EUCALYPT ECOSYSTEMS PREDISPOSED TO CHRONIC DECLINE:

ESTIMATED DISTRIBUTION IN COASTAL NEW SOUTH WALES

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SUMMARY

Most eucalypt ecosystems depend on frequent low intensity fire to maintain natural nutrient cycles and the balance between established trees and their competitors and arbivores. Absence of frequent fire alters these processes and sometimes allows mass establishment of fire sensitive seedlings. Mature trees can be affected directly by the soil changes and indirectly by enhanced competition and arbivory. This can result in chronic decline of eucalypts and gross changes in the structure and composition of ecosystems. Some species and provenances appear to be genetically predisposed to enhanced arbivory whilst some sites are physically and chemically predisposed to deleterious changes in soil conditions. Thus information on species/site combinations can be used to identify ecosystems that are predisposed to chronic decline in the absence of fire.

In New South Wales relatively unmodified eucalypt ecosystems mainly occur near the coast. We gathered observations of declining eucalypt ecosystems along the coast and used coarse GIS layers to estimate the extent and distribution of species and site combinations that are predisposed to decline. We estimated that 790, 000 hectares, about 18% of the total area, of forests and woodlands in our study area may be predisposed to decline if managed inappropriately. About half the area is private land and half is in conservation reserves and multiple use forests. This preliminary estimate may help to focus attention on areas where adaptive management is necessary to conserve or restore healthy, diverse ecosystems and areas where further investigations are required to identify forests that are predisposed to decline.

INTRODUCTION

Chronic decline of eucalypt forests and woodlands has occurred in Australia since Aboriginal burning was disrupted in the 19th Century (e.g. Curr 1883, MacPherson 1886, Norton 1887, Howitt 1891). Successive widespread episodes of eucalypt decline occurred after forest services implemented broadscale fire suppression in the early 20th Century, after farmers embraced broadacre pasture improvement in the mid 20th Century and after environmentalists prevailed to reduce prescribed burning and grazing in the late 20th Century (Jurskis 2005). This fourth 'episode' is ongoing (St Clair and Jurskis 2010), however Australia's State of the Forests Report does not recognize the problem, referring only to occasional outbreaks of pests and pathogens (Commonwealth of Australia 2008) and quantitative information on the extent of declining eucalypt systems is lacking (Close et al. 2009).

It has long been recognized that some specific instances of eucalypt decline were a consequence of disruption of frequent burning but it was often surmised that the main effect of burning was direct control of arbivores or competitors (e.g. Howitt 1891, Ellis 1964, Campbell and Hadlington 1967, Bowling and McLeod 1968). Mount (1964) suggested that burning may maintain eucalypt health through maintenance of natural nutrient cycling. Landsberg et al. (1990) found that elevated soil N and nutrient imbalance in trees were associated with rural tree decline. Ellis and Pennington (1992) found that soil N tended to increase in the absence of fire and that soil changes impacted directly on roots and mycorrhizae and affected foliar chemistry. Jurskis and Turner (2002) proposed that changes in soil N and consequent impacts on tree physiology were the primary cause of rural and forest tree declines across Australia and recent studies show a consistent association of decline with elevated soil N (e.g. Stone 2005, Close et al 2008, 2011, Turner et al. 2008). Jurskis (2005) extended the concept to encompass other tree species and regions of the world including tree declines associated with industrial emissions. It is now recognised that N accumulation is the main driver of changes in species composition in a wide range of ecosystems around the globe and that chronic tree decline is a facet of this phenomenon (Bobbink et al. 2010).

Turner et al. (2008) quantified soil changes with N accumulation in the absence of fire in dry eucalypt forests at Eden and found that these changes could adversely affect eucalypt roots and nutrition, particularly on infertile, poorly buffered soils in lower topographic positions. Better information on the distribution of native eucalypt systems that are prone to decline will allow better assessment of the potential losses of biodiversity and other socioeconomic values, and will encourage active and adaptive management to minimize losses and enhance benefits (e.g. St Clair and Jurskis 2010). Management options in native forests are limited to silviculture (Simpson and Podger 2000) which may include burning, grazing and other manipulation of vegetation. Burning is the only option that can have widespread application in both conservation reserves and multiple use systems (e.g. Institute of Foresters of Australia 2006, St Clair and Jurskis 2010). Information on the distribution of ecosystems prone to decline can allow managers to integrate fuel reduction burning with ecological burning to maintain or restore healthy ecosystems.

Eucalypt decline is associated with infertile (poorly buffered) and poorly structured soils (restricted rooting depth, drainage and aeration) on flat or concave topography, often low in the landscape, where water and nutrients can accumulate, reducing soil C:N, increasing acidity and creating nutrient imbalances directly or indirectly by impairing mycorrhizae and roots (Jurskis 2005, 2008, Turner et al. 2008). Difficult sites can also occur higher in the landscape, for example on shallow soils over bedrock. Some geological formations characteristically produce such sites (e.g. St Clair 2010) and some eucalypt species are characteristic of such sites, whilst others occur on a range of sites (Jurskis 2005a). Thus forest type (e.g. Jaggers 2004), geology or a combination of the two can indicate species/site combinations predisposed to decline.

Several investigations of chronic decline have occurred in coastal NSW since the Second World War. Moore (1961) identified localities affected by psyllid irruptions during the 1950s before broadscale prescribed burning including aerial ignition was introduced (Jurskis et al. 2003). Investigations recommenced in the 1990s (e.g. Stone et al. 1995) after burning and grazing were reduced in response to environmental concerns (Jurskis et al. 2003). Targeted surveys in State Forests on the north coast in 1992 identified 2000 ha of declining forest (Stone et al. 1995). In 2001 Jurskis and Turner (2002 Appendix 1) recorded observations of eucalypt decline in each coastal drainage system within Bega Valley Shire. Six hours of helicopter survey in 2002 identified 10,000 hectares of declining forest in three coastal regions. In the Eden Region, Jaggers (2004) estimated that roughly 20% of about a half a million hectares of forest appeared to be declining and a further 10% consisted of types that are prone to decline, in young stands that were below the age when decline becomes apparent. Limited sampling in the Batemans Bay Region during a drought in 2002 indicated that about 28% of State forests were stressed (Forests NSW unpublished data). Aerial surveys in the Urbenville region in 2004 identified about 20,000 hectares of declining forest (Jurskis 2005a).

Although much information has accumulated on the process and pattern of eucalypt decline (e.g. Jurskis 2005a, 2008, Turner et al. 2008, St Clair and Jurskis 2010, Jurskis et al. 2011) no broad systematic surveys of native forest health have occurred. We collated the available information together with local knowledge of forestry staff to classify species/site combinations according to their observed pre-disposition to decline. Our classification appears at Appendix 1. In an adaptive management framework, Forests NSW intends to use the information from coastal NSW to attempt to integrate ecological burning with community and asset protection (Jurskis 2011a).

ESTIMATES

Regions, land tenure, areas of native vegetation, and polygons of different categories of predisposition to decline are depicted on the attached CD together with locations of declining forest identified from targeted surveys north of Sydney (Stone et al. 1995, NSW Department of Environment and Climate Change unpublished data). Throughout coastal New South Wales, most eucalypt species and forest types appear to be prone to decline on soils derived from Quaternary alluvial sediments. These soils often have restricted drainage and aeration, and the rooting depth of trees may be restricted. All eucalypt forest types on these substrates were classed as highly prone to decline, except in the Eden Region where most forest types that occur on this substrate had already been individually classified as such by Jaggers (2004). Stands of swamp mahogany, *E. robusta*, appear to be generally predisposed to decline, but since they usually occur on Quaternary alluvium we did not attempt to distinguish them using vegetation layers. Forests or woodlands dominated by red gum, *E. tereticornis* and closely related species, appear to be generally predisposed to decline throughout New South Wales and were also placed in the High category. Other forest types and geological substrates did not occur in all Regions or were categorized differently amongst different Regions. Where a category within an individual Region occurs on more than one geological substrate the locations of the different substrates can be identified on the maps by using the ‘tabs’ on the pdf file to ‘turn each substrate on or off’. Categories of predisposition by Regions are summarized in Appendix 1.

It was estimated that there were in excess of 790, 000 hectares of eucalypt forest and woodland (approximately 18 % of the eucalypt forest area) in coastal New South Wales predisposed to decline by genetic and/or site factors. In some areas the presence of susceptible species (other than red gum) did not necessarily indicate predisposition to decline, and information was lacking on soil and site factors that may predispose trees to decline. An area of 167,000 ha (4 % of the eucalypt forest) was classified as moderately predisposed to decline. There were 149, 000 ha (3 % of the eucalypt forest) where the information on forest types is not sufficiently precise, but there is a likelihood that susceptible species and sites are present. These areas were classed as High/Low in susceptibility. We considered that about half this area was likely to be predisposed to decline, and we included 75, 000 hectares in our overall estimate.

Half (390, 000 hectares) of the identified area of susceptible forests and woodlands is privately owned, whilst approximately 226, 000 hectares are National Park and 175, 000 hectares are State Forest. Eucalypt forest and woodland occupied 105, 000 hectares of Quaternary alluvial substrates north of the Eden Region, and in addition there were 119, 000 hectares of red gum ecosystems on other substrates. These two major categories of susceptible ecosystems are mostly found on private lands. Areas by categories of predisposition, region and land tenure are summarized in an Excel file on the enclosed CD. In addition many declining stands occur in the water supply catchments, National Parks and Wilderness Areas west of Sydney, but little information was available on their distribution and extent.

Eden Region comprises the forests east of the Monaro Tablelands from the Victorian Border north to Cobargo. Forest type information is a combination of some mapping based on aerial photo interpretation (API) according to Forestry Commission of New South Wales (1989) Research Note 17 (RN17) and a modeled vegetation layer (Keith and Bedward 1999). The general distribution of declining forest in most of the region is well known from targeted ground and helicopter surveys and API work over the last decade (Jaggers 2004).

Species that are predisposed to decline include *Angophora floribunda Eucalyptus angophoroides*, *E, bauerana*, *E. bosistoana*, *E. botryoides*, *E. consideniana*, *E. elata*, *E. longifolia*, *E. melliodora*, *E. ovata*, *E. radiata*, *E. smithii* and *E. tereticornis* (Jurskis and Turner 2002, Jurskis 2004b). Forest types containing these species were classified as High in predisposition (Jaggers 2004) and are listed in Appendix 2. Some of the susceptible species may or may not be prevalent in three widespread forest types: Yellow Stringybark - Gum (RN17), Hinterland Wet Shrub Forest and Coastal Foothills Dry Shrub Forest (Keith and Bedward 1999) and these were classed as High/Low in predisposition to decline (Jaggers 2004). Altogether we estimated that 163, 000 hectares of forest and woodland were susceptible to decline including 55, 000 ha where the regrowth stands were still too young (in 2003) to exhibit symptoms of chronic decline (Jaggers 2004). About 52, 000 hectares were State Forest.

The specifications are based solely on vegetation, thus the estimates do not include some declining stands of normally resistant species on difficult sites such as *E. pilularis* on Quaternary alluvium (e.g. Jurskis and Turner 2002 Figure 1). We visually compared our estimates against manual sketches of 121 patches of declining forest identified by aerial reconnaissance in 2002. Fifty three percent of these overlapped with the High category in our estimates and eighty nine percent overlapped with the High and the High/Low categories combined. Ten percent were classed as Low and one patch was classed as non eucalypt forest in the estimates.

Batemans Bay Region extends from Cobargo to Milton and is bounded on the west by Deua and Budawang National Parks. We have no information on the health of forests in these parks. Forest typing based on API is available for most of the public forest in the region, either according to RN17 or the Comprehensive Regional Assessment system (CRAFTI). The remainder of the Region is covered by the southern forest ecosystems (SFE) layer compiled for the Comprehensive Regional Assessment (CRA) using a combination of API and modeling.

A small (0.5%) systematic sample of State Forests during drought in 2002 indicated that about 28% of the forest area was stressed (FNSW unpublished data). Gum – Box – Woolybutt types and Peppermint types were generally unhealthy and remained so after the break of drought. These types were classed as highly predisposed to decline along with any types containing the predisposed species listed for Eden Region. The susceptible species may or may not be prevalent in RN17 types 66 Grey Ironbark - Stringybark, 123 Costal Stringybark, 132 Stringybark – Gum and133 Stringybark – Appletopped Box, and in the Southern Coastal Lowlands Shrub/Grass Dry Forest – *E. globoidea/E. longifolia* 10, Southern Coastal Hinterland Shrub/Vine/Grass Moist Forest – *E.cypellocarpa/E. muelleriana* 18, and the Deua Ecotonal Shrub Forest – *E. smithii/E. cypellocarpa* 34. These were classed as High/Low. White topped box (*E. quadrangulata*) near Milton is prone to decline but it is not distinguished by vegetation mapping or modeling and therefore doesn't factor in the estimates.

Limited field observations suggest that resistant species/types including Sydney blue gum (*E. saligna*), blackbutt (*E. pilularis*) and spotted gum (*Corymbia maculata*) appear to be more predisposed to decline where they occur on the Wagonga Beds near Narooma and Batemans Bay, and possibly on the Moruya Granites near Bodalla, Moruya, Mogendoura, Buckenboura and Currowan. Unless categorized as above, eucalypt forest types on these substrates were classed as moderately predisposed to decline and further field observations are required to test the reliability of this classification. Altogether it was estimated that 98, 000 hectares of forest, including 39, 000 hectares of State Forest, were predisposed to decline.

West of the Region, around Yowrie, Belowra and Araluen, the SFE layer depicts 18, 000 ha of a red gum (*E. tereticornis* and close relatives) type which is likely to be highly predisposed to decline. These were included in the tabular estimates but not mapped.

Nowra Region extends from Milton to Albion Park and west to Morton National Park. We have no information on the health of forests in the National Park. Forest typing based on API is available for most of the public forest in the region, either according to RN17 or CRAFTI. The remainder of the Region is covered by SFE. Little information appears to be available on the health of eucalypt ecosystems in this region, possibly because there are limited areas of declining forest. Some patches of declining Sydney blue gum and mixed stringybark forest have been observed on shelves and slopes under sandstone cliffs on McDonald and Yerriyong State Forests. These may be associated with the Wandrawandian Siltstone. Sydney Blue Gum, Stringybark and Gum types on Wandrawandian Siltstone were classed as highly predisposed to decline and further field observations are required to test the reliability of this classification. Some normally susceptible types on Nowra Sandstone at Currambene appear to be generally healthy. Forests on Nowra Sandstone were categorized as having a low predisposition to decline.

North of the Shoalhaven River, around Kangaroo Valley and Berry, stands of red gum and stands of Sydney blue gum are mostly declining. However some stands of Sydney blue gum and other susceptible species at Barrengarry, Foxground and Macquarie Pass are generally healthy. The declining stands appear to be associated with Budgong Sandstone and the Sydney Subgroup of the Illawarra Coal Measures, whereas the healthy stands appear to be associated with the undifferentiated Illawarra Coal Measures and Quaternary talus. The Sydney blue gum and red gum stands could not be distinguished using SFE. They appear to be depicted as Northern Coastal Hinterland Moist Shrub Forest – *Corymbia maculata/E. pilularis* 21 or as various types of rainforest. Type 21 north of the Shoalhaven River and not on undifferentiated Illawarra Coal Measures or Quaternary talus was classed as highly predisposed to decline.

The SFE layer depicts 13, 400 ha of Shoalhaven Gorge Forest – *E. tereticornis/E. melliodora* 174 to the west of the Region. This type is likely to be highly predisposed to decline. It was included in the tabular estimates but not mapped. An estimated 39, 000 hectares of forest, including 4, 000 hectares of State Forest are predisposed to decline.

Illawarra – Sydney Catchments Region extends from Albion Park to Appin and takes in Sydney Catchment Authority lands east of the Hume Freeway. Detailed forest typing based on API is available for the whole region. The Illawarra vegetation classification covers the coast and escarpment whilst the Woronora classification covers the water supply catchments.

Decline appears to be prevalent in the moist forests of the Illawarra escarpment north of Dapto. Healthy escarpment forests south from Dapto appear to be associated with the undifferentiated Illawarra Coal Measures or Quaternary talus. The moist and the dry, grassy forests on the coastal foothills and plains are predisposed to decline. The following types were classed as highly predisposed to decline unless growing on undifferentiated Illawarra Coal Measures or Quaternary talus: Escarpment Moist Blue Gum Forest 8, Moist Blue Gum - Blackbutt Forest 11, Moist Coastal White Box Forest 9, Moist Gully Gum Forest 10, Tall Open Gully Gum Forest 17, Tall Open Peppermint – Blue Gum Forest 18, Lowland Woolybutt – Melaleuca Forest 24, Coastal Sand Bangalay – Blackbutt Forest 33.

Above the escarpment, woodlands containing some generally susceptible species include: Cumberland Shale Hills Woodland 20, Cumberland Shale Plains Woodland 21 and Highlands Swamp Gum – Melaleuca Woodland 48. These were classed as highly predisposed to decline. Other types contain species that may be predisposed to decline on some sites but we did not have specific information for this Region. The following types were classed as High/Low in predisposition: Nepean Gorge Moist Forest 9, O'Hares Creek Shale Forest 17, Highlands Shale Tall Open Forest 18, Transitional Shale Open Blue Gum Forest 19 and Transitional Shale Dry Ironbark Forest 22. It was estimated that 8, 000 hectares of forest are predisposed to decline.

To the west of the Region in the Nattai and Bargo Conservation Reserves, many of the ecosystems contain species that are susceptible to decline including red gums, round leaved gum (*E. deanei*), and river peppermint (*E. elata*). Descriptions of some of these ecosystems (Department of Environment and Conservation 2004) include photographs of stands that appear to be declining. Examples are Nepean Gorge Moist Forest Mapping Unit (MU) 6, Sheltered Escarpment Blue Gum Forest MU 10, Permian Footslopes Grassy Red Gum – Box Forest MU 18 and Devonian Red Gum – Grey Box Woodland MU 30.

The Cumberland Plain extends north and west from Appin to the Hawkesbury/Nepean River. The Cumberland vegetation classification (National Parks and Wildlife Service 2004) covers most of the native vegetation. More than 90% of the native woodland has been cleared since European settlement (Office of Environment and Heritage 2011), however there appears to be little information on the health of remnant eucalypt stands in this Region. Red gum (*E. tereticornis*) is one of the predominant species, and many stands are declining. The 'profile' of the Cumberland Plain Woodland Endangered Ecological Community (National Parks and Wildlife Service 2004) contains a photograph of a declining stand (evidenced by epicormic growth on branches) of grey box (*E. moluccana*) with a dense shrub layer. Most eucalypt types, except for some woodlands on sandstone, were classed as highly predisposed to decline. Western Sydney Dry Rainforest includes declining eucalypt stands as well as stands with no surviving eucalypts. It was classed as High/Low in predisposition to decline. An area of 56, 000 ha of forest and woodland was estimated to be prone to decline.

In addition many declining stands occur in the water supply catchments, National Parks and Wilderness Areas west of this region (VJ pers. obs.) For example patches of declining forest to the west of Lake Burrogorang are visible from commercial flights between the south coast and Sydney. However little information appears to be available on their distribution and extent in these areas of limited public access.

North of the Hawkesbury Most State Forests are covered by RN17 forest typing and the remainder of each Region is covered by the North Coast Ecosystems layer developed for the CRAs. Some of the Central Coast and Dungog State Forests were covered by API under a different classification – the 'Milli' Types.

Central Coast Region extends north to the Hunter River and west to the Putty Road. There is considerable information on forest health in the Wyong-Morisset area going back to the 1950s (e.g. Moore 1961, Stone et al.

1995) and including some recent research (Stone et al. 2008) that elucidates the pattern of eucalypt decline in the landscape though it misconstrues the process (St Clair 2010, St Clair and Jurskis 2010). A brief helicopter survey in 2002 identified more than 2,500 ha of declining forest in this area (Forests NSW unpublished data). Stands of Sydney blue gum are particularly prone to decline. Ironbark (*E. paniculata* and *E. siderophloia*), narrow leaved white mahogany (*E. acmenoides*), grey gum (*E. propinqua* and *E. punctata*) and round leaved gum in some mixed hardwood stands are also declining (e.g. Stone et al. 1995, 2008). There is little information on forest health in the western part of the Region, however the geology is dominated by Hawkesbury Sandstone, and forests on this substrate do not appear to be prone to decline.

Poorly drained soils and declining forests were evident on the Patonga Claystone whereas soil drainage and forest health were generally better on sandstone substrates. All forests on Patonga Claystone and all forests dominated by blue gums (including *E. deanei* and *E. grandis*) on the Terrigal Formation were classed as highly predisposed to decline. Other undifferentiated formations of the Narrabeen Sediments group are not consistently associated with declining stands. Blue gum forests on these formations were classed as moderately predisposed to decline and further field observations are required to assess the reliability of the classification. Altogether 91, 000 hectares of forest and woodland, including 15, 000 hectares of State Forest, were estimated to be susceptible to decline. Visual comparison against manual sketches of 49 patches of declining forest identified by aerial reconnaissance in 2002 indicated that 80% overlapped with our estimates and 20% were on Permian sedimentary substrates which we classed as indicative of low predisposition to decline.

To the west of the Region, patches of declining eucalypt forest have recently been observed in the Wollemi Wilderness Area (Paul Meek NPWS pers. comm.).

Dungog Region is the area north from the lower Hunter River to Moonan Brook, Gloucester and Taree. Plagues of psyllids were reported from the Barrington Area in 1952 (Moore 1961). In 1992, forest decline was reported in Barrington Tops, Chichester, Copeland Tops, Gloucester Tops and Myall River State Forests in stands dominated by Sydney blue gum or white topped box, *E. quadrangulata* (two stands only) (Stone et al. 1995). Some of these areas are now in conservation reserves. In 1994, four additional areas of declining forest totaling 10 ha were reported in Craven (now a conservation reserve) and Wang Wauk State Forests but details were not given by Stone et al. (1995). Surveys by the Hunter – Central Rivers Catchment Management Authority in 1993 and 2001 revealed extensive decline in stands dominated by yellow box (*E. melliodora*), red gums (including *E. camaldulensis*), rough barked apple (*Angophora floribunda*), various ironbarks, grey gums, grey box (*E. molucanna*) and spotted gum (*Corymbia maculata*) near the coast.

Decline is prevalent in stands currently due for commercial thinning in Chichester State Forest where Sydney blue gum stands at lower elevations are affected. There is a fine scale mosaic with declining stands on concave or flat topography in sheltered positions, and healthy stands on slightly more exposed convex slopes. A fine scale DEM was not readily available, therefore flat/concave topography could not be included as a factor in our estimates. Lower altitude was used as a surrogate. Stands of white topped box, and blue gum types on the 'Cx2' Carboniferous sandstone/siltstone geological unit below 500m altitude were categorized as highly predisposed to decline. However nearly half of the 1992 records (Stone et al. 1995) of declining forest at Chichester were at higher altitudes (> 500m) suggesting that the estimates of extent may have been improved at the expense of location.

Limited field observations suggest that blue gum types on the Bowman Beds (around Gloucester Tops) and on the Booral Formation (around Myall River State Forest) are moderately predisposed to decline and further observations are required to assess the reliability of this classification. An estimated 40, 000 ha of ecosystems, including 5,000 hectares on State Forest, are predisposed to decline.

Wauchope Region

This region is bounded by the Manning/Barnard River, the Northern Tablelands and the Macleay River. Psyllid plagues were reported in Doyles River and Enfield State Forests in the 1940s and 1950s (Moore 1961). Patches of declining forest dominated by Sydney blue gum or mixed hardwoods were reported from Ballengarra, Bril Bril, Bulga, Dingo, Doyles River, Enfield, Giro, Kipparra, Knorrit, Mt Boss, Nowendoc and Riamukka State Forests in 1992 (Stone et al. 1995). Many of these areas are now in conservation reserves. Two virgin stands of Sydney blue gum in the west of the region were declining, and one of these contained white topped box. Eighteen additional declining stands were reported from the western part of the region in 1994. Two were in Tuggolo State Forest, but no details were given by Stone *et al.* (1995). There appears to have been little investigation of forest decline in this Region during the last decade, however areas of declining forest have recently been reported in Kumbatine National Park (Paul Meek NPWS pers. comm.).

North of the Hastings River decline appears to be associated with blue gum and mixed hardwood stands on the Pappinbarra Formation and the Boonanghi Beds in Boonanghi, Bril Bril and Kippara State Forests and Kumbatine National Park. These stands were classed as moderately predisposed to decline. Drier mixed hardwood stands in Ballengarra State Forest were generally healthy. In the south west of the Region, patches of declining forest occur in blue gum, Sydney blue gum – tallowwood and mixed hardwood stands (Stone et al. 1995) on the Carboniferous sediments of the 'DCs' geological unit. These were also classed as moderately predisposed to decline. Stands of white topped box were speculatively classified as highly predisposed to decline. A total area of 115, 000 hectares of susceptible forest was estimated, including 19, 000 hectares of State Forest.

Bellbrook Region lies between the Macleay and Bellinger Rivers and the Oxley - Wild Rivers National Park. There does not appear to be any information on forest health in the National Park. In 1992 small areas of declining forest were reported in Carrai, Irishman, Lower Creek, Nulla Five Day, Oakes, Thumb Creek and Yessabah State Forests (Stone et al. 1995). Many of these areas are now in National Parks. Several declining stands along Georges River were reported in 1994, but no details were given by Stone et al. (1995). Blue gum, Sydney blue gum - tallowwood and mixed hardwood types on the Nambucca Beds or Permian siltstones of the 'Pncx' geological unit were classed as moderately prone to decline**.** Stands of white topped box were speculatively classified as highly predisposed to decline. Altogether 74, 000 hectares, including 9, 000 hectares of State Forest, were estimated to be susceptible.

Coffs Harbour Region extends north from the Bellinger River to the Clarence River and west approximately to the Armidale Grafton Road. Psyllid plagues were reported near Clouds Creek around 1950 in blue gum, white mahogany (*E. acmenoides*) and white gum (*E. dunnii*) stands (Moore 1961), and five small patches of declining forest were reported in 1992 (Stone et al. 1995). There was extensive drought stress in forests between Dorrigo, Glenreagh and Coffs Harbour in 2002 (VJ pers. obs.). In recent years there have been psyllid plagues and decline in some flooded gum, *E. grandis*, and Sydney blue gum stands near Coffs Harbour (VJ pers. obs.). To the north west of this Region, in Gibraltar Range State Forest, a declining patch of several hectares of Sydney blue gum was reported by Stone et al. (1995).

Limited field observations suggest that blue gum and white gum types on the Brooklana, Coramba and Moombil geological units are highly predisposed to decline and further investigations are required to assess the reliability of this classification. Based on observations from Casino and Urbenville Regions, blue gum, white gum and mixed hardwood stands on the Walloon Coal Measures were classified as highly predisposed to decline. The total area estimated to be predisposed to decline was 17, 000 hectares, including 7, 000 hectares of State Forest.

Casino Region comprises the area between the Clarence River and Queensland, excluding the Urbenville Region. No declining forest was reported from Casino Region by Moore (1961) or Stone et al. (1995). However a declining stand of blue gum and ironbark on the Walloon Coal Measures was observed south of Mt. Belmore around 1980 and in recent years declining stands of red gum have been observed in the Bungawalbyn Creek catchment (VJ pers. obs.). To the west of the Region, Stone *et al.* (1995) reported one declining stand in each of Forest Land, Girard and Little Spirabo State Forests, and declining stands have recently been reported from Ewingar State Forest. Blue gum, white gum and mixed hardwood stands on the Walloon Coal Measures were classed as highly predisposed to decline. Altogether 57, 000 ha of susceptible forest and woodland were estimated, including 9, 000 hectares of State Forest.

Urbenville Region lies between Queensland, the Richmond River, the Clarence River and the Bruxner Highway. Near this area, Forestry Commissioner Jolly described declining stands of ironbark (*Eucalyptus siderophloia*) that were affected by scrub invasion and psyllids in the early 20th Century (Forestry Commission N.S.W. 1920). In the early 1980s, decline was evident in a high quality mixed hardwood stand at Section E, South Yabbra (VJ pers. obs.). Some large patches of declining forest dominated by Sydney blue gum or mixed hardwoods were reported from Mt Lindesay, Unumgar and Toonumbar State Forests in 1992 (Stone et al. 1995). Additional areas were known in these forests as well as South Toonumbar and Bald Knob State Forest and a small number of isolated patches of declining blue gum were known from Richmond Range, but no details were given by Stone et al. (1995). Between 1992 and 2002, State Forests that had been frequently burnt in the Urbenville Management Area (Forestry Commission of New South Wales 1995) remained unburnt (Jurskis et al. 2003). Over the same period the area of declining forest increased from about 1000 ha to at least 20,000 ha (Jurskis 2005a).

Forest decline in this region is very closely associated with blue gum, white gum and mixed hardwood types on the Walloon Coal Measures. These were classed as highly predisposed to decline. A total area of 33, 000 hectares of forest and woodland was estimated to be predisposed to decline. About 9, 000 hectares of this are State Forest. Aerial reconnaissance in 2004 identified about 20, 000 hectares of declining forest largely within this region (NSW Department of Environment and Climate Change unpublished data). These areas are depicted on the maps for the Urbenville and Casino Regions. Some displacement of the sketched areas relative to our estimates is evident where boundaries coincide in shape but not position with boundaries of cleared land or non eucalypt forest. Recognising these minor discrepancies, our estimates overlap substantially with the observations of the aerial survey.

The specifications for our estimates capture some areas of declining forest that were previously identified but overlooked in the 2004 reconnaisance, for example at ‘Section E’, south Yabbra and at Edinburgh Castle and Unumgar. The specifications do not capture three moderately large areas of declining forest observed in National Park at upper Duck Creek (on the Woodenbong Beds), and some other small areas scattered through the region. Some blue gum, white gum, and mixed hardwood stands on the Woodenbong beds and on some basalt substrates are declining. Where these stands are close to the mapped boundaries of the Walloon Coal Measures, the mapped boundaries may be inaccurate or the soil conditions may be influenced by the nearby substrate (e.g. St Clair 2010). Some declining stands occur on shallow soils over basalt bedrock where there is poor drainage and aeration. The soils are brown or black and periodically waterlogged whereas forest soils on basalt are more typically well structured krasnozems.

DISCUSSION

Reliability of estimates and potential improvements

Some eucalypts appear to be predisposed to decline throughout their range suggesting a genetic predisposition and/or a fidelity to difficult sites. Along the New South Wales coast these include *Angophora floribunda*, *E. acmenoides*, *E. angophoroides*, *E. bosistoana*, *E. botryoides*, *E. consideniana*, *E. elata*, *E. longifolia*, *E. ovata*, *E. radiata*, *E. robusta*, *E. tereticornis* and its close relatives (Stone et al. 1995, Jurskis and Turner 2002, Jurskis 2004b, Stone *et al.* 2008). These species typically occur as grassy open forests low in the landscape as do red gum systems including *E. blakelyi*, *E. camaldulensis* and *E. rudis* more widely across Australia (Boland et al. 1984). These ecosystems exemplify the interdependence of Aborigines, fire, grassy understoreys and healthy eucalypts that was noted by European explorers and naturalists (e.g. Mitchell 1848, Curr 1883, Howitt 1891, Pyne 1991, Noble 1997, Gammage 2011, Jurskis 2011b).

Other species such as *E. deanei*, *E paniculata*, *E. propinqua*, *E. punctata*, *E. siderophloia* and *E. smithii*, appear to have less site fidelity but are consistently predisposed to decline on difficult sites. Some geological substrates such as Patonga siltstone and the Walloon coal measures reliably indicate these sites. The Wagonga beds and

Moruya granites in the Batemans Bay Region, the Wandrawandian siltstones in the Nowra region and the Brooklana, Coramba and Moombil beds at Coffs Harbour require further assessment. Species such as *E. dunnii*, *E. grandis*, *E. quadrangulata* and *E. saligna* occur on fertile and well structured soils such as krasnozems in the form of wet sclerophyll forests and on poorly structured, drained and aerated soils as naturally grassy forests or woodlands. The wet sclerophyll forests are naturally adapted to high intensity fires at intervals of several centuries and remain healthy over this period whereas the naturally grassy forests are predisposed to decline in the absence of frequent low intensity fire. We speculated that limited areas of *E. quadrangulata* in Dungog, Wauchope and Bellbrook Regions occur on poorly structured soils. Quaternary alluvium typically indicates difficult sites low in the landscape and all eucalypts that grow on these sites are predisposed to decline.

Other geological substrates are very coarse surrogates for soil conditions because they can vary dramatically with microtopography, rainfall, shelter, drainage and upslope catchment area. Fine scale (~ 5 m) DEMs can be used to construct models of microtopography and upslope catchment areas and improve predictions based on species and geological substrates (e.g. Stone et al. 2008), however this is costly and may be impractical for broad areas. We suspect that estimates for the Central Coast, Dungog, Wauchope and Bellbrook Regions, where combinations of forest type and geology were used to classify areas as moderately predisposed to decline could be resolved into precise estimates of High and Low classes in this way. There is no question that estimates for the High class at Dungog based on forest type, geology and altitude would be improved using a DEM rather than altitude.

Comparisons of our estimates against assumed point locations (centroids of nominated compartments) of declining stands identified by targeted surveys in 1992 were not enlightening because forest type at two thirds of the locations did not correspond with the descriptions by Stone et al. (1995), indicating that the assumed point locations were mostly inaccurate. We are aware of many instances where species site combinations that are not considered to be predisposed are suffering chronic decline as a result of very long term absence of fire, modified runon, runoff or watertables, eutrophic runoff from developed areas, rubbish dumping and so on. On the other hand some healthy stands occur where we classed their predisposition as High because management by grazing, burning or slashing has maintained a healthy soil environment (e.g. Jurskis 2004a, 2005a, 2008).

Species and site combinations that are predisposed to decline may remain healthy, despite inappropriate management, until stands reach the pole stage (Manion 1991, Jurskis 2005a, Stone et al. 2008). This was apparent at Chichester State Forest in Dungog Region where there was a rapid expansion in areas of declining blue gum as young stands reached about 30 years of age. In the Eden Region, Jaggers (2004) was able to use detailed logging history and stand structure layers to identify young stands. Detailed information is not generally available for broad areas in other regions. Stand age should be considered in assessing the reliability and the implications of the estimates.

Our specifications encompass 149, 000 hectares of forest classed as High/Low that may contain species predisposed to decline throughout their range. These broadly defined forest types could potentially be examined using remote sensing to distinguish susceptible species and sites, however improving the precision of species typing over broad areas would be costly. In any case remote sensing can be used to directly determine canopy condition. However current research is focused on expensive analysis of imagery with high spatial and/or spectral resolution (e.g. Haywood and Stone 2011) and is unlikely to have broadscale application.

IMPLICATIONS FOR MANAGEMENT

Chronic eucalypt decline has increased across Australia over the past three decades as a result of protracted droughts together with reduced burning and grazing of native vegetation but information on the extent of the problem is lacking (Jurskis 2005, 2008, Close et al. 2009, St Clair and Jurskis 2010). In coastal New South Wales there appears to be little information regarding the forests on the Northern Tablelands escarpment, the Wollemi Wilderness Area, the Sydney water catchments, the upper Shoalhaven, and the Monaro escarpment north of the Bega Valley. These deficiencies should be rectified to inform adaptive management. In State

Forests there appears to be less information in the Wauchope, Bellbrook and Coffs Harbour Regions than in the other Regions, however this appears to reflect a lesser area of declining forest, a greater proportion of less susceptible forest types such as blackbutt and a lower proportion of difficult sites. Improved estimates would involve costly analysis of fine scale DEMs.

Our preliminary estimates provide a starting point for adaptive management in State Forests to improve forest health and productivity, fire safety and conservation of biodiversity. We hope that they will encourage other land managers and regulators to recognize the extent of the problem and address it. Most Endangered Ecological Communities (EECs) (Office of Environment and Heritage 2011) dominated by eucalypts are prone to decline. Red gum ecosystems typify the situation. They were open grassy forests and woodlands in broad river valleys. Aboriginal people managed these areas intensively and they were later targeted by European settlers for agricultural, and eventually urban, development, hence their endangered status. Ironically, frequent fire and removal of dead wood are listed as threats to many of these EECs which were frequently burnt and subject to intensive firewood harvesting by Aborigines (e.g. Mitchell 1848). Management of conservation reserves and EECs needs to recognize that human economy shaped these ecosystems over many millennia and that frequent fire or some ecological surrogate is necessary to maintain their natural processes (Jurskis 2011c).

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APPENDIX 1

Description of Categories

UNIT	TYPE	SPECIFICATION	CATEGORY
NSW1	Vegetation	Forest Type: 216, 219, 220 NE CRA number: 166, 173	Cleared
NSW2	Vegetation	Forest Type: 1 – 26, 179 – 235 Broad Forest Type: Rainforest, Non eucalypt forest SFE gridcode: 20, 24, 25, 35, 53, 65, 69, 134, 135, 140, 141, 144, 148, 152, 157, 164 – 170, 177, 178, 185 - 190 Illawarra: Acacia, Allocasuarina, Artificial – Coachwood, Coastal headland – coastal rock, Coastal sand freshwater, C.S. scrub, Coastal swamp, Estuarine alluvial, Estuarine lagoons, Fig, Floodplain, Hind – Lowland dry, Modified, Offshore, Riparian, Robertson cool – Saltmarsh, Seagrass, Submerged, Upland – Weeds Milli: C, Ca, Ca+, Cn, Cr, D, Ls, Nn, P, R, RF, Rb Rb+, Rb-, River, Rm Rm+, Rm-, Rs, T, NE CRA number: 5, 16, 18, 22, 56, 64, 66, 76, 77, 112, 120, 121, 125, 141, 143, 149, 151, 164, 167, 169, 170, 171,172, 192, 193, 199	Not euc forest
NSW3	Geology	Qa – Qd excluding beaches, dunes	High QA
NSW4	Vegetation	Forest Type Group 65 92 93 SFE gridcode 50, 171, 174 Illawarra: 23 Coastal Grassy Red Gum Forest, 13 Moist Box – Red Gum Foothills Forest, Woronora 24 NE CRA number: 42, 44, 46, 47, 54, 116, 183, 187, 190, 208, 238	High Red Gum
BB1	Vegetation	Broad Forest Types southcoastdata.xls	High Veg
BB2	Vegetation	Broad Forest Types southcoastdata.xls	High/Low
BB3	Vegetation	SFE gridcode 11, 28, 48, 49, 51	High Veg
BB4	Vegetation	SFE gridcode 10, 18, 34	High/Low
BB5	Geology	Wagonga Beds	Moderate
BB6	Geology	Moruya Granites	Moderate
N1	Geology X Veg	Wandrawandian Siltstone X Broad Forest Type Sydney blue gum, Stringybark, Gum	High GeoVeg
N2	Geology	Nowra Sandstone	Low
N3	Vegetation	Broad Forest Type Gum – Box – Woolybutt	High Veg
N4	Geology	Pi, Qt	Low
N5	Locality X Veg	North of Shoalhaven River X SFE gridcode 21	High Veg
I1	Geology	Pi, Qt	Low
I2	Vegetation	33 Coastal Sand Bangalay – Blackbutt Forest 8 Escarpment Moist Blue Gum Forest,	High Veg

		24 Lowland Woolybutt – Melaleuca Forest, 11 Moist Blue Gum - Blackbutt Forest, 9 Moist Coastal White Box Forest, 10 Moist Gully Gum Forest, 17 Tall Open Gully Gum Forest, 18 Tall Open Peppermint – Blue Gum Forest	
I3	Vegetation	Woronora: 20, 21, 48	High Veg
I4	Vegetation	Woronora: 9, 17, 18, 19, 22	High/Low
C1	Vegetation	Cumberland 1, 3, 4, 8, 9, 10, 11, 12, 14, 15, 33, 43, 61, 103	High Veg
C2		Cumberland 13	High/Low
C3	Vegetation	other veg types	Low
C4	Geology	no veg layer X Hawkesbury Sandstone	Low
CC1	Geology	Patonga Claystone	High Geo
CC2	Geology X Veg	Terrigal Formation X Forest Type Group: 46/48, Forest Type 52 Milli Types: G, G/D, Mm, Na-, S, Yf, Yh, Yl	High Geo Veg
CC3	Geology X Veg	Terrigal Formation X CRA Nos.: 7, 100, 123, 124, 137, 154, 194, 229, 231, 233, 234,	High Geo Veg
CC4	Geology X Veg	Narrabeen Group X Forest Type Group: 46/48, Forest Type: 52 Milli Types: G, G/D, Mm, Na-, S, Yf, Yh, Yl	Moderate
CC5	Geology X Veg	Narrabeen Group X CRA Nos.: 7, 100, 123, 124, 137, 154, 194, 229, 231, 233, 234,	Moderate
D1	Vegetation	Forest Type 54	High Veg
D2	Vegetation	CRA No 162	High Veg
D3	Geo X Veg X Elevation	Cx2 X < 500m X Forest Type Group: 46/48, Forest Type: 52 Milli Types: G, G/D, Mm, Na-, S, Yf, Yh, Yl	High GeoVegAlt
D4	Geo X Veg X Elevation	Cx2 X < 500m X CRA Nos.: 7, 100, 123, 124, 137, 154, 194, 229, 231, 233, 234,	High GeoVegAlt
D5	Geology X Veg	Bowman Beds X Forest Type Group: 46/48, Forest Type: 52 Milli Types: G, G/D, Mm, Na-, S, Yf, Yh, Yl	Moderate
D6	Geology X Veg	Bowman Beds X CRA Nos.: 7, 100, 123, 124, 137, 154, 194, 229, 231, 233, 234,	Moderate
D7	Geology X Veg	Booral Formation X Forest Type Group: 46/48, Forest Type: 52 Milli Types: G, G/D, Mm, Na-, S, Yf, Yh, Yl	Moderate
D8	Geology X Veg	Booral Formation X CRA Nos.: 7, 100, 123, 124, 137, 154, 194, 229, 231, 233, 234,	Moderate
W1	Vegetation	Forest Type 54	High Veg
W2	Vegetation	CRA No 162	High Veg
W3	Geology X Veg	DCs X Forest Type Groups: 46/48, 47, 60/62 Forest Type: 54	Moderate
W4	Geology X Veg	DCs X CRA Nos.: 7, 36, 69, 85, 91, 100, 104, 137,154, 162, 229, 234,	Moderate
W5	Geology X Veg	Pappinbarra Formation X Forest Type Groups: 46/48, 60/62, Forest Type: 54	Moderate

W6	Geology X Veg	Pappinbarra Formation X CRA Nos.: 7, 36, 91, 100, 137, 154,162, 229, 234,	Moderate
W7	Geology X Veg	Boonanghi Beds X Forest Type Groups: 46/48, 60/62 Forest Type: 54	Moderate
W8	Geology X Veg	Boonanghi Beds X CRA Nos.: 7, 36, 91, 100, 137, 154,162, 229, 234,	Moderate
B1	Vegetation	Forest Type 54	High Veg
B2	Vegetation	CRA No 162	High Veg
B3	Geology X Veg	Nambucca Beds X Forest Type Groups: 46/48, 47, 60/62, Forest Type: 52	Moderate
B4	Geology X Veg	Nambucca Beds X CRA Nos.: 7, 36, 69, 85, 91, 100, 104,123,124, 137,154, 194, 229, 231, 233, 234	Moderate
B5	Geology X Veg	Pncx X Forest Type Groups: 46/48, 47, 60/62, Forest Type: 52	Moderate
B6	Geology X Veg	Pncx X CRA Nos.: 7, 36, 69, 85, 91,100, 104,123,124, 137,154, 194, 229, 231, 233, 234	Moderate
CH1	Geology X Veg	Cc geology X Forest Type Group: 46/48, Forest Types 51, 52.	High Geo Veg
CH2	Geology X Veg	Cc geology X CRA Nos.: 7, 36, 45, 69, 85, 91, 100, 123, 124,137,154, 194, 229, 231, 233, 234	High Geo Veg
CH3	Geology X Veg	Walloon Coal Measures X Forest Type Groups: 46/48, 60/62, Forest Types 51, 52	High Geo Veg
CH4	Geology X Veg	Walloon Coal Measures X CRA Nos.: 7, 36, 45, 69, 85, 91,100,123,124, 137,154, 194, 229, 231, 233, 234	High Geo Veg
Ca1	Geology X Veg	Walloon Coal Measures X Forest Type Groups: 46/48, 60/62, Forest Types 51, 52	High Geo Veg
Ca2	Geology X Veg	Walloon Coal Measures X CRA Nos.: 7, 36, 45, 69, 85, 91, 100, 123,124, 137,154, 194, 229, 231, 233, 234	High Geo Veg
U1	Geology X Veg	Walloon Coal Measures X Forest Type Groups: 46/48, 60/62, Forest Types 51, 52	High Geo Veg
U2	Geology X Veg	Walloon Coal Measures X CRA Nos.: 7, 36, 45, 69, 85, 91, 100, 123,124, 137,154, 194, 229, 231, 233, 234	High Geo Veg

APPENDIX 2

Categories used by Jaggers (2004) for Eden Region

HIGH	HIGH/LOW	LOW
Woolybutt	Yellow stringybark-Gum	Silvertop Ash
Grey Ironbark-Stringybark	Hinterland Wet Shrub Forest	Blueleaved Stringybark
Gum-Box-Stringybark	Coastal Foothills Dry Shrub Forest	Coastal Stringybark
Yertchuk		Red Bloodwood
Peppermints		Southern Blue Gum
Bangalay		Yellow Stringybark
Stringybark-Gum		Mountain Wet Herb Forest
Appletopped Box		Hinterland Dry Grass Forest
Swamp Gum		Foothills Dry Shrub Forest
Myanba Dry Scrub Forest		Inland Intermediate Shrub Forest
Rocky Tops Dry Shrub Forest		Lowland Dry Shrub Forest
Flats Wet Herb Forest		Eden Dry Shrub Forest
Brogo Wet Vine Forest		Coastal Dry Shrub Forest
Brogo Wet Shrub Forest		Silvertop Ash-Stringybark
Coastal Gully Shrub Forest		
Lowland Gully Shrub Forest		
Dry Grass Forests		