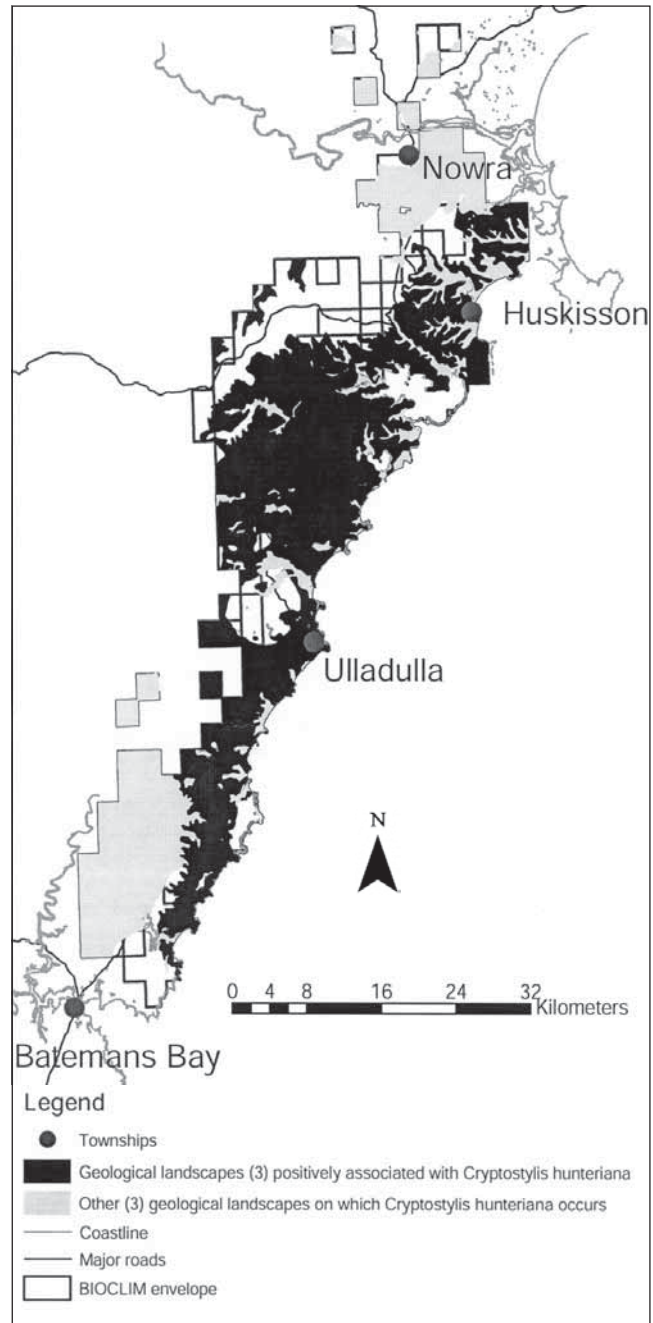


Fig. 3. Extent of the three geological formations positively associated with *Cryptostylis hunteriana* sites (black) and four additional geological formations on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

However it is possible to distinguish two categories of potential habitat by comparing the number of observed occurrences with the number of expected occurrences of the species in each geological unit, based upon the extent of that geological unit in the BIOCLIM envelope (e.g. 10% of known sites would be expected to occur in a geological unit occupying 10% of the BIOCLIM envelope). The observed occurrences are significantly greater than expected occurrences (g-statistic: $p < 0.05$, Sokal & Rohlf 1981) for three of the seven geological formations: Wandrawandian Formation (7 occurrences), Conjola Formation (10

occurrences) and Undifferentiated Sediments (2 occurrences). Taken together, these three formations occupy 81 303 ha or 56% of the study area defined by BIOCLIM and account for 76% of the 25 *Cryptostylis hunteriana* occurrences (Fig. 3).

The remaining 24% of *Cryptostylis hunteriana* occurrences are found on the Berry and Hawkesbury Sandstone Formations, Ordovician Sediments and Quaternary Sands. These geological units total an additional 40 574 ha or 28 % of the study area. Taken together, the potential habitat for the species as defined by geology constitutes 83 % of the study area, a somewhat limited reduction in area in which survey effort would need to be focussed (Fig. 3).

A similar approach taken with the distribution of occurrences of *Cryptostylis hunteriana* in relation to soil landscape mapping reveals the occurrence of the species on nine separately mapped Soil Landscapes. These Soil Landscapes are generally confined to coastal lowland areas which are underlain by sedimentary rocks or unconsolidated deposits, typically in gently undulating terrain. As noted for geological units, when the number of observed occurrences is compared with the number of expected occurrences in each of the soil landscape units, observed occurrences are significantly greater than expected occurrences (g-statistic: $p < 0.05$, Sokal & Rohlf 1981) for three of the nine Soil Landscape units. All of these occurrences are located on siltstones or sandstones in gently sloping country, which give rise to soils which can be described as yellow podzolic. In total they account for 72% of the known occurrences, and the area they occupy is 46 884 ha or 32% of the BIOCLIM envelope (Fig. 4).

The remaining 28% of *Cryptostylis hunteriana* occurrences are spread over the balance of six Soil Landscape types occupying an additional 39 520 ha or 27 % of the study area. In total, the potential habitat for the species defined by soil landscape is 59% of the study area. This is a significant reduction in the area in which surveys should be focussed in comparison with geological mapping (Fig. 4).

Forest ecosystem relationships

When the relationship between the known occurrences of *Cryptostylis hunteriana* and the vegetation community mapping carried out during the Comprehensive Regional Assessment (CRA) project (Thomas, Gellie & Harrison 2000) is examined, the species is found to be present in six mapped Forest Ecosystems (FEs). Observed occurrences of the species are significantly greater than expected occurrences (g-statistic: $p < 0.01$, Sokal & Rohlf 1981) in three of these FEs; short descriptions of these follow:

Forest Ecosystem 2 – Lowland Dry Shrub Forest

This is a medium height forest dominated by *Corymbia gummifera*, sometimes with *Eucalyptus globoidea*, *E. consideniana*, *E. piperita* and *Syncarpia glomulifera* in the Clyde and Shoalhaven catchments. It has a diverse dry shrub understorey, including *Personia linearis*, *Banksia spinulosa*, *Acacia obtusifolia*, *Tetratheca thymifolia*, *Leucopogon lanceolatus*, *Lomatia ilicifolia*, *Acacia terminalis*, *Platysace lanceolata*, *Bossiaea obcordata* and *Gompholobium*

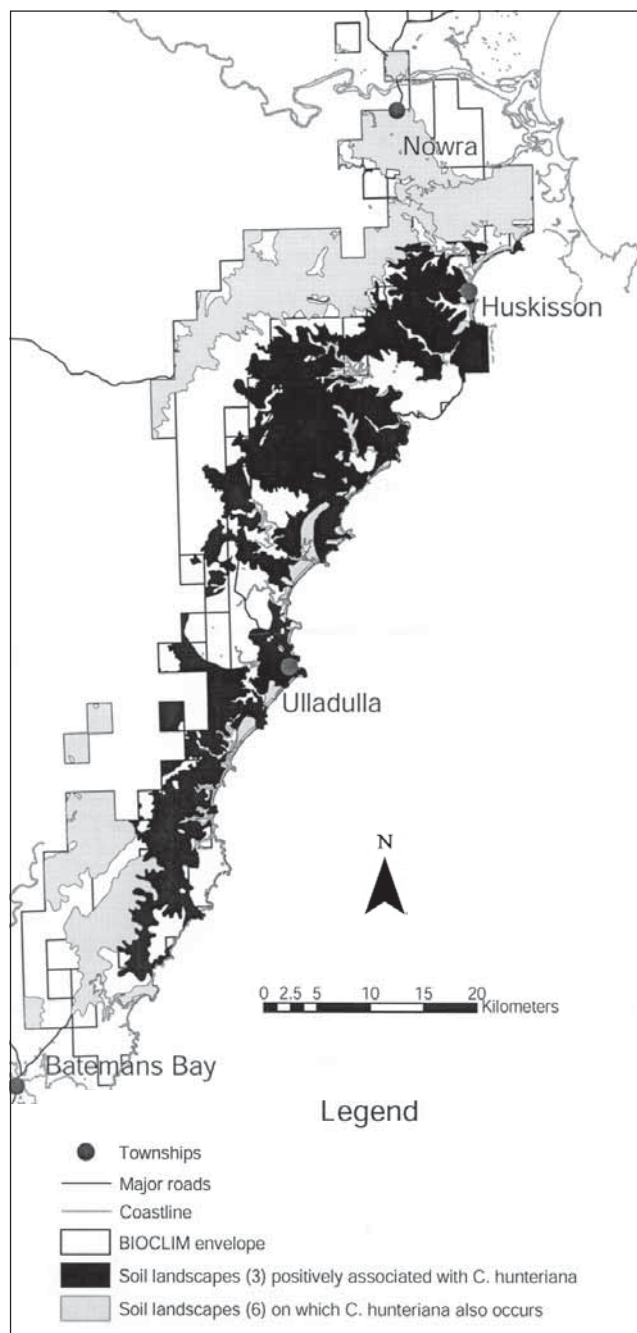


Fig. 4. Extent of the three soil landscape types positively associated with *Cryptostylis hunteriana* sites (black) and six additional soil landscape types on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

latifolium. The ground cover stratum contains grasses (*Entolasia stricta*) and herbs (*Patersonia glabrata*, *Dianella caerulea* var. *caerulea* and *Gonocarpus teucroides*).

Forest Ecosystem 139 – Northern Coastal Hinterland Heath Shrub Dry Forest

This vegetation type comprises mainly medium to low forest dominated by *Eucalyptus sclerophylla* with *Corymbia gummifera* usually present as a sub-dominant. It has a moderately dense heathy shrub layer dominated by species typical of sandstone including *Banksia paludosa*, *Banksia spinulosa*, *Lambertia formosa*, *Hakea dactyloides* and *Leptospermum trinervium*. Ground cover species include *Lepyrodia scariosa* and *Entolasia stricta*.

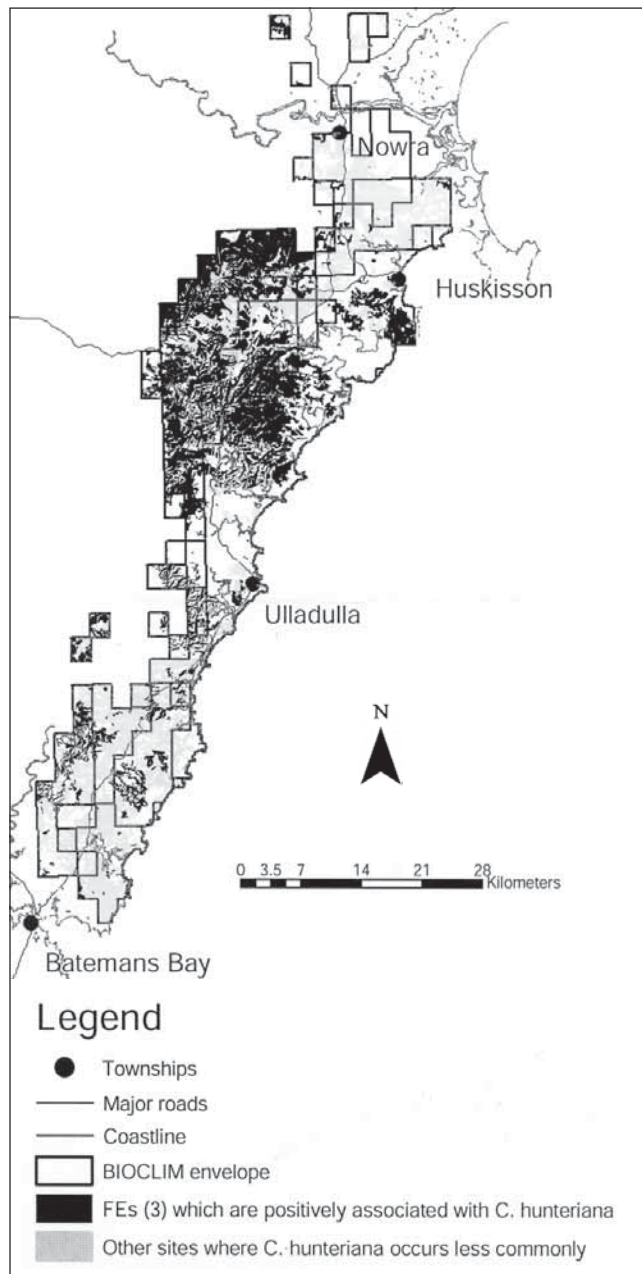


Fig. 5. Extent of the three mapped Forest Ecosystems positively associated with *Cryptostylis hunteriana* sites (black) and three additional Forest Ecosystems on which sites also occur (grey) (superimposed on the BIOCLIM habitat envelope).

Forest Ecosystem 140 – Northern Coastal Tall Wet Heath

This is a wet sedge shrubland up to 3 metres high, comprising an open cover of tall shrubs typically including *Hakea teretifolia*, *Allocasuarina distyla*, *Leptospermum trinervium* and *L. squarrosum*. It has a diverse intermediate shrub layer, with species including *Sprengelia incarnata*, *Banksia paludosa*, *Dillwynia floribunda*, *Bauera rubioides*, *Epacris obtusifolia*, *E. microphylla* subsp. *microphylla*, *Darwinia leptantha* and *Xanthorrhoea resinifera*. Sedges (*Lepidosperma filiforme* and *Restio fastigiatus*) and herbs (*Actinotus minor*) characterise the ground cover layer.

In total, these three Forest Ecosystems account for 84% of the occurrences of *Cryptostylis hunteriana*, occupying 36 451 ha or 25% of the study area (Fig. 5). The remaining

16% of the species' occurrences are found in Forest Ecosystem 5 (Jervis Bay Lowlands Shrub/Grass Dry Forest), Forest Ecosystem 28 (Coastal Sands Shrub/Fern Forest) and Forest Ecosystem 21 (Northern Foothills Moist Shrub Forest). These types (described below) total 22% of the study area or 32 771 ha.

Forest Ecosystem 5 – Jervis Bay Lowlands Shrub/Grass Dry Forest

This is a forest mainly dominated by *Eucalyptus punctata* along with *Corymbia gummifera* and *Eucalyptus eugenioides*. The shrub layer includes *Allocasuarina littoralis*, *Daviesia ulicifolia*, *Melaleuca decora* and *Pimelea linifolia* subsp. *linifolia*. The ground layer contains *Entolasia stricta*, *Themeda australis*, *Lomandra multiflora* subsp. *multiflora*, *Dianella caerulea* var. *caerulea*, *Lepidosperma laterale*, *Opercularia diphylla* and *Brunoniella pumilio*.

Forest Ecosystem 28 – Coastal Sands Shrub/Fern Forest

This is a medium to tall forest dominated by *Eucalyptus botryoides*. The shrub understorey consists of *Banksia serrata*, *Monotoca elliptica*, *Allocasuarina littoralis*, *Breynia oblongifolia* and *Acacia longifolia*. The ground cover is predominantly of *Pteridium esculentum*, *Imperata cylindrica* and *Lomandra longifolia*, along with herbs and twiners such as *Gonocarpus teucroides*, *Glycine clandestina* and *Viola hederacea*.

Forest Ecosystem 21 – Northern Foothills Moist Shrub Forest

This is a forest up to 30 m tall dominated by *Corymbia maculata* and *Eucalyptus pilularis* in the southern part of its range, and *Syncarpia glomulifera* and *Eucalyptus saligna* in the northern parts of its range. An intermediate tree layer comprises *Synoum glandulosum*, *Elaeocarpus reticulatus*, *Notolaea longifolia*, *Acacia mabelliae* and *Persoonia linearis*. An intermediate shrub layer comprises *Macrozamia communis*, *Hibbertia aspera* and *Breynia loblongifolia*. The groundcover is variable and comprises *Gahnia melanocarpa*, *Lomandra longifolia*, *Lepidosperma urophorum*, *Calochlaena dubia* and *Doodia aspera*. Climbing and trailing species include *Pandorea pandorana*, *Clematis aristata*, *Smilax australis* and *Morinda jasminoides*.

When Forest Ecosystems are used as a way of defining potential habitat for *Cryptostylis hunteriana*, there is a further increase in the concentration of the known sites, with all sites confined to 47% of the study area (69 224 ha) (Fig. 5). This represents a significant gain in ability to focus survey effort compared with both geological formations and Soil Landscape units.

Interdependence of environmental influences

As a consequence of the hierarchy of environmental influences broadly related to scale, the habitat variables considered in this paper are not independent of one another. Their interdependence can be seen clearly in Table 1 which summarises the information for lithology, soil landscape and vegetation for each site. The Heath Shrub Dry Forest (FE 139) tends to occur on parent material of the Conjola Formation (conglomerate/ sandstone) and the high silica (BFZ) soils derived from it. Coastal Tall Wet Heath (FE 140), in contrast, tends to be found on the Wandrawandian Formation (mudstone/siltstone) and related low silica (GPZ) soils. As can be seen from Table 1, there are exceptions to this pattern and these cross-overs are probably attributable to

the presence of sandy layers in the Wandrawandian Formation and silty layers in the Conjola Formation.

Lowland Dry Shrub Forest (FE 2) occurs on a greater variety of parent material including Hawkesbury Sandstone, Conjola Formation, Undifferentiated Sediments (generally alluvial material) and Ordovician Sediments. All of these lithologies (with the possible exception of Ordovician Sediments) give rise to high silica soils.

Forest Ecosystem 5 (Shrub/Grass Dry Forest) and Forest Ecosystem 21 (Northern Foothills Moist Shrub Forest) typically occur on silty/clay soils which, in the case of sites 4 and 20, are derived from Ordovician Sediments and Berry Formation parent material. Site 7 appears somewhat anomalous in that floristically it is closely related to FE 140 which is consistent with the GPZ (2) low silica soil, but not the lithology (Quaternary Sands). This site is close to the boundary with Wandrawandian Siltstone and this may have resulted in some influence on the soil and vegetation of the site.

Forest Ecosystem 28 (Coastal Sands Shrub/Fern Forest) is represented by only one site (24) which is found on high silica soils (BFZ); this site is associated once again with the Conjola Formation. It is interesting that this combination of lithology and soil landscape occurs in association with four of the six FEs in which *Cryptostylis hunteriana* is found; this is a useful reminder that other factors apart from lithology and soil have a significant influence on vegetation and possibly also on the orchid's occurrence.

Multivariate analyses

Surveys undertaken as a part of the CRA vegetation mapping provided floristic data comparable in terms of plot size with data collected from sites at which *Cryptostylis hunteriana* is known to occur. While the CRA surveys were not undertaken specifically to add to our understanding of the occurrence of threatened species, the plot data make it possible to compare the floristics of known sites with floristics of sites located within FEs (related in terms of species composition) for which there are no known occurrences of the species. This comparison was found to be more informative than one with a broader range of FEs, given the sensitivity of Multidimensional Scaling (MDS) analysis to floristic differences between samples (M. Austin pers. comm.)

The results of the MDS analysis (Fig. 6) show that even with a two-dimensional representation (stress of 0.15 indicating that two dimensions are reasonably adequate), differences in floristic composition between the sites result in good separation between the sites with *Cryptostylis hunteriana* (designated numerically) and those sites from FEs with no known occurrences of *Cryptostylis hunteriana* (designated alphabetically). This suggests distinct floristic differences between sites with and without the orchid and could provide a further means of determining in the field which sites might repay more intensive survey effort for the species.

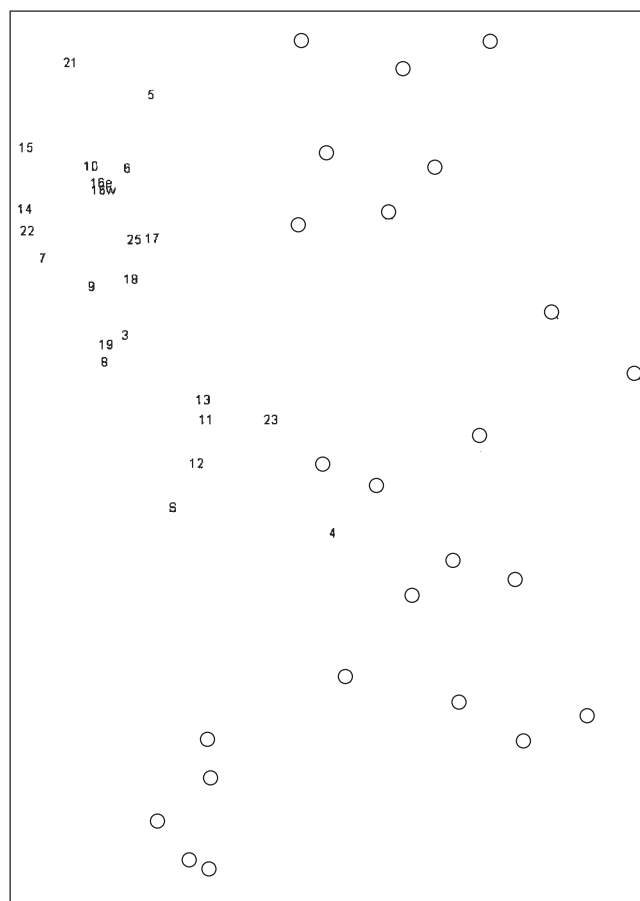


Fig. 6. Multidimensional Scaling representation of the relative position of the sites with *Cryptostylis hunteriana* (numbers) and Forest Ecosystem sites where the species has not been found (○) based on floristic composition.

This possibility is further explored by using the similarity percentages routine (SIMPER) to calculate the percentage frequency of species in both groups of sites. The species most useful as indicators of the possible presence of *Cryptostylis hunteriana* are those with a high frequency of occurrence in the sites where the orchid is present; these species also have a low frequency of occurrence at sites in FEs in which the species has not been recorded. Conversely, species of value as predictors of the likely absence of *Cryptostylis hunteriana* are those with a high frequency of occurrence in FEs where the species has not been recorded and a low frequency of occurrence in sites where the orchid is present. The smaller number of species in the latter category may be due to greater variability in the FEs in which the orchid has not been found (also reflected in the greater spread of these sites on the MDS plot). The species found to be of highest value in this regard are shown in Table 2 together with their frequencies in both groups of sites.

Discussion and conclusions

Since climate is recognised as a fundamentally important environmental factor acting at the broad regional scale, BIOCLIM was a logical starting point in this investigation as

a means of defining the study area within the Shoalhaven Local Government area. It has effectively reduced the area of potential preferred habitat for *Cryptostylis hunteriana* from 468 536 ha of the Shoalhaven LGA to a 146 065 ha bioclimatic habitat envelope, which meets the temperature and rainfall requirements of the species determined from the known sites.

It is often the case that rare species exhibit disjunct distributions: *Cryptostylis hunteriana* is a good illustration of this with occurrences outside the Shoalhaven LGA on the Central Coast of New South Wales as well as in Victoria and Queensland. While it would have been possible to generate a bioclimatic envelope based on all of these sites, the gain in generality would have been at the expense of precision, because over such a large geographic range the local environments utilised by the species would differ significantly. As a general rule, we believe that where disjunct distributions occur, the consideration of each region separately will lead to a more effective delineation of preferred habitat for rare species.

It is noteworthy in this regard that previous habitat descriptions from the NSW Central Coast, Victoria and Queensland (Bell 2001) consistently refer to sandy soils. South Coast occurrences expand information on preferred habitat to include silt/clay loam soils developed on low silica silt/mudstone lithologies of Permian and Ordovician age. It may also be significant in terms of the distributional behaviour of the species over its considerable range that the Central Coast occurrences are all in woodland communities (Bell, 2001) which correspond broadly to the Forest Ecosystems 2 and 139 in this study, while the South Coast and Victorian habitats encompass both woodland and heath.

Within the Shoalhaven LGA, the FEs in which no occurrences of *Cryptostylis hunteriana* have been found to date tend to occur on Permian and Ordovician mudstone/siltstone lithologies, with their associated low silica soils or on granitic parent material. They are also more likely to occur some distance from the coast, at higher elevations and in more sheltered and moist topographic positions and aspects.

The comparison of lithology, soil landscape and vegetation as alternative approaches to the definition of preferred habitat has been both useful and revealing. While these variables are clearly interrelated, they differ markedly in the degree to which they restrict the areal extent of habitat warranting further intensive investigation. While any of the three could be used as a guide in focusing future survey or in evaluating individual sites for their potential to support populations of *Cryptostylis hunteriana*, there are significant gains to be made in using vegetation when all of the known sites are restricted to FEs covering 47% of the study area. This is a significant reduction in the area of potential habitat when compared with lithology (where the preferred habitat based on all of the known sites is 83% of the study area) or with soil landscape (with all known sites occupying 59% of the study area).

Table 1. Interrelationships between geology, soil landscape and forest ecosystem for the 25 known occurrences of *Cryptostylis hunteriana*. * Bold type indicates a statistically significant association between the geology, soil landscape or forest ecosystem units and *Cryptostylis hunteriana*.

Site	Geology*	Soil Landscape	Forest Ecosystem
1	Conjola Fm	BFZ	139
2	Conjola Fm	BHZ	139
3	Conjola Fm	BFZ	139
6	Wandrawandian Fm	GPZ	139
8	Conjola Fm	BFZ	139
17	Conjola Fm	BFZ	139
18	Conjola Fm	BFZ	139
19	Wandrawandian Fm	GPZ	139
9	Conjola Fm	BFZ	140
10	Wandrawandian Fm	GPZ	140
14	Conjola Fm	BFZ	140
15	Wandrawandian Fm	GPZ	140
16	Wandrawandian Fm	GPZ	140
21	Wandrawandian Fm	GPZ	140
22	Quaternary Sands	ABZ	140
25	Wandrawandian Fm	GPZ	140
5	Hawkesbury Ss	BAZ	2
11	Conjola Fm	BFZ	2
12	Undifferentiated Seds	ULZ	2
13	Undifferentiated Seds	ULZ	2
23	Ordovician Sedim	TJZ	2
4	Ordovician Sedim	TJZ	21
7	Quaternary Sands	GPZ (2)	5
20	Berry Fm	NOZ	5
24	Conjola Fm	BFZ	28

For each of the three variables a distinction has been made between two levels of preferred habitat. The testing for significance of the difference between the number of observed vs. expected occurrences in the different FEs provides a basis for this distinction. These two levels may be regarded as more optimal and less optimal habitat. The fact that all but one of the sites with populations > 7 individuals are found in FEs which have a significantly greater number of observed than expected occurrences lends weight to this distinction. Nevertheless, it must be recognised that all known sites carry information about where additional populations might be found. In addition, occurrences that are not in optimal environments may be unusual or restricted in a way that makes them important for conservation of this species.

The use of vegetation in this study as a means of defining preferred habitat and guiding survey has been further refined by making use of floristic data from the sites where *Cryptostylis hunteriana* is known to occur. We know, on the basis of the CRA mapping, that these sites are confined to six FEs. The multivariate analyses used in this study have proven very helpful in comparing site floristics for these six FEs with site floristics for related FEs in which the orchid has not been

found. The MDS analysis shows clearly that, on the basis of floristics, there is good separation between these six FEs and other related FEs in the study area. The PRIMER analysis identifies a set of indicator species characterising the differences between the two groups of FEs.

These species provide a further tool which can be used in the field to decide whether a particular area should be regarded as preferred *Cryptostylis hunteriana* habitat. Their presence at a site can serve as a useful confirmation that the site does in fact constitute preferred habitat. Conversely, the absence of these species (or the presence of species indicative of FEs that are not preferred habitat for the species) may indicate that the species is less likely to occur there.

Table 2. Species with a preference for sites with or without *Cryptostylis hunteriana* (expressed as a high frequency of occurrence at one group of sites and a low frequency of occurrence at the other group of sites).

Species	Frequency	
	Sites with <i>Cryptostylis hunteriana</i>	Sites without
<i>Lomandra filiformis</i>	0.86	0.04
<i>Pimelea linifolia</i>	0.86	0.15
<i>Xanthosia tridentata</i>	0.82	0.04
<i>Lomandra obliqua</i>	0.82	0.23
<i>Lambertia formosa</i>	0.82	0.12
<i>Dampiera stricta</i>	0.73	0.04
<i>Hakea dactyloides</i>	0.73	0
<i>Entolasia marginata</i>	0.64	0.12
<i>Isopogon anemonifolius</i>	0.64	0.04
<i>Kunzea capitata</i>	0.64	0
<i>Dianella caerulea</i>	0	0.65
<i>Lepidosperma laterale</i>	0.09	0.50
<i>Persoonia linearis</i>	0.09	0.50

It is important to stress that in making this comparison the 25 known sites represent an independent data-set superimposed on the CRA mapping. No new occurrences of *Cryptostylis hunteriana* were found during the CRA survey. Though the survey work was largely, if not entirely, carried out at times of the year when the species would not have been detected, it is highly unlikely that survey work at more favourable times of the year would have discovered any new populations, given the limited areas surveyed (400 m² plots) and the rarity and cryptic nature of the species.

We are fully aware that these preliminary steps toward identifying preferred habitat for *Cryptostylis hunteriana* represent hypotheses which remain to be tested. It is important to recognise that as such tests cannot be done for rare or cryptic species such as this by systematic sampling; a different approach is needed. The framework presented in this paper should be seen as a valuable starting point in a process of successive approximation for the identification of preferred habitat. Ideally, it will make it possible to more

readily assess the significance of new occurrences as they are found, and to expand and refine our understanding of habitat preferences.

There are other lines of enquiry which could also be followed to refine habitat preferences for this species. *Cryptostylis hunteriana* is commonly observed to occur in relatively open areas in the Forest Ecosystems in which it is found. Better understanding of the significance of disturbance regimes and competition in determining where the species occurs could be helpful in predicting its presence. The recognised close relationships between orchid species and their pollinators, and with soil fungi, also need to be investigated. It is possible that areas of habitat which are otherwise favourable may be unoccupied because of the absence of a particular pollinator or soil fungus. The fungi associated with saprophytic orchids (ectomycetes) may have alternative host species (Peter McGee pers. comm.) whose presence or absence could also influence *Cryptostylis hunteriana* occurrence.

Several limitations are intrinsic to the approach taken here. The first is the scale at which the three habitat variables were mapped. Mapping at a scale of 1:100 000 is, by its very nature, generalised; however, being all that was available, it was accepted as a useful starting point. More detailed mapping of vegetation for the Shoalhaven LGA is currently underway; and could be used to refine the definitions of preferred habitat presented here. A possible source of such error in mapping at this scale is that a site is incorrectly assigned to a geological, soil landscape or Forest Ecosystem unit where it falls close to a mapping boundary. Sites were checked for all three variables. With regard to geology and soil landscapes, since no independent information was available on these parameters, a conservative position was adopted and no reallocations were made. In the case of FEs, detailed floristic data available for the sites enabled an independent evaluation to be made of the mapping validity. Two sites were considered to be incorrectly mapped on the basis of floristic data. Site X was reassigned from FE 24 to FE 5 (the boundary between these two FEs was 0.02 km from the site). Site W was reassigned from FE 138 to FE 21 also on the basis of a much closer floristic match even though the mapping did not record the presence of the FE in the vicinity of the site.

Existing records constitute a valuable source of information on habitat preferences, although we recognise that there are limitations. We had 25 reliable records for *Cryptostylis hunteriana* extending as far back as thirty years and have endeavoured to show how maximum use can be made of such information to identify preferred habitat and for progressively refinement. Systematic survey work, however desirable, is likely to remain prohibitively expensive and is likely to yield little additional information relative to the effort expended.

We would stress that the results of this study should be used only as an indicator of the types of habitat which are likely to repay further survey effort. They should not be used to argue that no survey is required in areas which have not been shown

to be preferred habitat for the species. This is particularly the case for areas subject to applications to clear or substantially modify native vegetation. It is necessary to continue to gather data, either to confirm hypotheses or to expand understanding of what constitutes preferred habitat for this species.

We recommend that future survey work for *Cryptostylis hunteriana* within the Shoalhaven Local Government Area should:

- Concentrate on areas mapped as one of the six Forest Ecosystems with which *Cryptostylis hunteriana* is associated within the BIOCLIM envelope;
- Within these Forest Ecosystems, particular attention should be paid to sites where species positively associated with the orchid are found to be present; and
- Searching elsewhere should continue, albeit at a lower level of intensity.

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References and bibliography

Austin, M. P. & Heyligers, P. C. (1989) Vegetation survey design for conservation: gradsect sampling of forests in North-east New South Wales. *Biological Conservation* 50: 13–32.

Backhouse, G.N. & Jeanes, J.A. (1995) *The orchids of Victoria* (Melbourne University Press: Carlton).

Bell, S.A.J. (2001) Notes on population size and habitat of the vulnerable *Cryptostylis hunteriana* (Orchidaceae) from the Central Coast of New South Wales. *Cunninghamia* 7(2): 195–204.

Briggs JH & Leigh JD. (1996) *Rare and threatened Australian plants* (Australian NP&WS: Canberra).

Chapman, A.D. (1999) Quality control and validation of point-sourced environmental resource data. In: Lowell, K. A. & Jaton (Eds) *Spatial accuracy assessment: Land information uncertainty in natural resources* (Ann Arbor Press: Ann Arbor, Michigan).

Claridge, A.W. (2002) Use of bioclimatic analysis to direct survey effort for the long-footed potoroo (*Potorous longipes*), a rare forest dwelling rat-kangaroo. *Wildlife Research* 29: 193–202.

Clarke, K. R. & Gorley, R. N. (2001) *Plymouth routines in multivariate ecological research* (PRIMER v5. PRIMER-E Ltd. UK).

Davey, S. M. & Stockwell, D. R. (1991) Incorporating wildlife habitat into an AI environment: concepts, theory and practicalities. *AI Applications* 5: 59–104.

Elith, Jane (2003) *Modelling plant distributions*. PhD Thesis. University of Melbourne.

Geological Survey NSW (1966a) *Wollongong map sheet*. Geological Series Sheet S1 56-9 (1:250,000).

Geological Survey NSW (1966b) *Ulladulla map sheet*. Geological Series Sheet S1 56-13 (1:250,000)

Graham-Higgs, N. (2002a) Meroo-Barnunj vegetation survey and mapping. Unpubl. Report, National Parks & Wildlife Service.

Graham-Higgs, N. (2002b) Murramarang and offshore islands vegetation survey and mapping. Unpubl. Report, National Parks & Wildlife Service.

Guisan, A. & Zimmermann, N. E. (2000) Predictive habitat distribution models in ecology. *Ecological Modelling* 135: 147–186.

Harden, G. (ed.) (1990–93) *Flora of New South Wales*. Vols 1–4. (UNSW Press: Kensington).

Harden, G. ed. (2002) *Flora of New South Wales. Volume 2* (2nd Ed.) (UNSW Press: Kensington).

Harden, G. J. & Murray, L. J. (eds) (2000) *Supplement to Flora of New South Wales Volume 1* (UNSW Press: Kensington).

Joint Commonwealth NSW Regional Forest Agreement Steering Committee (1999) *NSW Comprehensive Regional Assessments Project* (Southern Region).

Lindenmayer, D. B., Mackey, B. G. & Nix, H. A. (1997) The bioclimatic domains of four species of commercially important eucalypts from south eastern Australia. *Australian Forestry* 59: 74–89.

Logan, A. E. (1998) *Cryptostylis hunteriana* Nicholls in Queensland. *The Orchadian* 12(10): 460.

Mackey B. G. & Lindenmayer, D. B. (2001) Towards a hierarchical framework for modelling the spatial distribution of animals. *Journal of Biogeography* 28: 1147–1166.

Nix, H.A. (1986) *BIOCLIM – a bioclimatic analysis and prediction system*. CSIRO Division of Water and Land Resources Annual Report. Pp. 59–60 (CSIRO: Canberra).

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

Prober, S. M. & Austin, M. P. (1991) Habitat peculiarity as a cause of rarity in *Eucalyptus paliformis*. *Australian Journal of Ecology* 16: 189–205

Sokal, R. R. & Rohlf, F. J. (1981) *Biometry. The principles and practice of statistics in biological research*. W. H. Freeman. San Francisco.

Thomas, V., Gellie, N. & Harrison, T. (2000) *Forest ecosystem classification and mapping for the southern CRA Region*. A report undertaken for the NSW CRA/RFA Steering Committee, Project Number NS 08EH.

Yee, T. W. & Mitchell, N. D. (1991) Generalized additive models in plant ecology. *Journal of Vegetation Science* 2: 587–601.