1 Coastal Sandstone Upland Swamps, south-eastern Australia

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Classification

International: Most Australian vegetation has not yet been classified in an international system. Regionally, this ecosystem is classified as an Endangered Ecological Community, 'Coastal upland swamps in the Sydney Basin bioregion' under New South Wales legislation (NSW Scientific Committee 2011), also 'Coastal Upland Swamp (map unit FrWp129)' according to Tozer et al. (2010). It does not occur outside New South Wales.
IUCN Habitats Classification Scheme (Version 3.0): 5. Wetlands (inland) / 5.4 Bogs, Marshes, Swamps, Fens, Peatlands.
Key references: Keith & Myerscough (1993), Tozer et al. (2010), NSW Scientific Committee (2011).

Ecosystem description

Characteristic native biota

Upland swamps are soligenous valley bogs, characteristised by a diverse assemblage of hydrophilous, mostly sclerophyllous shrubs, graminoids and forbs (Keith & Myerscough 1993). These bogs are essentially treeless and form relatively abrupt boundaries with surrounding eucalypt-dominated forests and woodlands that occupy more freely draining soils (Fig. 1). Many of the plant species that characterise the bogs are absent from or rare in the surrounding matrix, making them highly distinctive and easily recognised landscape features. Large numbers of characteristic plant taxa belong to families Cyperaceae, Restionaceae, Proteaceae, Myrtaceae, Fabaceae, Ericaceae, Haloragaceae and Droseraceae. Detailed descriptions of the vegetation are given by Keith & Myerscough (1993), Tozer et al. (2010) and NSW Scientific Committee (2011). Although their characteristic vertebrate fauna also occurs in surrounding forests and woodlands, the swamps provide essential resources including permanent water during drought and shelter from predators in dense vegetation cover. The macro- invertebrate fauna and micro-invertebrate stygofauna is highly distinctive, with species of burrowing crayfish, dragonflies, arachnids, hemipterans, dipterans and collembola dependent on the hydrological conditions or host plants that characterise the swamps (Bailey 2010; NSW Scientific Committee 2011).

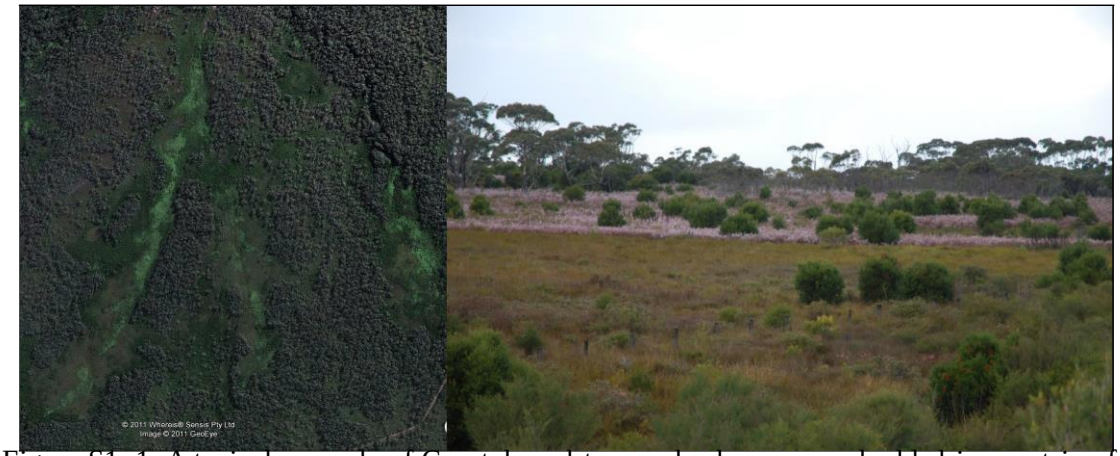

Figure S1. 1. A typical example of Coastal sandstone upland swamp embedded in a matrix of eucalypt forest and woodland from Dharawal Nature Reserve, 45 km south of Sydney, Australia. Note distinctive vegetation zonation within swamps.

Abiotic environment

Coastal sandstone upland swamps are strongly associated with high levels of climatic moisture (mean annual precipitation >1000 mm and exceeding evapotranspiration), low- relief, elevated terrain and poorly drained mineral-organic and peaty sediments on relatively impermeable sandstone substrates (Keith & Myerscough 1993). Several geomorphological and hydrological features of the swamps are typical of those found in uplands on all continents except Antarctica (Gore 1983).

Distribution

Coastal sandstone upland swamps are scattered on sandstone plateaux to the north and south of Sydney (Figure 2).

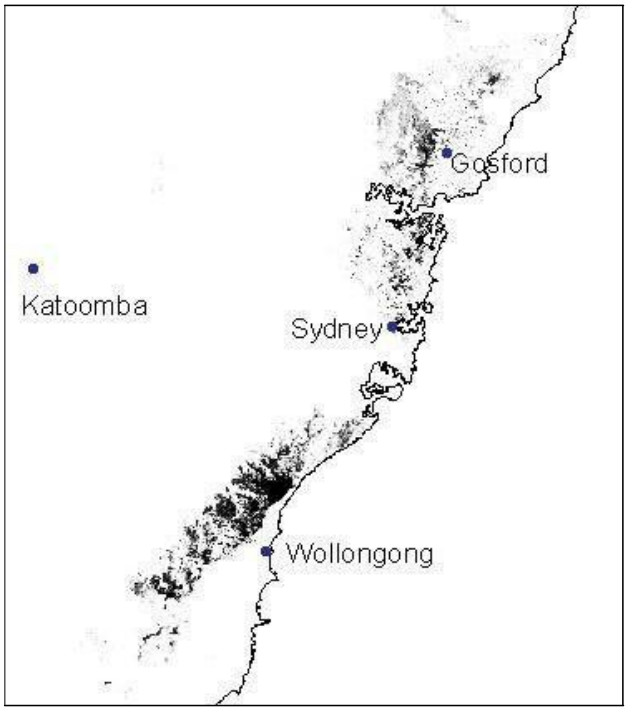

Figure S1. 2. Distribution of Coastal sandstone upland swamps.

Key processes and interactions

Interactions between hydrological processes and fire regimes are crucial to the development of upland swamps and maintenance of their diverse and characteristic biota (Figure 3). Development and persistence of the mire depends on an excess of precipitation over evapotranspiration combined with high surface run-on and low rates of low percolation and run-off. This promotes soil waterlogging, development of dense vegetation and sediment deposition, with positive feedbacks resulting in further impedance to surface and subsurface flow (Young 1982, 1986). Fires regulate plant regeneration niches and vegetation turnover, maintaining fine-scale diversity (Keith et al. 2007). Distinctive zonations of plant assemblages within the swamps (Figure 2 & 3) contribute to high beta diversity and are structured by hydrological gradients and recurring fires (Keith & Myerscough 1993). Variations in hydrological conditions combine with particular fire events (e.g. short fire intervals, intense crown fires, peat fires) to regulate transitions between these assemblages, resulting in a dynamic mosaic over decadal time scales (Keith et al. 2006; 2007; 2010a).

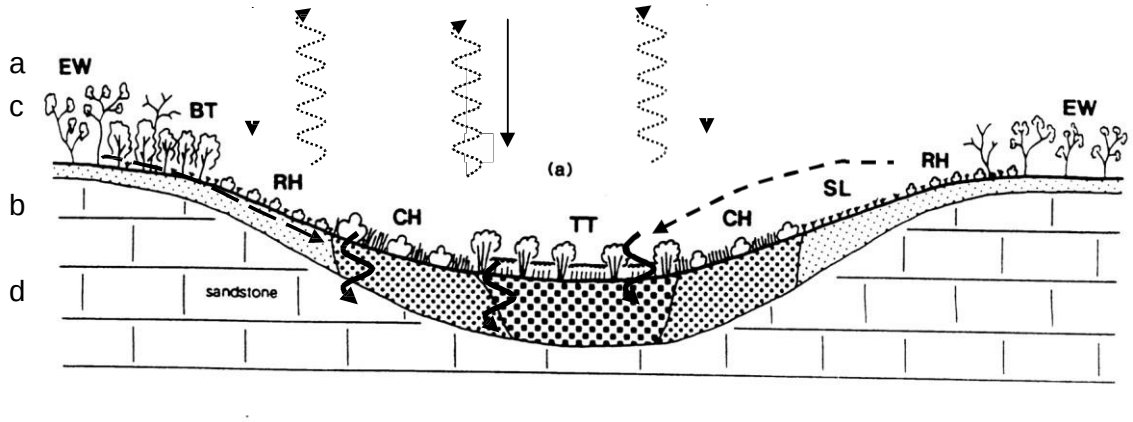

Figure S1. 3. Schematic cross section of upland swamp showing zonation of plant assemblages within upland swamps (TT- Ti-tre Thicket, CH- Cyperiod Heath, SL- Sedgeland, RH- Restioid Heath, BT- Banksia Thicket) and surrounding eucalypt woodland (EW) in relation to soil types with increasing organic matter content (represented by increasingly coarse stippling). Hydrological processes involve an excess of precipitation (a) and run- on/seepage (b) over evapotranspiration (c), percolation (d) and run-off/seepage discharge (not shown, perpendicular to page surface).

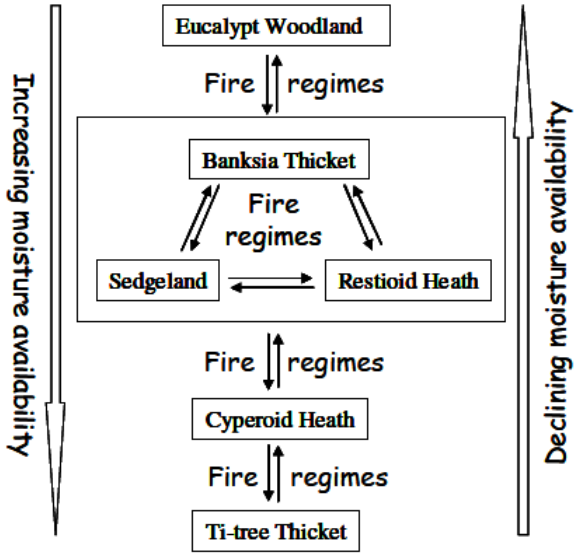

Figure S1. 4. A cause-effect process model summarizing ecosystem dynamics in coastal sandstone upland swamps (adapted from Keith et al. 2006; 2007; 2010).

THREATENING PROCESSES

Three main processes threaten the persistence of this ecosystem. First, extraction of coal and/or gas from underground coal seams beneath the swamps affects their hydrological function by shattering bedrock strata, warping the land surface and disrupting perched aquifers (NSW Scientific Committee 2011). Impacts are highly variable, depending on patterns of bedrock jointing and subsidence, but may include increased percolation, decline of piezometric levels, water quality impacts from unconfinement of groundwater, creation of erosion knick points, valley closure and redistribution of overland flows (Krogh 2007). Second, severe fires may initiate shifts in swamp/woodland boundaries, consumption of peat or erosion. These effects may be mediated or amplified by extremes in post-fire rainfall (Keith et al. 2010). Fire frequencies may also mediate diversity through differential selection of plant life history types (Keith et al. 2007). Third, swamps may be threatened by global climate change through its effects on regional hydrology and fire regimes (Keith et al. 2010a). IPCC projections suggestion declining precipitation, increased evapotranspiration and increased frequency of extreme fire weather days (Hennessy et al. 2004; Lucas et al. 2006).

Ecosystem collapse

For assessment of criteria A and B, collapse was assumed to occur when the mapped distribution of the ecosystem declines to zero, signalling the replacement of upland swamp either by developed areas (e.g. quarries, mines, rural-residential development and roading) or when by dryland ecosystems (e.g. woodland), due to changes in hydrology and fire regimes. Under future scenarios, a collapsed state was assumed when there were no areas remaining of even low modelled hydrological suitability based on the hydrological characteristics of the current distribution of the ecosystem. For criterion C, ecosystem collapse was defined using models of hydrological suitability based on precipitation, evapotranspiration, slope and substrate. Collapse was assumed to occur when summed hydrological suitability reaches zero. Under criterion D, the abundance of woody respouters was identified as the most appropriate biotic variable for assessment, as these species provide crucial habitat structure and sediment stability in the early post-fire environment and are the most sensitive functional group of swamp plants to adverse fire regimes. Collapse was assumed to occur when the abundance of woody resprouters declined to zero.

ASSESSMENT

Summary

Criterion	A	B	C	D	E	overall
subcriterion 1	LC EN(EN-CR)	EN	LC EN(EN-CR)	NT(NT-VU)	DD	EN(EN-CR)
subcriterion 2		EN		DD		
subcriterion 3	LC	LC	DD	DD		

Criterion A

Current decline: In a sample catchment located centrally within the distribution, Keith et al. (2010) compared the extent of upland swamps on aerial photographs flown in 1961 and 1998. They found a 10.2% net expansion of swamps into surrounding woodland (range -3 to 32% between subcatchments), coincident with moistening climatic conditions over that period and a major fire in the late 1960s. In addition, within this same area, it is estimated that approximately 5 to 7% of the area of swamps has been destroyed by quarries, mines, rural- residential development and roading in the past 50 years (Keith 1994 and unpubl. data). Combining these estimates produces an estimated -10 to +27% change in the distribution of the ecosystem over

the past 50 years. Assuming the study area of Keith et al. (2010) is representative of trends across the whole distribution of Coastal sandstone upland swamps,
the status of the ecosystem is Least Concern in under criterion A1. This assumption appears reasonable, given that the study area is centrally located within the core range of the ecosystem and includes both protected and unprotected land tenures.

Future decline: Global climate change may threaten the future persistence of Coastal sandstone upland swamps, given their hydrological dependencies (Figure 2). Keith et al. (2011) developed bioclimatic distribution models for the ecosystem to predict its distribution under future climate scenarios. They developed a range of plausible models based on climatic and terrain variables that were selected to represent the hydrological processes represented in Figure 2 and projected the distributions into the future using two different emission scenarios. Based on these models and scenarios, the distribution of the ecosystem was projected to decline by 58-90% (median 74%) over the next 50 years (Figures 5 & 6). Changes in land use may add to these estimates of decline, but the majority of the ecosystem is within conservation reserves and protected water catchments (Tozer et al. 2010). The status of the ecosystem is therefore Endangered (plausible range Endangered - Critically Endangered
under criterion A2. This estimates does not include changes to hydrology that may be brought about by extraction of underground coal and gas.

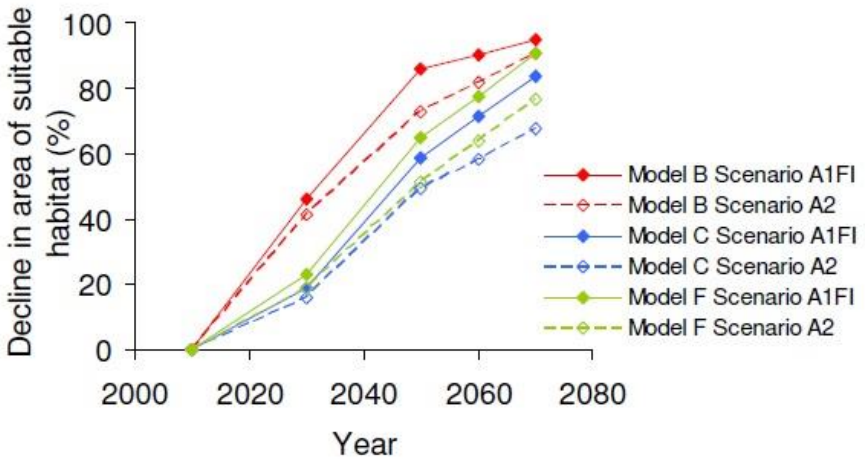

Figure S1. 5. Modelled trends in the distribution of Coastal sandstone upland swamps under climate change scenarios from AR4 (after Keith et al. 2011). See Figure 6 for example maps of projections based on model C and A1FI scenario.

Historic decline: There is insufficient data to estimate changes in swamp-woodland boundaries since 1750. However, 90% the current distribution of the ecosystem has been mapped from recent high resolution aerial photography (Tozer et al. 2010;) and, using historical imagery and mapping of headwater valleys in climatically suitable areas, this distribution has been interpolated into areas that have been transformed by human land use since 1750. Based on this mapping and interpolation, the decline in distribution since 1750 was estimated to be 6 to 8%. Based on its similar landscape and human activity, the remaining 10% of the distribution was assumed to have undergone a similar decline. The status of the ecosystem is therefore Least Concern under criterion A3.

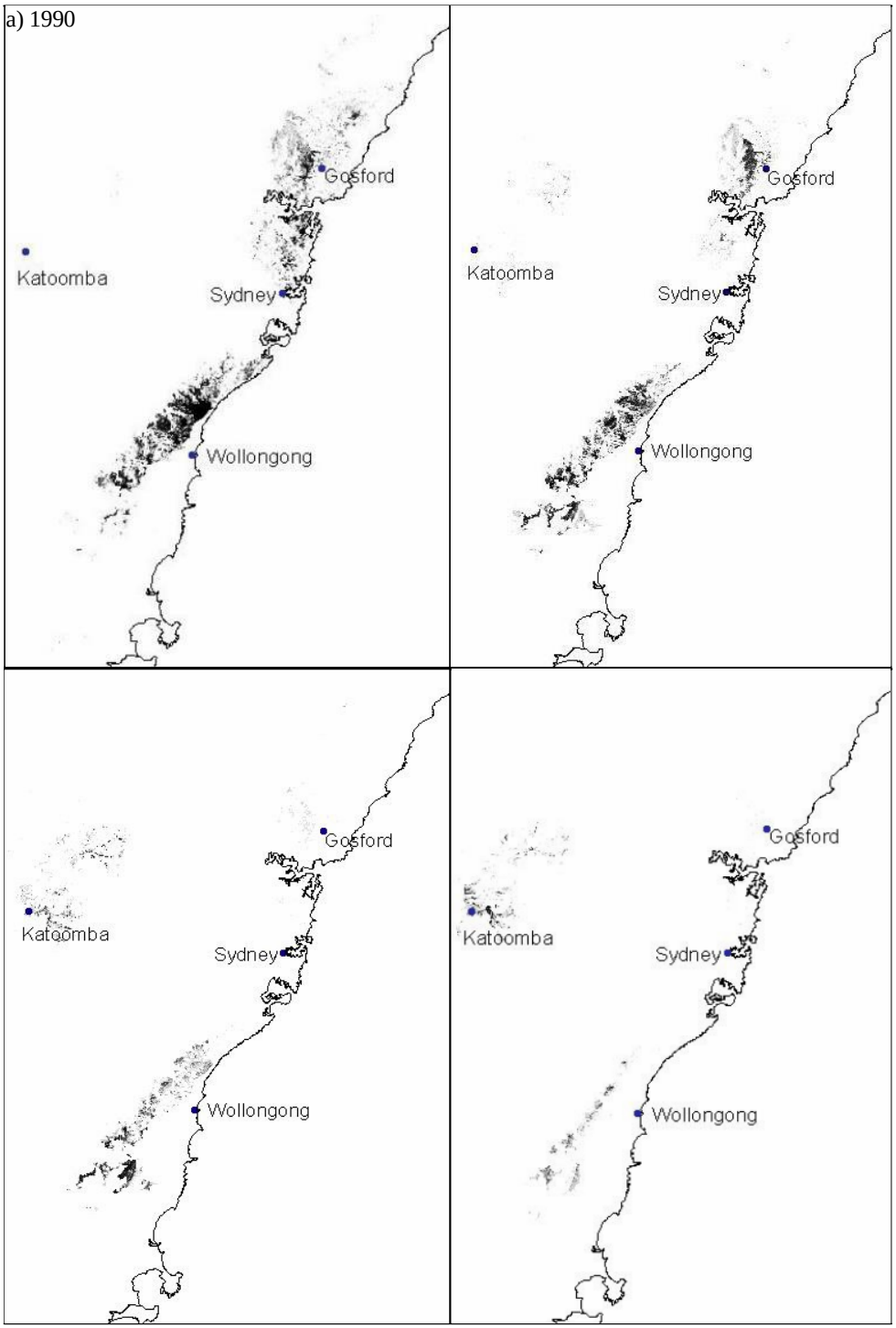

Figure S1. 6. Future distribution of Coastal sandstone upland swamps projected by a distribution model including wetness (incorporating precipitation and evapotranspiration), maximum and minim temperatures and topographic roughness under climate change (AR4 scenario A1FI).

Criterion B

Approximately 5360 ha of Coastal sandstone upland swamps have been mapped from recent high resolution aerial photography (NPWS 2000, DECCW 2009, Tozer et al. 2010). The

swamps occur naturally in small patches, with approximately 42% of mapped swamps covering less than 1 ha, and making up about 6% of the total mapped area.

Extent of occurrence: A minimum convex polygon enclosing all mapped occurrences of Coastal sandstone upland swamps (Figure 7) has an area of 4960 [4730-5200] km^2 (NSW Scientific Committee 2011). There is weak evidence of a current decline in distribution (subcriterion B1a), although the distribution could be currently stable (see criterion A1). Global climate change is projected to cause a future decline in distribution (subcriterion B1b), based on a substantial contraction in hydrological and climatic environment suitable for swamp persistence (see criterion A2). Underground coal and gas extraction and severe wildland fires are the most serious plausible threats to persistence of the swamps. Based on spatial extent and location of current mining leases and previous fire events, Coastal sandstone upland swamps are estimated to occupy five locations (subcriterion B1c). The status of the ecosystem is therefore Endangered under criteria B1b and B1c.

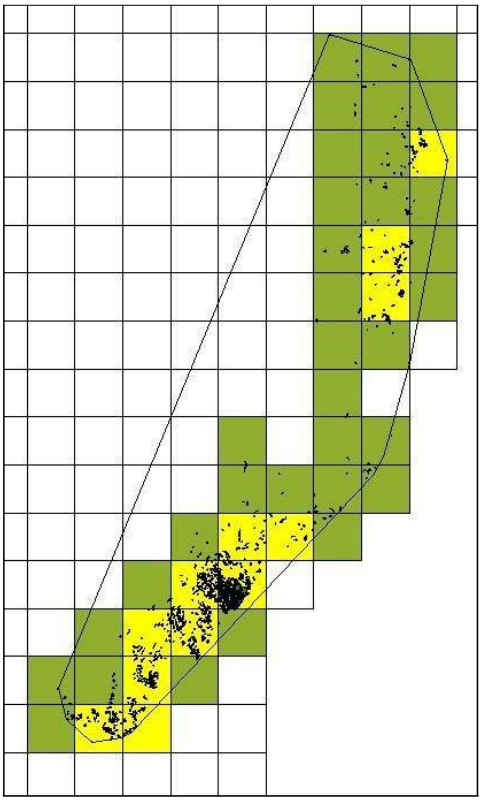

Figure S1. 7. Mapped distribution of Coastal sandstone upland swamps showing minimum convex polygon enclosing all occurrences (Extent of occurrence) and occupied 10 × 10 km grid cells (Area of occupancy). Green- all occupied cells. Yellow- cells with more than 1% of cell area occupied.

Area of occurrence: Superimposing a 10 km grid over the mapped polygons of Coastal sandstone upland swamps (Figure 7) indicates that they are present within 46 grid cells. Of these, 34 grid cells contains less than 1 km^2 of the ecosystem (i.e. <1% of the area of a grid cell). Excluding these small occurrences, the swamps are therefore estimated to occupy twelve 10 × 10 km grid cells. Assessments of B2 subcriteria are identical to those for criterion B1 (see Extent of occurrence, above). The status of the ecosystem is therefore Endangered under criteria B2b and B2c.

Number of locations: Based on underground coal and gas extraction and severe wildland fires as the most serious plausible threats, Coastal sandstone upland swamps are estimated to occupy five locations (see Extent of occurrence, above). Although serious, these threats seem unlikely to result in collapse or Critically Endangered status within a short time period due to ecological time lags in responses. The status of the ecosystem is therefore Least Concern under criteria B3.

Criterion C

The principal mechanism of environmental degradation is through declines in hydrological processes related to global climate change (Figures 2 & 3). Suitable hydrological variables for assessing criterion C include stream discharge volumes from swamp catchments, rates of precipitation and evapotransipration and organic carbon stocks and fluxes within the swamps. Data from stream flow gauges are available, but only for a few relatively large catchments. No data were available on stocks and fluxes of organic carbon.

Current decline: Trends in climatic data from regional weather stations suggest an increase in climatic moisture has occurred over recent decades, driven primarily by a steady decline in pan evaporation (Keith et al. 2010a). The status of the ecosystem is therefore Least Concern under criteria C1.

Future decline: Despite trends in recent decades, global circulation models project a decline in climatic moisture for the region in which this ecosystem occurs. The same distribution models used to assess future change in distribution (Figure 6) were also used to assess trends in climatic suitability. Predicted suitability values summed across the whole distribution were calculated for present day (2010) and fifty years into the future (2060). It was assumed that the proportional change in summed climatic suitability was assumed to represent the severity of environmental degradation and that ecosystem collapse occurs when summed suitability reaches zero. Based on the range of distribution models and emission scenarios described above, the proportional change in suitability (= severity of degradation) was estimated to be 62-93% (median 78%) over the next 50 years. As the ratio of summed suitability averages trends across the entire distribution, the estimate of severity applies across 100% of ecosystem extent. The status of the ecosystem is therefore Endangered (plausible range Endangered - Critically Endangered) under criterion C2.

Historic decline: There are currently insufficient spatial climatic data to assess changes in climatic suitability since 1750. The status of the ecosystem is therefore Data Deficient under criterion C3.

Criterion D

Current decline. Fire-mediated competition between overstorey shrubs and understorey plants is an important biotic interaction within upland swamps that affects persistence of the characteristic native biota. Fire regimes that promote development and persistence of dense overstorey strata result in declines in diversity of understorey flora, especially woody resprouters that are intolerant of shade and have low rates of growth, fecundity and recruitment (Keith & Bradstock 1994; Keith et al. 2007). The severity and extent of declines in woody resprouters was assessed using data from Keith et al. (2007) and Keith (unpubl. data), on the summed abundance of woody resprouters at 53 sites in 1983 and 2009. During this 26-year period, the summed abundance of woody resprouters declined by a mean of 37% at 72% of sampled sites. These are just below the severity and extent thresholds, respectively, for Vulnerable under criterion D1, assuming that zero abundance of resprouters marks the

point of ecosystem collapse. No data are available prior to 1983, but if current declines were initiated prior to that time, they may exceed the threshold for Vulnerable status. Hence, the status of the community is likely to be Near Threatened (plausible range Near Threatened - Vulnerable) under criterion D1.

Future and historic decline. Insufficient data were available to assess criteria D2 and D3.

Criterion E

No quantitative analysis has been carried out to assess the risk of ecosystem collapse for Coastal sandstone upland swamps. The status of the ecosystem is therefore Data Deficient under criterion E.

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