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Habitat requirements for two of Australia's most threatened birds: King Island Brown Thornbill and King Island Scrubtit

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Abstract. King Island Brown Thornbill *Acanthiza pusilla magnirostris* and King Island Scrubtit *Acanthornis magna greeniana* are amongst the top three bird taxa in Australia thought most likely to become extinct within the next 20 years. Despite being recognised as endangered for almost three decades, little is known of the distribution, population size and habitat characteristics of these endemic King Island subspecies and few on-ground recovery actions have been initiated. To establish baseline information to guide conservation decision making, in 2019–2022 we surveyed 1677 sites across the island for King Island Brown Thornbill and King Island Scrubtit and recorded a range of habitat variables at detection and non-detection sites to characterise the habitat requirements of both these taxa. King Island Brown Thornbill was found to occur in wet forests in a range of patch sizes. Mature eucalypts and a high tree canopy cover were found to be strong predictors of its presence, with most detections in Brooker's Gum *Eucalyptus brookeriana* wet forest and Blue Gum *Eucalyptus globulus* King Island forest. King Island Scrubtit was found to be restricted to five isolated locations. Swamp Paperbark *Melaleuca ericifolia* swamp forest supporting mature Swamp Paperbark and a high cover of coarse woody debris were found to be significant predictors of its presence. Protection of all remaining potential habitat for King Island Brown Thornbill and King Island Scrubtit may be required to prevent the extinction of these subspecies on King Island.

Introduction

Since European settlement more than two-thirds of King Island has been cleared for agricultural purposes (Barnes *et al.* 2002), with ~14% of the original native vegetation protected in formal reserves. Several fauna and flora species that previously occurred on King Island have become locally extinct and one subspecies, King Island Emu *Dromaius novaehollandiae minor*, globally extinct. Land clearing has continued over recent decades. Forest accounts for <30% of the remaining native vegetation and most patches are small, fragmented, and isolated in a predominantly agricultural landscape.

Several bird species have become extinct on King Island (e.g. Grey Goshawk *Tachyspiza novaehollandiae*, Glossy Black-Cockatoo *Calyptorhynchus lathami*, Gang-gang Cockatoo *Callocephalon fimbriatum*, Forty-spotted Pardalote *Pardalotus quadragintus*) and many birds are threatened, including endemic subspecies with conspecifics on mainland Tasmania, including King Island Green Rosella *Platycercus caledonicus brownii*, King Island Yellow Wattlebird *Anthochaera paradoxa kingi*, King Island Scrubtit *Acanthornis magna greeniana*, King Island Brown Thornbill *Acanthiza pusilla magnirostris*, and King Island Black Currawong *Strepera fuliginosa colei* (Garnett & Baker 2021).

King Island Brown Thornbill and King Island Scrubtit are amongst the top three bird taxa in Australia thought most likely to become extinct within the next 20 years (Geyle *et al.* 2018). King Island Scrubtit is listed as Endangered in the Tasmanian *Threatened Species Protection Act 1995* (TSP Act) and Critically Endangered in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and King Island Brown Thornbill is listed as Endangered on both the TSP Act and EPBC Act. The very high predicted extinction risk for both these subspecies led to their priority status in the Australian Government's *Threatened Species Strategy Action Plan 2022–2032* (DCCEEW 2022). This plan set a pathway for conservation and recovery of threatened species over 10 years, including preventing any new extinctions of plants and animals (DCCEEW 2022).

Webb *et al.* (2016) found King Island Scrubtit extant at only three locations on the island – Nook Swamps, Colliers Swamp and Pegarah State Forest – and confirmed local extinctions at Pass River, Yellow Rock and Yarra Creek (Figure 1). Webb & Crates (2019) extended the known distribution of the subspecies within Pegarah State Forest but Baker & Holdsworth (2019) and Webb & Bell (2020) were unable to find further locations for this taxon.

Until surveys by Webb & Crates (2019), there were few confirmed records of King Island Brown Thornbill. It was recorded in Pegarah State Forest in 1968 (Green & McGarvie 1971) and at Loorana in 1971 (McGarvie & Templeton 1974) and thought to be possibly extinct (Webb *et al.* 2016) until sightings in Pegarah State Forest in 2002. Baker & Holdsworth (2019), Webb & Crates (2019) and

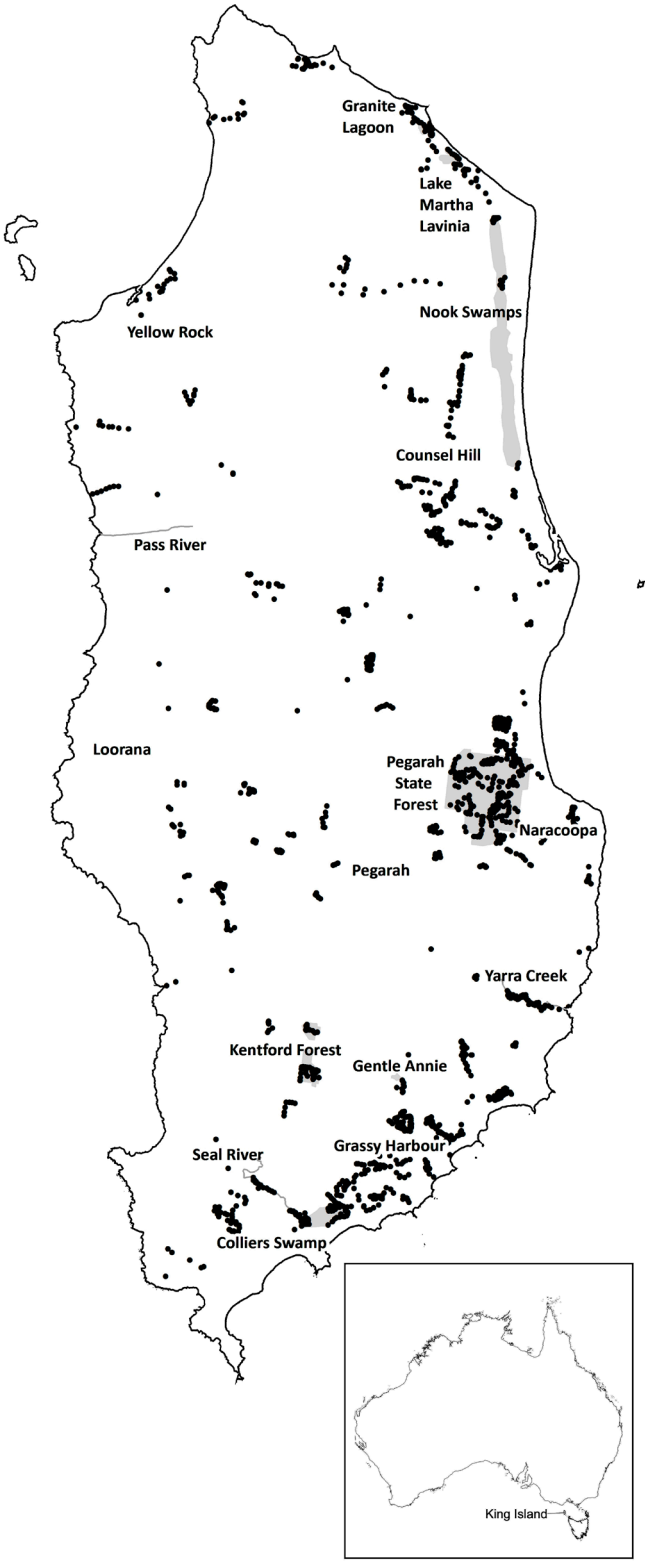

Figure 1. Distribution of King Island Brown Thornbill and King Island Scrubtit survey sites (black dots). The grey shaded areas show the extent of Colliers Swamp in the south, Pegarah State Forest in the central east and Nook Swamps in the north-east of King Island.

Webb & Bell (2020) found it at several sites in Pegarah State Forest and in small forest remnants to the west of Pegarah State Forest, near Counsel Hill in the north-east and at several sites in the south including Gentle Annie Conservation Area, Yarra Creek, Seal River Reserve, Kentford Forest Conservation Area and Grassy Harbour (Figure 1).

The habitats of King Island Scrubtit and King Island Brown Thornbill have been little studied, mainly because of the rarity of the birds and few observers on King Island, but also because of apparent low detectability and the logistical challenges of traversing the dense forests and scrubs of King Island. Webb *et al.* (2016) identified common habitat features at King Island Scrubtit sites, including the presence of Swamp Paperbark *Melaleuca ericifolia*. Green & McGarvie (1971) found King Island Brown Thornbill in wet Blue Gum *Eucalyptus globulus* forest and Webb & Crates (2019) found eucalypts present at all King Island Brown Thornbill sites.

The aim of our study was to determine the range of King Island Brown Thornbill and King Island Scrubtit on the island and to identify the habitat requirements to inform strategic planning of land use and development of conservation management actions to ensure viability of these taxa in the wild.

Methods

Survey sites

Sixteen hundred and seventy-seven surveys were conducted for King Island Brown Thornbill and King Island Scrubtit across native forest and scrub vegetation types on the island in 2019–2022.

TASVEG 4.0 mapping (The Digital Vegetation Map of Tasmania – hereafter TASVEG: DPIPWE 2020) was interrogated to determine the distribution of forests and scrubs. TASVEG was supplemented by contemporary satellite imagery to interpret the maturity of vegetation. We tried to maximise the spatial coverage of our surveys across public (43% of surveys) and private land (57% of surveys) and across forest (52% of surveys) and scrub vegetation types (48% of surveys). However, the actual distribution of our survey sites was constrained by project resources, logistics and landowner consent.

The importance of vegetation containing eucalypts for King Island Brown Thornbill and Swamp Paperbark for King Island Scrubtit is well established (Webb & Crates 2019), so our surveys targeted forest communities known to support eucalypts and/or Swamp Paperbark *Melaleuca ericifolia* [i.e. TASVEG mapping units *M. ericifolia* swamp forest (NME), Blackwood *Acacia melanoxylon* swamp forest (NAF), *A. melanoxylon* forest on rises (NAR), Brooker's Gum *Eucalyptus brookeriana* wet forest (WBR), Blue Gum *E. globulus* King Island forest (WGK), King Island eucalypt woodland (DKW), and Swamp Gum *E. ovata* forest and woodland (DOV)]. Webb & Crates (2019) and Webb & Bell (2020) detected King Island Brown Thornbill in Scrub complex on King Island (SSK) (albeit always associated with nearby eucalypts) so scrub vegetation communities were also included in our surveys.

Habitat variables

TASVEG communities (Kitchener & Harris 2013) were recorded at 972 survey sites. Additional habitat variables were recorded within a 30-m radius of the centre of each survey site at 824 sites (Table 1).

Table 1. Maximum set of habitat variables recorded at King Island survey sites.

1.	TASVEG vegetation mapping unit (code).
2.	Dominant tree canopy height (m) and cover (%).
3.	Dominant tree canopy species occupying >50% of the cover (species name), <50% of cover (Species 1), <50% of cover (Species 2), <50% of cover (Species 3), <50% of cover (Species 4), <50% of cover (Species 5).
4.	Dominant canopy eucalypt DBH (cm): mean, minimum, maximum.
5.	Tree canopy Blackwood maximum DBH (cm).
6.	Tree canopy Swamp Paperbark DBH (cm): minimum, maximum.
7.	Understorey tree height (m) and cover (%).
8.	Understorey tree species occupying >50% of the cover (species name), <50% of cover (Species 1), <50% of cover (Species 2), <50% of cover (Species 3), <50% of cover (Species 4), <50% of cover (Species 5).
9.	Shrub layer minimum height (cm), maximum height (cm), and cover (%).
10.	Shrub layer species occupying >50% of the cover (species name), <50% of cover (Species 1), <50% of cover (Species 2), <50% of cover (Species 3), <50% of cover (Species 4), <50% of cover (Species 5).
11.	Ground layer cover (%).
12.	Ground layer species occupying >50% of the cover (species name); <50% of cover (Species 1), <50% of cover (Species 2), <50% of cover (Species 3), <50% of cover (Species 4), <50% of cover (Species 5).
13.	Ground cover (%): litter, herbs, moss, grass, coarse woody debris, fine woody debris, bare ground.
14.	Ground cover: Species 1, Species 2, Species 3, Species 4.

Bird surveys

In the current study we used a rapid call-playback survey protocol of duration *c.* 5 minutes, similar to that used by Webb *et al.* (2016) for King Island Scrubtit. Call-playback was used to increase the detectability of both subspecies by eliciting a call or other behavioural response. Several repeat surveys may be required to achieve a high confidence of the subspecies' absence. However, the duration of the survey (typically *c*. 5 minutes) was extended as a substitute for repeat surveys because of the remoteness and inaccessibility of many survey sites. We broadcast recordings of King Island Brown Thornbill and King Island Scrubtit calls separately through portable speakers, approximately every 20–30 seconds.

Presence/absence and estimated abundance of King Island Brown Thornbill and King Island Scrubtit were recorded at each survey site. Detection type was recorded as visual or audible. For most surveys, two observers were used, each visually surveying with binoculars about half of the site. We avoided surveys in rain or during periods when wind speeds exceeded ~20 km per hour.

Modelling

A statistical *t*-test assessed whether there was a significant difference between the means of continuous habitat variables collected at sites with and without detection of King Island Brown Thornbill and King Island Scrubtit.

Bayesian additive regression trees (BART) were used for data modelling, implemented with the 'embarcadero' *R* package (version 1.2: Carlson 2020). BART is a 'sum-of-trees' method that employs a Bayesian framework to sum an ensemble of regression trees. This 'ensemble model' generates a single prediction from the predictions of many simple models, thereby mitigating the risk of overfitting (Chipman *et al.* 2010). The Bayesian structure of BART inherently estimates uncertainty without the need of bootstrapping (Carlson 2020).

Model-fitting performance was evaluated using the area under the receiver operating characteristic curve (AUC). In general, AUC values ≥0.7 indicate adequate performance, and ≥0.8 indicate excellent performance (Hosmer & Lemeshow 2000). The covariate importance was estimated by measuring the proportion of the total branches used for a given covariate.

For each model in the ensemble, a standardised and automated stepwise covariate selection was used to reduce their number. The algorithm initiated with the full covariate set, fitted a model, measured its root mean square error (RMSE) and estimated the least important covariate to fit a new model (Sparapani *et al*. 2021). Covariates were iteratively eliminated until there were only three covariates left.

To assess the response to individual variables, partial dependence plots were generated.

Distribution of survey sites

Figure 1 shows the distribution of survey sites for King Island Brown Thornbill and King Island Scrubtit, combining detection data from all surveys conducted in 2019–2022 (i.e. Baker & Holdsworth 2019; Webb & Crates 2019; Webb & Bell 2020; and our study 2019–2022). The distribution of survey sites represented a good spatial coverage of the forests and scrubs supporting potentially suitable habitat for both subspecies, but survey sites were not necessarily independent. However, only where survey sites were at least 50 m from their nearest neighbour were they used in the statistical analysis. Most surveys were along the northern, eastern and southern coasts of the island. Only a small number of surveys were in scrubs on dune vegetation along the western coast [comprising mostly Coastal scrub on alkaline sands (SCA)].

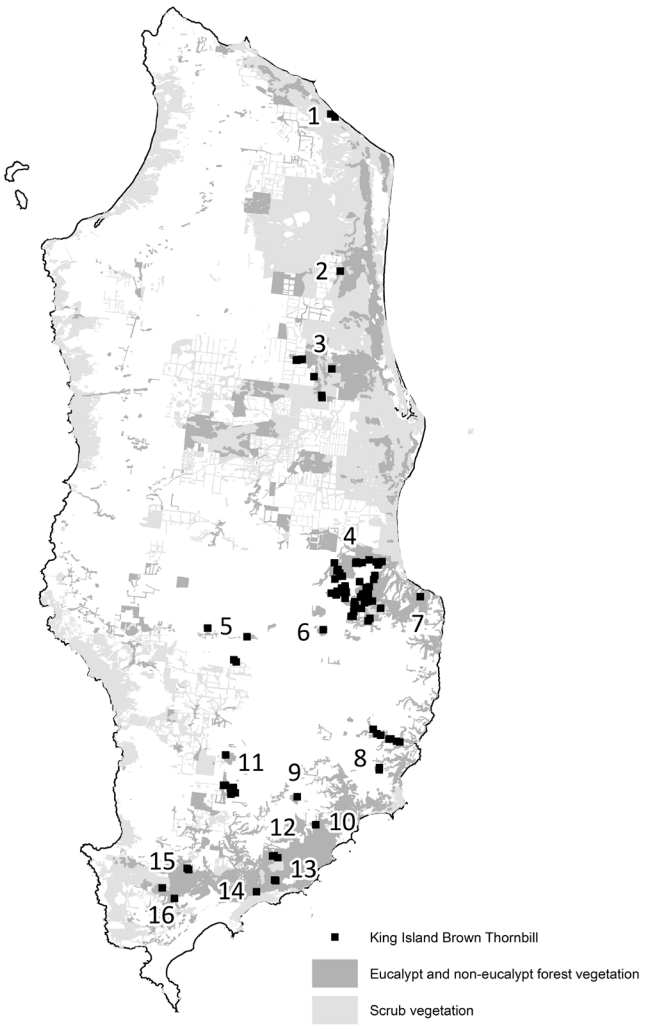

Figure 2. Locations of 16 survey sites where King Island Brown Thornbill was detected (102 sites) overlaid on the distribution of forest and scrub vegetation types. White areas indicate mainly agricultural land. The numbered sites are named with further details provided in Table 2. See text for further details.

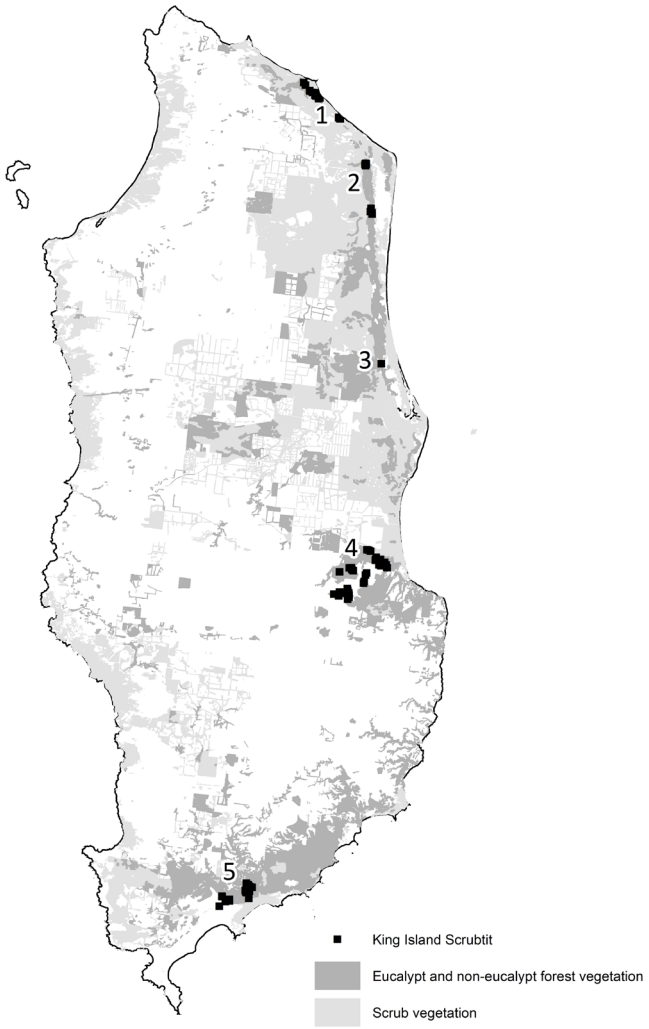

Figure 3. Locations of survey sites where King Island Scrubtit was detected (81 sites) overlaid on the distribution of forest and scrub vegetation types. The numbered locations are named with further details provided in Table 2. See text for further details.

Table 2. Locations of detections of King Island Brown Thornbill, 2019–2022 (102 sites).

1.	Lake Martha Lavinia	2 detections on north-eastern shore of Lake Martha Lavinia, Lavinia State Reserve
2.	Counsel Hill North	1 detection on private land at Saltwater Creek, adjacent to Lavinia State Reserve
3.	Counsel Hill South	Detections on private land including 1 conservation covenant
4.	Pegarah State Forest	Detections in Pegarah State Forest and on private land to the south including 1 conservation covenant
5.	Pegarah West	Detections in 3 native forest remnants on private land west of Pegarah
6.	Pegarah East	1 detection in native-forest remnant on private land south-west of Pegarah State Forest
7.	Naracoopa	1 detection on private land at Bronzewing Creek
8.	Yarra Creek	Detections on private land on Yarra Creek and a native-forest remnant on Bold Head Road
9.	Gentle Annie	1 detection in Gentle Annie Conservation Area
10.	Grassy Harbour	Detections at Parer Creek west of Grassy Harbour Road on private land
11.	Kentford Forest	Detections in Kentford Forest Conservation Area and Kentford Forest Nature Reserve
12.	Red Hut Road East	Detections on private property east of Red Hut Road
13.	Red Hut Road South	Detections on private land in a conservation covenant near Crown Creek
14.	Colliers Swamp East	Detection on eastern boundary of Colliers Swamp Conservation Area
15.	Seal River	Detections on private land on Seal River north-west of Colliers Swamp
16.	South Road	Detections east and west of South Road near Macks Creek in Seal Rocks Conservation Area and Colliers Swamp Conservation Area

Table 3. Locations of detections of King Island Scrubtit, 2019–2022 (81 survey sites).

1	Granite Lagoon	Detections from north-east of Granite Lagoon to Lake Martha Lavinia in Lavinia State Reserve and on private land
2	Nook Swamps North	Detections in northern portion of Nook Swamps in Lavinia State Reserve
3	Nook Swamps South	Detections in southern portion of Nook Swamps in Lavinia State Reserve
4	Pegarah State Forest	Detections in Pegarah State Forest and near Fraser River on private land
5	Colliers Swamp	Detections in Colliers Swamp, near Seal River and Mt Stanley Creek in Colliers Swamp Conservation Area, and near Mt Stanley Creek on private land in a conservation covenant

Results

Distribution of King Island Brown Thornbill detections

King Island Brown Thornbills were detected at 102 sites over all surveys conducted in 2019–2022 (Figure 2). No attempt was made to assess the sampling independence of survey sites. For the purpose of conservation planning and management, detection sites were grouped spatially (i.e. 16 locations). The boundaries of these broad locations were arbitrary though in most cases they are grouped detections where individual detections were <2 km apart (Table 2).

Distribution of King Island Scrubtit detections

King Island Scrubtit was detected at 81 sites over all surveys conducted in 2019–2022 (Figure 3). No attempt was made to assess the sampling independence of survey sites. For the purpose of conservation planning and management, sites were grouped spatially (i.e. five locations). The boundaries of these broad locations are arbitrary though in most cases they are grouped detections where individual detections were <2 km apart (Table 3).

Characteristics of habitat

Habitat data that included a minimum record of TASVEG community were collected at 972 survey sites.

Most of the 102 detections of King Island Brown Thornbill were in wet eucalypt forests including *Eucalyptus brookeriana* wet forest (WBR, *n* = 40 detections across 241 sites), *Eucalyptus globulus* King Island forest (WGK, *n* = 27 detections across 142 sites), Plantations for silviculture – hardwood (FPH, *n* = 16 detections across 24 sites), *Melaleuca ericifolia* swamp forest (NME, *n* = 10 detections across 256 sites), *Acacia melanoxylon* swamp forest (NAF, *n* = 4 detections across 61 sites). Two detections were made in King Island eucalypt woodland (DKW, across 46 sites) and a single detection in Scrub complex on King Island (SSK, across 116 sites). The prevalence of detections in FPH at Pegarah State Forest was extremely high (67%).

Most of the 81 detections of King Island Scrubtit were in *Melaleuca ericifolia* swamp forest (NME, *n* = 31 detections across 256 sites), with some detections in *Eucalyptus brookeriana* wet forest (WBR, *n* = 2 detections across 241 sites), Plantations for silviculture – hardwood (FPH, *n* = 2 detections across 24 sites), *Acacia melanoxylon* swamp forest (NAF, *n* = 2 detections across 61 sites) and Coastal scrub on alkaline sands (SCA, *n* = 2 detections across 33 sites). A single detection was made in Scrub complex on King Island (SSK, across 116 sites).

The dominant tree canopy species most common at King Island Brown Thornbill sites was Brooker's Gum (*n* = 39, 41%), Blue Gum (*n* = 24, 26%) or Stringybark *Eucalyptus obliqua* (*n* = 16, 17%). Swamp Paperbark (*n* = 8) and Blackwood (*n* = 4) were less common. King Island Brown Thornbill was recorded at only one of 25 sites with Coast Teatree *Leptospermum laevigatum*, a location where Coastal scrub on alkaline sands (SCA) was associated with a highly localised occurrence of eucalypts. The dominant tree canopy species most common at King Island Scrubtit sites was Swamp Paperbark (*n* = 23, 72%) with Brooker's Gum present at three sites (9%).

Dominant understorey tree species most common at King Island Brown Thornbill sites included Swamp Paperbark (*n* = 31, 40%), Silver Banksia *Banksia marginata* (*n* = 9, 12%), Blackwood (*n* = 9, 12%), Satinwood *Nematolepis squamea* (*n* = 6, 8%) or the absence of an understorey tree layer (*n* = 6, 8%). Common understorey tree species at King Island Brown Thornbill sites included species typical of wet eucalypt forest such as Satinwood, Swamp Paperbark and Blackwood but also key dominant tree species found in Scrub complex on King Island (SSK) such as Silver Banksia, Caterpillar Wattle *Acacia mucronata* and Common Teatree *Leptospermum scoparium*. The dominant understorey tree species most common at King Island Scrubtit sites was Swamp Paperbark (*n* = 11, 44%) though many sites did not have an understorey tree layer (*n* = 7, 28%).

Dominant shrub layer species most common at King Island Brown Thornbill sites included Swamp Paperbark (*n* = 20, 29%), Goldey Wood *Monotoca glauca* (*n* = 28, 26%), Native Currant *Coprosma quadrifida* (*n* = 7, 10%) and Satinwood (*n* = 7, 10%). Less commonly, the dominant shrub layer species was Scented Paperbark *Melaleuca squarrosa* (*n* = 4), Dogwood *Pomaderris apetala* (*n* = 3), Caterpillar Wattle (*n* = 2), Prickly Moses *Acacia verticillata* (*n* = 2) or the absence of a shrub layer (*n* = 3). Dominant shrub layer species most common at King Island Scrubtit sites was the absence of a shrub layer (*n* = 10, 42%).

Dominant ground layer species most common at King Island Brown Thornbill sites included Cutting Grass *Gahnia grandis* (*n* = 39, 46%) and Bracken *Pteridium esculentum* (*n* = 33, 39%). Asparagus Fern *Asparagus scandens* (an introduced weed with an expanding distribution on King Island) was dominant at one site. Dominant ground

Table 4. Statistics of continuous habitat variables collected at King Island Brown Thornbill survey sites. The *t*-test *P*-value is indicated for each variable; n = number of sites; mean, standard deviation (Std), minimum and maximum. DBH = diameter at breast height (cm).

Covariate	*Detection*	*n*	*Mean*	*Std*	*Min.*	*Max.*	*P*
Canopy tree cover	No	683	57.2	26.8	2	100	0.14
	Yes	89	52.9	19.9	5	90	
Coarse woody debris cover	No	369	1.8	3.2	0	20	0.35
	Yes	69	2.2	3.8	0	25	
DBH of canopy eucalypts	No	140	51.4	18.5	10	120	0.18
	Yes	57	55.1	14.6	30	120	
DBH of canopy Swamp Paperbark	No	140	25.2	12.3	6	60	0.26
	Yes	14	21.4	8.6	10	40	
Fine woody debris cover	No	370	5.4	4.7	0	40	0.17
	Yes	69	6.3	7.5	0	60	
Ground layer cover	No	474	31.8	30.9	0	100	0.38
	Yes	81	35	25.2	1	90	
Shrub cover	No	436	24.1	24.6	0	100	0.64
	Yes	77	25.5	19.6	2	80	
Understorey tree cover	No	271	42.5	30.3	2	250	0.23
	Yes	64	37.7	21.4	5	90	

layer species most common at King Island Scrubtit sites included Bracken (*n* = 8, 27%), Cutting Grass (*n* = 5, 17%), Fishbone Waterfern *Blechnum nudum* (*n* = 4, 13%) and Swamp Paperbark (*n* = 3, 10%).

Ground layer cover was similar between sites with King Island Brown Thornbill detections and non-detections (mean: 35% vs 32%) (Table 4). Likewise, sites with King Island Scrubtit detections exhibited similar ground layer cover compared with non-detections (mean: 37% vs 32%) (Table 5).

For both taxa, the average cover of fine woody debris was similar across sites regardless of detection (Tables 4–5).

The average coarse woody debris cover was similar at King Island Brown Thornbill sites compared with sites with no detection (Table 4). In contrast, the average coarse woody debris cover at King Island Scrubtit sites was higher than sites with no detection (Table 5).

There does not appear to be a relationship between DBH of canopy Swamp Paperbark and King Island Brown Thornbill detections (Table 4). In contrast, there appears to be a positive but not significant correlation between the DBH of canopy Swamp Paperbark and King Island Scrubtit detections (*P* = 0.06: Table 5).

There appears to be a positive relationship between distribution of eucalypt DBH-High data (i.e. the maximum DBH of eucalypts) and King Island Brown Thornbill detections (Table 4). King Island Brown Thornbill was detected only at sites where eucalypts had DBH of >30 cm. Eucalypts were present at only three King Island Scrubtit detection sites.

There does not appear to be a relationship between detections and the percentage canopy tree cover for either King Island Brown Thornbill or King Island Scrubtit (Tables 4–5).

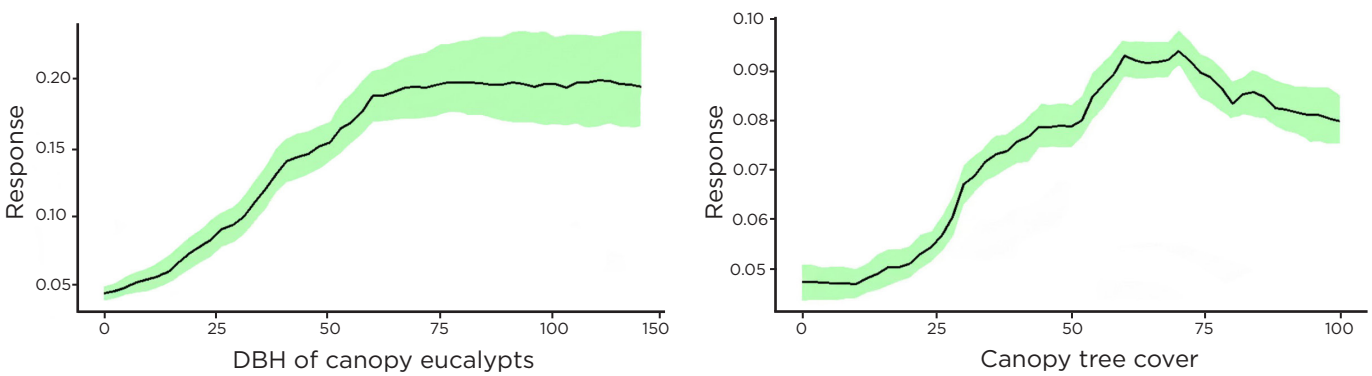

Figure 4. Partial dependence plots for habitat covariates associated with King Island Brown Thornbill presence: diameter at breast height of canopy eucalypts (DBH, cm), and canopy tree cover (%). Green envelope is the confidence interval.

Table 5. Statistics of continuous habitat variables collected at King Island Scrubtit survey sites. The *t*-test *P*-value is indicated for each variable; *n* = number of sites; mean, standard deviation, minimum and maximum. DBH = diameter at breast height (cm). NA = not applicable.

Covariate	*Detection*	*n*	*Mean*	*Std*	*Min.*	*Max.*	*P*
Canopy tree cover	No	741	56.5	26.2	2	100	0.15
	Yes	31	63.4	23.3	5	95	
Coarse woody debris cover	No	414	1.7	3	0	25	<0.001
	Yes	24	5	6.3	0	20	
DBH of canopy eucalypts	No	196	52.5	17.6	10	120	NA
	Yes	1	40	0	40	40	
DBH of canopy Swamp Paperbark	No	139	24.3	11.7	6	60	0.06
	Yes	15	30.3	14.2	8	50	
Fine woody debris cover	No	415	5.5	5.3	0	60	0.91
	Yes	24	5.6	4.7	0	15	
Ground layer cover	No	528	32.1	30.1	0	100	0.44
	Yes	27	36.7	30.3	1	90	
Shrub cover	No	494	24.4	23.9	0	100	0.94
	Yes	19	23.9	24	1	70	
Understorey tree cover	No	319	42.4	29	2	250	0.03
	Yes	16	25.9	21.4	5	90	

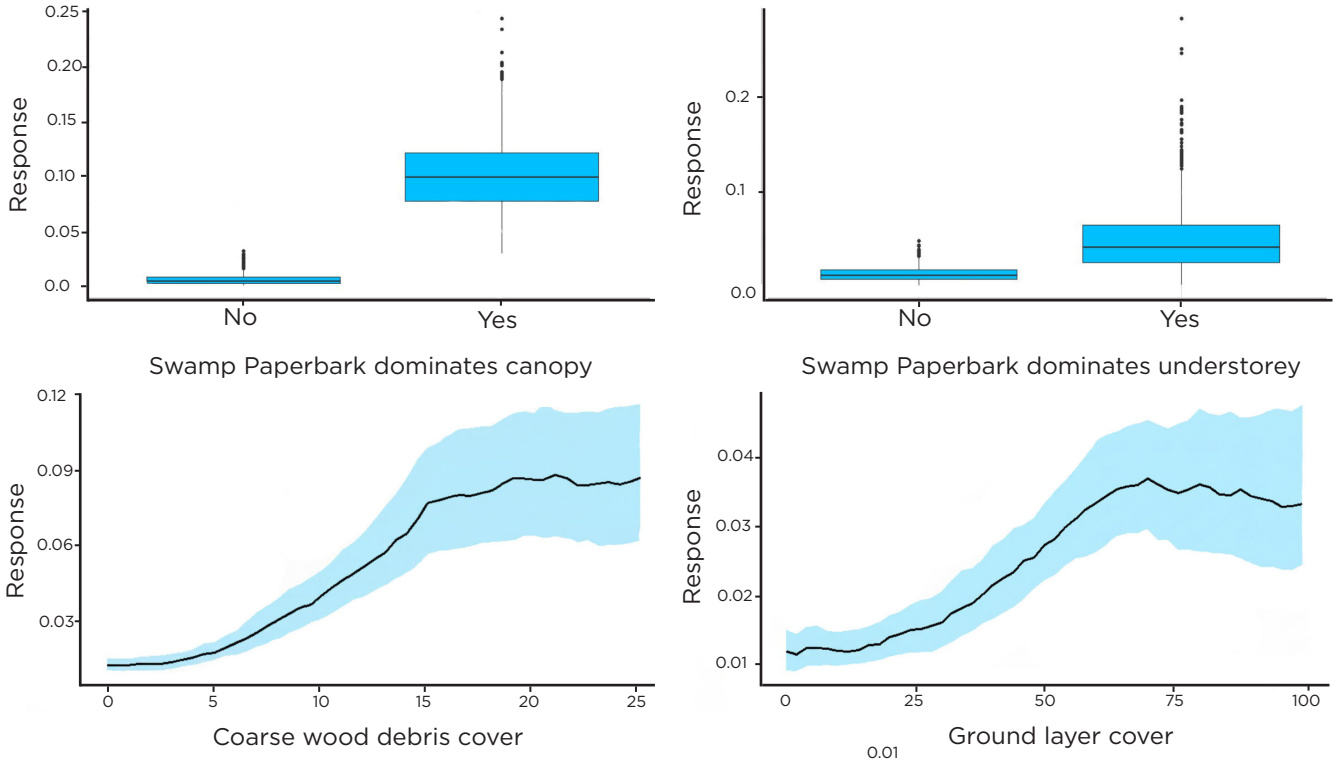

Figure 5. Partial dependence plots for habitat variables associated with King Island Scrubtit presence: Swamp Paperbark in canopy and in understorey, coarse woody debris cover (%), and ground layer cover (%). Blue envelope is the confidence interval.

Modelling – TASVEG vegetation community

The model's explanatory power for identifying sites where King Island Brown Thornbills were present when considering TASVEG community data was strong (AUC = 0.78). The model indicated a positive response of the King Island Brown Thornbill to *Eucalyptus brookeriana* wet forest (WBR) and *Eucalyptus globulus* King Island forest (WGK) with high model confidence (confidence intervals of 0.07 and 0.11 respectively). The model's response to Plantations for silviculture – hardwood (FPH) was very strong but uncertain, with a wide confidence interval of

0.31, which might be explained by the influence of mature native wet eucalypt forests along drainage lines and other remnants adjacent to FPH.

The model's explanatory power for identifying sites where King Island Scrubtits were present when considering TASVEG community data was strong (AUC = 0.82). The King Island Scrubtit model exhibited the strongest positive response to *Melaleuca ericifolia* swamp forest (NME) with a high level of model confidence (confidence interval of 0.07).

Modelling – site-level habitat variables

The model's explanatory power for the site-level habitat data was very strong for both taxa: King Island Brown Thornbill (AUC = 0.93) and King Island Scrubtit (AUC = 0.96). Important habitat covariates at King Island Brown Thornbill sites included DBH of the dominant eucalypt and percentage cover of the dominant tree canopy. Important covariates at King Island Scrubtit sites included the percentage ground layer vegetation cover, Swamp Paperbark dominant in the tree canopy layer, percentage cover of coarse woody debris, and Swamp Paperbark dominant in the understorey layer.

Partial dependence plots show the response of habitat variables to King Island Brown Thornbill presence (Figure 4). The importance of eucalypt DBH in the dominant canopy reflects the relationship of this taxon with mature eucalypts. The response of eucalypt DBH rises rapidly to ~60 cm then plateaus, after which the confidence interval increases. Beyond 60 cm DBH, there is no increased likelihood of detection, probably since maturity of the eucalypts has already been established. The response of percentage cover of the dominant tree canopy appears to be highest between about 50% and 75%, after which a more closed canopy appears to be less suitable.

Partial dependence plots show the response of habitat variables to King Island Scrubtit presence (Figure 5). The importance of Swamp Paperbark as the dominant tree canopy species at detection sites is overwhelming and likely reflects the association of King Island Scrubtit with mature Swamp Paperbark trees. There is also a strong response of King Island Scrubtit presence to Swamp Paperbark dominating the understorey tree layer. The response of percentage cover of coarse woody debris rises sharply to ~15%, after which the response plateaus and the confidence interval increases. There is a similar response for percentage cover of ground layer vegetation, whereby there is a sharp rise in the response to ~60% cover, following which the response plateaus and the confidence interval increases.

Discussion

King Island Brown Thornbill

Our study has extended the known distribution of King Island Brown Thornbill north to Lake Martha Lavinia, west to Pegarah and south to Colliers Swamp, Seal River and Macks Creek. Based on the distribution of historical and current locality records, and knowledge of the species' habitats within its range on the Tasmanian and Australian mainland, there is strong evidence that the subspecies probably occurred in suitable habitat throughout King Island before European settlement.

We detected King Island Brown Thornbills at many new locations across the island though at most of these the number of detections was low. Therefore, we consider that no evidence has been collected in our study to warrant a review of the estimated abundance of the subspecies by Holdsworth *et al.* (2021a) (i.e. 100 mature individuals, range 50–200). Detailed site-level surveys will be required to improve the population estimate.

We found that the vegetation communities most likely to support habitat critical to the survival of King Island Brown Thornbill include *Eucalyptus brookeriana* wet forest (WBR), *Eucalyptus globulus* King Island forest (WGK), *Acacia melanoxylon* swamp forest (NAF), *Melaleuca ericifolia* swamp forest (NME), King Island eucalypt woodland (DKW), Scrub complex on King Island (SSK) and Plantations for silviculture – hardwood (FPH) at Pegarah State Forest. Based on the results of our study, habitat critical to the survival of King Island Brown Thornbill is likely to include all vegetation communities that support mature eucalypts (as an immediate priority for protection and conservation management of the subspecies) and support regrowth eucalypts with the potential to reach maturity (as a secondary priority for protection and conservation management of the subspecies).

The functional use and importance of Scrub complex on King Island (SSK) (which commonly occurs in a mosaic with forest dominated by eucalypts or Swamp Paperbark) to King Island Brown Thornbill remains poorly understood. We suggest that more detailed site-level investigations will be required to understand the role of SSK in the subspecies' ecology, including its use for breeding, foraging and/or dispersal. Nonetheless, we found flora species typically dominant in SSK (e.g. Silver Banksia, Swamp Paperbark, Common Teatree, Prickly Moses and Caterpillar Wattle) comprising the understorey tree layer at some King Island Brown Thornbill detection sites. Although detections in SSK were few, it is clear that SSK forms part of the habitat matrix used by King Island Brown Thornbill and likely serves to buffer habitat from the impacts of land clearing, browsing and trampling, weeds, windthrow and other potential threats. We recommend that SSK, where it occurs in native vegetation patches known to support King Island Brown Thornbill, be protected. In its strict sense, Coastal scrub on alkaline sands (SCA) is unlikely to contain habitat critical to the survival of King Island Brown Thornbill as the community supports few flora species associated with the presence of the subspecies.

Canopy dominance by eucalypts is an essential component of King Island Brown Thornbill habitat, and the subspecies' presence is strongly associated with *Eucalyptus brookeriana* wet forests (WBR) and *Eucalyptus globulus* King Island forest (WGK). A high prevalence of detections in FPH reflects the suitability of old unmanaged eucalypt plantation for the subspecies. The modelled response of FPH is dispersed, which may reflect the influence of native mature wet eucalypt forest in nearby drainage lines and other forest remnants scattered throughout Pegarah State Forest. Plantations for silviculture – hardwood (FPH) is a TASVEG mapping unit categorised as 'modified land'

and distinguished from native forest mapping units by comprising a monoculture of eucalypt trees planted in rows. On the Tasmanian mainland, plantation eucalypts are predominantly Shining Gum *Eucalyptus nitens* or Blue Gum. Plantations of Stringybark (and a small area of Smithton Peppermint *E. nitida*) were established in Pegarah State Forest in the 1940s and 1950s. Most of the plantation has never been harvested, allowing an understorey of native vegetation to establish over many years. Native-forest remnants (mostly associated with drainage lines) are scattered across Pegarah State Forest interspersed with eucalypt and Radiata Pine *Pinus radiata* plantations. It is likely that the King Island Brown Thornbill was abundant in the forests dominated by Brooker's Gum and Blue Gum in Pegarah State Forest before 1940, and has persisted in native-forest remnants, and eventually colonised FPH as the plantation trees have matured and a complex wet-forest understorey has established. Given our current understanding of the distribution and abundance of the King Island Brown Thornbill, Pegarah State Forest and the surrounding wet forests on private land contain the largest area of suitable habitat where the subspecies has been found and are therefore the most important location for conservation actions targeting the subspecies.

The very strong relationship between King Island Brown Thornbill detections and the presence of eucalypts in the forest tree canopy is qualified by the subspecies' relationship with eucalypt DBH at survey sites. The response of King Island Brown Thornbill to DBH plateaus at 50–60 cm, suggesting that once a threshold maturity of the eucalypt forest (or of individual eucalypts) is reached, there is little additional influence of DBH on the likelihood of detection. The strong influence of tree canopy cover with a maximum response of 50–70% suggests a requirement for high canopy cover but not for a closed canopy typical of swamp forests on King Island. Although we detected strong relationships between site-level covariates and King Island Brown Thornbill presence, habitat suitability is also likely to be linked to patch size, fragmentation and connectivity.

King Island Scrubtit

Our study has extended the known distribution of King Island Scrubtit in the north of the island from Nook Swamps, west to Lake Martha Lavinia and Granite Lagoon, on both reserved and private land. Based on our study, there is no evidence to warrant review of the estimated abundance of this taxon by Holdsworth *et al.* (2021b) (i.e. 50, range 30–70). Indeed, we are concerned for the viability of King Island Scrubtit in isolated remnant patches of mature Swamp Paperbark forest as a result of the catastrophic wildfire in the Nook Swamps in 2007. Further, we observed substantial windthrow in habitat remnants in both Nook Swamps and Colliers Swamp that requires assessment and ongoing monitoring to determine the level of threat to the subspecies.

We found that the vegetation communities most likely to contain habitat critical to the survival of King Island Scrubtit include *Melaleuca ericifolia* swamp forest (NME), Plantations for silviculture – hardwood (FPH) in Pegarah State Forest, Coastal scrub on alkaline sands (SCA), *Acacia melanoxylon* swamp forest (NAF), *Eucalyptus brookeriana* wet forest (WBR) and Scrub complex on King Island (SSK). Based on the results of our study, habitat critical to the survival of the subspecies is likely to include all vegetation communities containing mature Swamp Paperbark (as an immediate priority for protection and conservation management) and support regrowth Swamp Paperbark with the potential to reach maturity (as a secondary priority for protection and conservation management).

Melaleuca ericifolia swamp forest (NME) is a strong predictor of King Island Scrubtit presence. However, the importance of Scrub complex on King Island (SSK) and Coastal scrub on alkaline sands (SCA), which can support localised occurrences of mature Swamp Paperbark, remains poorly understood. Neither SSK nor SCA, in isolation, is likely to contain habitat critical to the survival of the subspecies because of their dense scrub structure, lack of understorey and lack of complexity in the ground layer. These scrub communities are more likely to assist in dispersal and provide buffering from the array of recognised threats to King Island Scrubtit. On this basis, we recommend the protection of Scrub complex on King Island (SSK) and Coastal scrub on alkaline sands (SCA), where these occur in native vegetation patches known to support the subspecies.

The presence of mature Swamp Paperbark is a key predictor of King Island Scrubtit presence. Accordingly, the most common dominant tree canopy species was Swamp Paperbark, as well as the most common dominant understorey species. The presence of coarse woody debris is also a strong predictor of King Island Scrubtit presence, probably reflecting the subspecies' preference for habitats with high structural understorey complexity such as fallen trees and decaying logs.

Conservation implications

Since European settlement, King Island has been subject to landscape-level changes, with most of the native vegetation cleared and significant lagoons and swamp forests drained. Swamp Paperbark and Blackwood swamp forests, and historically extensive Blue Gum forests, have been decimated. The loss of forests has been exacerbated by major fires in the late 19th and early 20th centuries and more recent fires (i.e. 2001 and 2007) over extensive tracts of native vegetation, particularly in Lavinia State Reserve. Native-vegetation remnants are now scattered throughout a rural landscape where most are small, fragmented and isolated. Unless the loss and degradation of native forest on King Island can be halted, and protected from wildfire, the extinction of King Island Brown Thornbill and King Island Scrubtit remains highly likely within the next few decades.

All native eucalypt and Swamp Paperbark-dominated forests (capturing most of the likely habitat critical to the survival of King Island Brown Thornbill and King Island Scrubtit) are listed as Threatened Native Vegetation Communities (TNVCs) under the Tasmanian *Nature Conservation Act 2002*. Further, *Eucalyptus brookeriana* wet forest (WBR) and Scrub complex on King Island (SSK) equate to Threatened Ecological Communities under the EPBC Act.

Acacia melanoxylon swamp forest (NAF) is the only forest vegetation community likely to be an important habitat for King Island Brown Thornbill and King Island Scrubtit that is not currently recognised as threatened on King Island. However, NAF represents only a small proportion (<2%) of the forest vegetation on the island, having been extensively cleared for agricultural purposes. NAF currently occupies an area of <650 ha spread over more than 250 patches on the island (most <1 ha in size), although NAF is considered to be secure in Tasmania so has no legislative protection as a vegetation community from land clearing on King Island.

Plantations for silviculture – hardwood (FPH) at Pegarah State Forest are clearly utilised by both King Island Brown Thornbill and King Island Scrubtit and the plantations form part of a mosaic of habitats that includes remnants of native forest retained across the State Forest block. Pegarah State Forest is managed by Forestry Tasmania (a Government Business Enterprise owned by the Government of Tasmania) and supports both hardwood (mainly Stringybark but also Blue Gum and Smithton Peppermint) and softwood (Radiata Pine) plantations. The importance of Pegarah State Forest for both King Island Brown Thornbill and King Island Scrubtit will require close liaison and cooperative management arrangements between Forestry Tasmania and conservation ecologists to ensure the viability of habitats for these taxa across the State Forest estate.

We have made considerable progress in identifying the current distribution of King Island Brown Thornbill and King Island Scrubtit and the habitats likely to be critical to the viability of these taxa. Nonetheless, targeted research is now required, including standardised population monitoring and studies on demography, functional habitats and movements to better understand the subspecies' ecology and inform strategies for their recovery. The protection of existing and future potential habitat for the King Island Brown Thornbill and King Island Scrubtit is fundamental to their maintenance and eventual recovery in the wild. To achieve this, we recommend that, as a minimum, the viability of the King Island Brown Thornbill requires protection of all native vegetation supporting eucalypts, and the King Island Scrubtit requires protection of all native vegetation supporting Swamp Paperbark.

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