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Palaeoecological Analyses Reveal Recent Fires Have Destroyed Late-Holocene Peat Deposits in Tasmania's Largest Ramsar Reserve

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ABSTRACT

Australian peat-forming wetlands are some of the most biodiverse in Oceania. King Island, the second largest offshore island from mainland Tasmania, has the largest Ramsar-wetland area in Tasmania—the Lavinia State Reserve (LSR). The reserve has been under threat of peat loss from swamps over past decades due to wildfires, deforestation and drainage. To provide a framework and baseline to assess the resilience or susceptibility to future climate change and fire impacts at the LSR, we apply a palaeoecological approach to understand Holocene peat dynamics in two different LSR wetlands. This contributes to resolving the dynamics and rate of peat loss, thereby assisting in prioritising areas for further swamp conservation actions. Both LSR wetlands were once lakes, and peat accumulation only started due to terrestrialisation during a period of low water levels and drought in the Mid-Holocene. Fires have resulted in the loss of at least 4000 years' worth of accumulated peat in the largest peat-forming swamp, with the greatest loss likely linked to summer fires in the LSR in the 2000s. This finding shows the long-term vulnerability of the LSR wetlands to climate and fire impact, underscoring the need for effective fire management to conserve the remaining peat through fire control and careful hydrological management.

1 | Introduction

Peat-forming wetlands provide key environmental services. Unfortunately, their health and persistence are at risk globally (Bonn et al. 2016) due to human impact such as drainage for

fuel and agricultural activities, and greenhouse gas-driven climate change (Dohong et al. 2017; Fluet-Chouinard et al. 2023; Leifeld et al. 2019; Turetsky et al. 2020). At least 35% of global wetlands have been lost since 1970, and though protected wetlands have minimal human influence, they are also threatened

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Summary

- A palaeoecological study of wetlands in Tasmania's largest Ramsar reserve shows recent wildfires have burned ~4000 years accumulated peat, highlighting the need for improved fire and hydrological management to protect these vulnerable ecosystems.

by climate-change impact (e.g., sea-level rise, drought, flooding) especially in high-latitude and highland areas (Convention on Wetlands 2021). This is true for Australia, particularly the southern temperate and mountainous part of the continent where most protected wetlands are located (Bino et al. 2016). Australian peat-forming wetlands have been heavily impacted by land-use change and fire; those remaining (<50%, Finlayson and Rea 1999) are protected but still under degradation threat (Corbett 2010a; Cowley and Fryirs 2020; Treby and Grover 2024), especially from climate-change impacts (Corbett 2010a; Filkov et al. 2020; Pemberton 2005; Prior et al. 2020, 2024). A good example of these is wetlands on King Island, Australia's second largest island situated in Bass Strait between Tasmania and mainland Australia.

King Island was settled for agriculture by Europeans following the exploitation of the seal population in the early 19th century (Warneke 2013). Land clearing has removed over 70% of the native vegetation with the last large tract of native vegetation on the island today being part of the Lavinia State Reserve (LSR) in the northeast corner of the island. The LSR, is a 7000 ha wetland-vegetation complex (Figure 1). It is the largest Ramsar site in Tasmania (Aboriginal-given name: Lutruwita) and is known for the chains of peat-forming swamps that hosts unique fauna (Corbett 2010a). However, the reserve has been recognised as under constant fire threat since the 1970s due to forest clearance, climate drying and increased frequency of uncontrolled fires (Corbett 2010a; King Island Natural Resource Management Group 2002). Previous land surveys and assessments have provided detailed records of present ecological state of the reserve, as well as changes that have occurred in recent times, especially since European settlement on the island in 1802 AD (Corbett 2010a, 2010b; Newall and Lloyd 2012). Vascular plant species and communities have been documented across the reserve, as well as the condition of key Ramsar sites, including two wetland sites considered in this study (Lake Martha Lavinia and Pedestal Swamp; Figure 1) (Corbett 2010a, 2010b; Newall and Lloyd 2012). These wetlands are thought to have always supported peat, with long-term cyclical pattern between peat accumulation and loss shaped by fire (Corbett 2010a) (Figure 2).

Corbett (2010a) hypothesised model suggests that peat destruction by fire in the swamp usually starts with a partial loss of peat and pedestal formation, followed by a total peat loss and the development of open water (lake) that supports fresh peat accumulation (Figure 2). Corbett's model was based on field observation rather than historical reconstruction using space for time substitution. Different swamps were interpreted as being in different fire-impact stages. Thus, according to this model Lake Martha Lavinia and Pedestal Swamp wetlands represent different stages in this cyclic process. Here, we use a palaeoecological approach to reconstruct long-term development of the LSR wetlands.

Our goal is to: (1) understand the impact of climate and fire impact on the wetlands over the past millennia; (2) determine the extent of peat already lost to fire in the reserve's largest peat swamp (Pedestal Swamp); and (3) test existing hypothesis that the swamp has always supported peat, with long-term cycle between peat formation and loss shaped by fire (Corbett 2010a). Results will help assess Corbett's (2010a) model in millennial time scales for a finer understanding of how important wetlands have responded to fire and past climate in the LSR and King Island in general, thereby enhancing our understanding of the system's resilience or susceptibility to climate change and fire impacts. Such knowledge will assist in evaluating conservation and management interventions to protect these and other wetlands in the Lavinia State Reserve.

2 | The Lavinia State Reserve and King Island Environment

The Lavinia State Reserve (LSR) is a ~7034-ha area of coastal sand dunes and swampy sand plains on the northeast coast of King Island in Lutruwita. The geology of the area is largely characterised by unconsolidated clastic sediment, basalt, minor sandstone and granite (Seymour et al. 2006). King Island has a maritime climate modulated by the exposure to the Southern Ocean and the mid-latitude westerly wind, with average temperatures of about 13°C–21°C and annual average rainfall of around 862–978 mm (Grose, n.d.; Grose et al. 2010). Average temperatures have increased on King Island since the 1950s at about 0.1°C per decade and there has been a decline in average rainfall since the 1970s, aggravated by the 1995–2009 drought known as the 'big dry' period (Grose, n.d.). King Island's spring 2023–winter 2024 experienced the driest period on record over the summer and autumn period of 2024 (Australian Bureau of Meteorology 2024; Department of Natural Resources and Environment Tasmania 2024).

The LSR is a designated Ramsar site as it represents King Island's largest area of native ecosystem communities, including swamp forests, freshwater wetlands, herbfields, wet grasslands, sedge and rush wetland (Ramsar.org; Corbett 2010a). The reserve wetlands host a range of globally significant threatened species, including a critically endangered, orange-bellied parrot (*Neophema chrysogaster*) and green and gold frog (*Litoria raniiformis*) species. The reserve also falls within an eco-transitional zone between the Australian mainland and north-west Tasmanian mainland, supporting species from both regions, representing a biodiversity hotspot in the broader southeast Australian region (<https://rsis.ramsar.org/ris/253>).

Prior to permanent European settlement, the vegetation of King Island was a mix of dense impenetrable tea brush and tall wet forest communities with open grassy heath in some areas. The survey of the island's vegetation in 1827 AD by Barnard shows that by this time burned and dead *Eucalyptus* spp. forests were common on the island (Scott 1850; Royal Society of Tasmania 1873). Fires that burned these forests are likely a result of human visits to King Island (whalers and sealers) who were operating throughout the Bass Strait islands during the period of 1798–1830 AD (Lawrence and Davies 2011; Ryan 2020). Widespread fires caused adverse biodiversity effects and

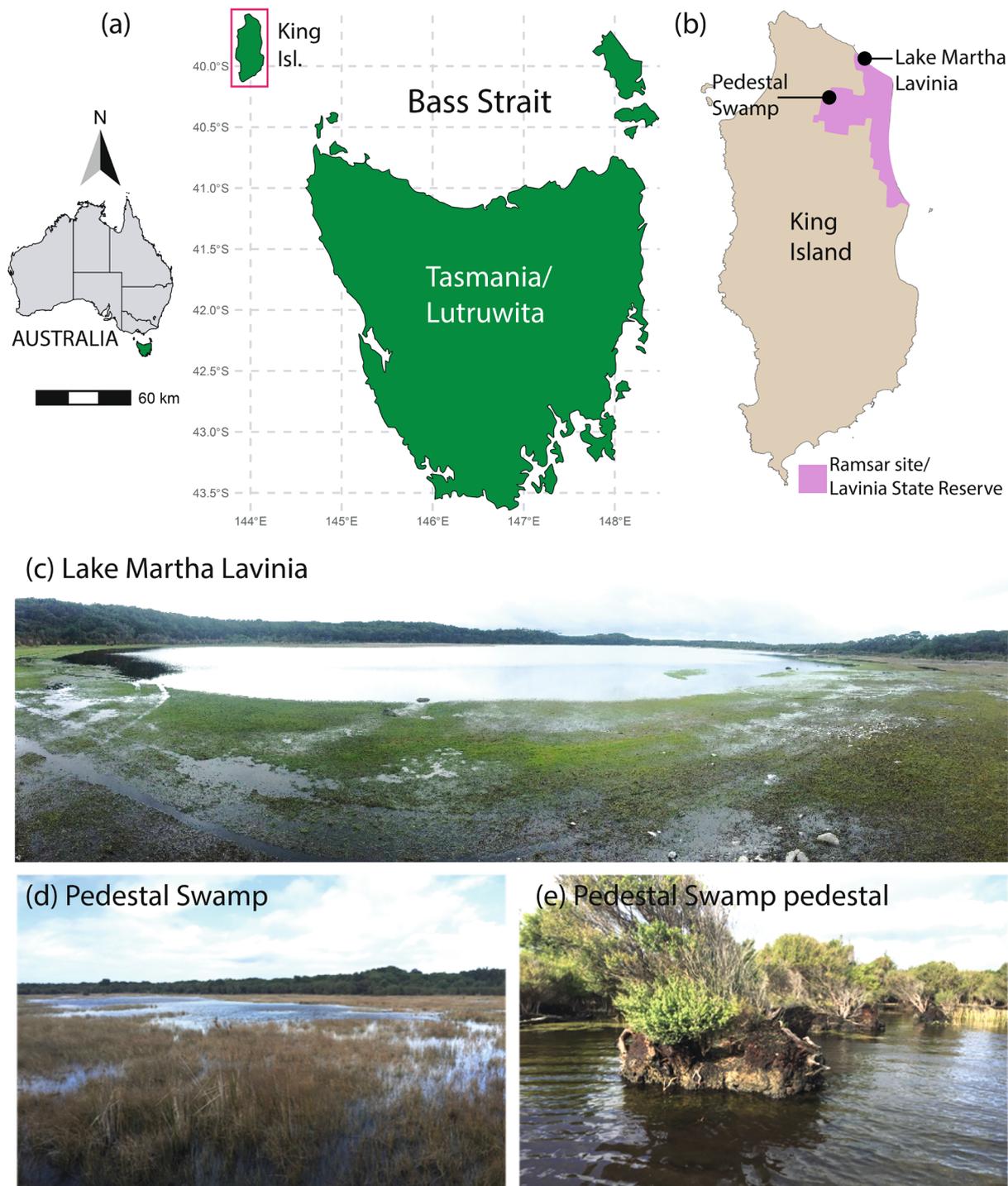


FIGURE 1 | Study area and coring locations in Lutruwita/Tasmania (a–e), with panel (b) focused on the core study sites on King Island [red box around King Island in the Tasmania map in panel (a)]. Panel (d) shows remnant peat pedestals following recent peat fires in Pedestal Swamp.

degradation of wildlife habitats, contributing to the extinction of a dwarf emu (King Island emu, *Dromaius novaehollandiae minor*) that was heavily predated by humans and introduced dogs (Hume and Robertson 2021) and the local extinction of the Tasmanian endemic conifer celery-top pine (*Phyllocladus aspleniifolius*) (Scott 1850; Royal Society of Tasmania 1873). Since European settlement from the 1800s, about 70% of the island's native vegetation has been cleared for agriculture (King Island Natural Resource Management Group 2002). Of the remaining wetlands on the island today, only a few have not been fully

cleared and drained, and are now protected as the LSR and a Ramsar site (Corbett 2010a). These include our study/sampling sites for the present research: Lake Martha Lavinia and Pedestal Swamp (Figure 1).

3 | Methods

Sediment cores were collected from wetlands (Pedestal Swamp and Lake Martha Lavinia) in the LSR 2022 using a D-section

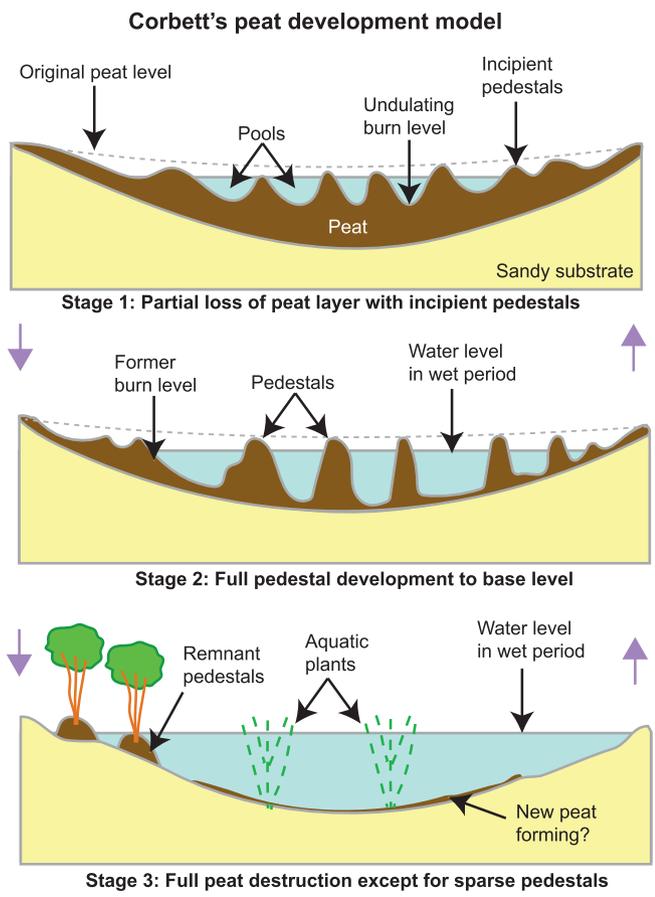


FIGURE 2 | Corbett's conceptual model of peat swamp in the Lavinia State Reserve (Corbett 2010a).

corer, and core lithologies were described on site before any oxidation effect and colour changes occurred in the cores (see Tables 1 and 2 for site information). Sediment cores were taken from open water in catchments. However, cores were also taken from standing peat pedestals, assumed to have been created following a recent fire that burned peats in Pedestal Swamp (Corbett 2010a).

Sediment subsamples were analysed for radiocarbon dating at DirectAMS, Washington and the Australian Nuclear Science and Technology Organisation, New South Wales (Hua et al. 2001; Fink et al. 2004). A total of 22 AMS radiocarbon dates were obtained for all sites and used to build a Bayesian age-depth model in 'rbacon' version 4.4.1 (Blaauw et al. 2022; Blaauw and Christen 2011). An age-depth model was only built for Lake Martha Lavinia which has a continuous sequence, and no age-depth model was constructed for Pedestal Swamp with a non-continuous sequence. Calibrated ages of measured radiocarbon values for Pedestal Swamp were reported using OxCal program version 4.4 (Bronk Ramsey 2009). All dates were calibrated using the latest calibration curve for the Southern Hemisphere, SHCal20 (Hogg et al. 2020).

Sediment/peat subsample (1.25 cm³) was taken at 2–4 cm intervals across cores for microfossil analysis (pollen and non-pollen palynomorphs) and at 1 cm interval for macrocharcoal analysis to reconstruct changes in wetland and fire activity, respectively. Microfossil analysis follows standard palynological procedure including HCl, KOH and acetolysis treatment (Faegri and Iversen 1975), while sediment subsamples were bleached using household bleach overnight (15h) and washed through 125 μm

TABLE 1 | Coring site information and vegetation at Lavinia State Reserve, King Island.

Site	Core depth (cm)	Location	Elevation (m)	Setting and vegetation
Lake Martha Lavinia	300	-39.647570, 144.064310	20	A deep open lake (depth > 1 m), with <i>Leptospermum laevigatum</i> and <i>Melaleuca ericifolia</i> forests characterising lake surroundings. <i>Leptospermum</i> forest understory is dominated by <i>Acacia</i> sp. and <i>Eucalyptus</i> occasionally presents. Dwarf <i>Melaleuca</i> dominates lake margins
Pedestal Swamp	200	-39.704444, 144.015000	30	A shallow swamp (depth < 1 m), with semi-open water dominated by <i>Myriophyllum</i> sp., <i>Eleocharis</i> sp., <i>Isolepis nodosa</i> , and <i>Juncus</i> . Some parts of swamp have been recently burnt and burnt leftovers formed peat islands (pedestals) within swamp, with shrubs growing on pedestals, especially <i>Leptospermum scoparium</i> . Immediate surrounding vegetation is dominated by <i>Leptospermum scoparium</i> scrub, as well as heathland/scrub regrowth with abundant <i>Pteridium esculentum</i> . Other plants present in regrowth vegetation include <i>Banksia maginata</i> , <i>Allocasuarina monilifera</i> , <i>Selaginella</i> sp., <i>Lepidosperma</i> sp., <i>Monotoca elliptica</i> and <i>Leucopogon parviflorus</i>

TABLE 2 | AMS radiocarbon dates of bulk sediment measured at direct AMS, Washington and the Australian Nuclear Science and Technology Organisation (ANSTO).

Sites	LabID	14C age (year BP)	Error (1 σ)	Depth (cm)	Median calibrated age (cal. yr. BP)	Calibrated age range (cal. yr. BP)
Lake Martha Lavinia	D-AMS 043097	963	28	34	844	771–920
Lake Martha Lavinia	D-AMS 043098	3321	22	72	3490	3454–3570
Lake Martha Lavinia	D-AMS 043099	4405	25	125	4931	4867–5041
Lake Martha Lavinia	D-AMS 043100	5326	25	175	6080	5997–6189
Lake Martha Lavinia	D-AMS 043101	6414	32	225	7303	7259–7421
Lake Martha Lavinia	D-AMS 043102	11 654	48	275	13 480	13 435–13 591
Pedestal Swamp deep	OZAW31	3620	20	0	3885	3840–3979
Pedestal Swamp deep	OZAW32	12 545	30	30	14 825	14 584–15 030
Pedestal Swamp deep	OZAW32	12 100	40	30	13 922	13 813–14 050
Pedestal Swamp deep	OZAW33	5025	25	60	5708	5609–5887
Pedestal Swamp deep	OZAW33	6580	30	60	7457	7423–7563
Pedestal Swamp deep	OZAW34	17 110	45	90	20 619	20 527–20 800
Pedestal Swamp deep	OZAW34	16 800	60	90	20 305	20 187–20 457
Pedestal Swamp deep	OZAW35	11 945	30	115	13 772	13 614–14 001
Pedestal Swamp deep	OZAW36	28 530	200	145	32 640	32 220–33 323
Pedestal Swamp deep	OZAW36	25 000	150	145	29 203	28 930–29 701
Pedestal Swamp pedestal-A	OZAW37	3495	25	3	3740	3646–3832
Pedestal Swamp pedestal-A	OZAW38	3960	25	25	4355	4296–4509
Pedestal Swamp pedestal-A	OZAW39	3995	25	47	4420	4312–4522
Pedestal Swamp pedestal-B	OZAW40	3350	25	3	3526	3485–3633
Pedestal Swamp pedestal-B	OZAW41	3990	25	25	4415	4300–4521
Pedestal Swamp pedestal-B	OZAW42	4140	25	45	4618	4527–4816

Note: Calibrated ages are median probability ages and age ranges at the 95% confidence interval. Duplicate dates were obtained for some depths in the Pedestal Swamp core.

sieve for macrocharcoal analysis. At least 300 terrestrial pollen grains were identified and counted in each sample, converted to relative abundances. The base sum for this conversion is the sum of dryland trees, shrubs and herbs, and the abundance of wetland/aquatic taxa was calculated relative to the base sum. Non-pollen palynomorphs (NPPs) were identified in pollen slides and expressed as concentration (NPPs/cm³). Given the context and focus of this study, only aquatic/wetland and related terrestrial pollen taxa and NPPs are presented. Detrended Correspondence Analysis (DCA) was performed on wetland taxa using 'vegan' package in R (Oksanen et al. 2024) and the first axis (DCA1) was extracted to infer changes in wetland water levels through time (Adeleye et al. 2021). CharAnalysis was used to convert macrocharcoal counts to influx (charcoal pieces/cm²/year) (Higuera et al. 2009).

4 | Results

4.1 | Chronology

The Bayesian age-depth model produced a basal age of ~14800 calendar years before present (cal. yr. BP) or ~14.8 ka for Lake Martha Lavinia (Figure 3). Pedestal Swamp sequence is not continuous and age reversals are present which may be linked to peat/sediment mixing or downcore contamination when the peat burned significantly in the past (Corbett 2010a). Therefore, we presented the site's unmodelled calibrated dates (no age-depth model), and pollen stratigraphical zones were compared to that of Lake Martha Lavinia as an additional anchor for the site's chronology (Figure 4).

Severe burning of Pedestal Swamp, which is later discussed, is likely to have resulted in downcore sediment contamination at least in the area cored for this study, which is near a remnant peat pedestal that formed after a recent major peat fire in the swamp. For instance, the comparable median age of the top of the elevated Pedestal core A (~3.8 ka) and that of the deep core (~3.9 ka) may reflect peat transfer from a pedestal surface into the open water by wind or erosional activity during high water level period (Figure 2). While additional dated deep-core sequences from other parts of the swamp are required to fully resolve its chronology, present dates and the abundance of Poaceae at the base of Pedestal Swamp record strongly indicate that the swamp is of glacial age—potentially the last glacial maximum (Figure 4). Furthermore, the more reliable dates of the top Pedestal cores A and B, as well as the overall pollen zones of the swamp and that of the nearby Lake Martha Lavinia, provide sufficient chronological context for the aim of the current study (Figures 3 and 4).

4.2 | Wetland History

Lake Martha Lavinia was characterised by wetland/aquatic plants Restionaceae and Cyperaceae and green algae Zygnemataceae between 15 and 13 ka and gradually declined through to ~10 ka. Fine organic mud generally characterised the lake deposits between 15 and 7.5 ka and woody organic mud and other organic detritus after 7.5 ka (Figure 4a). Pedestal Swamp was also characterised by Restionaceae, Cyperaceae and

Zygnemataceae between 150 and 80 cm (~14–5/7 ka), with a brief *Myriophyllum* expansion at ~14 ka. Organic clay accumulated in the basin through this time with a brief deposition of coarse sand at ~14 ka (Figure 4b). Restionaceae largely recovered at Lake Martha Lavinia from ~5.4 ka with diatoms, especially *Aulacoseira* increasing from ~4 ka. Restionaceae also expanded at Pedestal Swamp from ~4.5 ka with woody peat accumulation (Figure 4b).

The first axis of the Detrended Correspondence Analysis (DCA1) for Lake Martha Lavinia wetland taxa shows the greatest score at ~8–5 ka, which we interpret as a shift to lower wetland water level taxa at this time (Figure 4a). DCA was not performed for the Pedestal Swamp record due to the incompleteness of the record. The shift in water level at ~8 ka was immediately followed by high fire activity and then increases in *Melaleuca* and *Leptospermum* either in or around the swamp. This pattern is also observed in Pedestal Swamp (Figure 4b). Fire may have initially reduced *Melaleuca* between 7 and 6 ka, with recovery after 6 ka. DCA1 score was lowest (highest water level) for Lake Martha Lavinia in the last ~4000 years, with a decline in fire activity, as well as *Melaleuca* and *Leptospermum* abundance (Figure 4a).

5 | Discussion

Corbett (2010a) proposed a cyclic model to explain temporal changes of wetlands and peat loss in the Lavinia State Reserve on King Island based on a field survey and time-for-space substitution (assumed chronosequence). The wetland palaeoecological records which span the past millennia provide the first empirical test of Corbett's model as well as dating the rate of peat loss (Corbett 2010a). First, we discuss wetland development over the past millennia, the impact of fire on wetlands, and then use our results to evaluate Corbett's hypothesis of peat formation and loss in the Lavinia State Reserve.

5.1 | Inferred Wetland Development and the Onset of Peat Formation in the Lavinia State Reserve

Pedestal Swamp and Lake Martha Lavinia sedimentary sequences indicate that wetland development started with the formation of a lacustrine system (fine lake muds over a sandy substrate) during the last glacial period (Figure 4). Aquatic vascular plants Restionaceae and Cyperaceae mostly grow on the shores of swamps/lakes in the area today (Corbett 2010b) and this was likely the case since at least the late glacial period. The presence of freshwater algae Zygnemataceae in both records also indicates a generally shallow-fluctuating water levels in Lake Martha Lavinia until ~9 ka and in Pedestal Swamp until sometime in the mid-Holocene (Adeleye et al. 2021; Cook et al. 2011; Van Geel 2001). The abundance of fungal type HdV-12 at the base of the record possibly reflects shrubs growing at least near the lake until 12 ka (Van Geel 1978; Van Geel et al. 1980). However, a brief period of high water levels likely occurred in Pedestal Swamp around 14 ka, as indicated by the presence of floating aquatic herb *Myriophyllum* and small presence of open water algae *Pediastrum* (Singh et al. 1981; Dodson 1974). Coarse sand in the swamp during this time may have been wind-blown

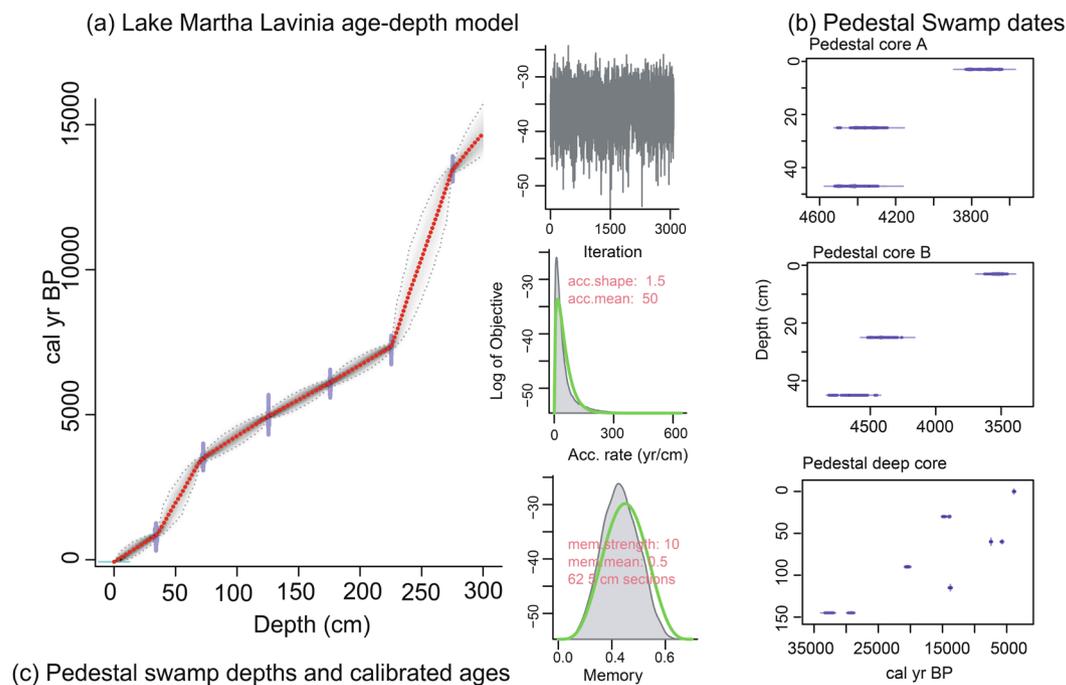


FIGURE 3 | Bayesian age-depth model for Lake Martha Lavinia (a), calibrated dates for Pedestal Swamp cores (b, c). Cal yr BP, calendar years before present.

or brought in by erosion linked to an increased water supply to the site (Figure 4b).

A major decline in aquatic herbland in relation to woody taxa, especially *Melaleuca* at Lake Martha Lavinia from ~9 to 5 ka suggests a marked shift in lake size/water level through the Early–Mid-Holocene, possibly a drop in lake levels with increased

terrestrialisation (Figure 4a). Salt-tolerant *Amaranthaceae*, which usually characterises Pedestal Swamp's exposed floor in drought years (Corbett 2010a) was also at the site between 5.7 and 4.4 ka during what would have been a drier period in the Mid-Holocene (Figure 4b). The onset of major lowering of lake levels was likely from ~7.5 ka, as reflected by Lake Martha Lavinia wetland taxa compositional change—DCA1, which

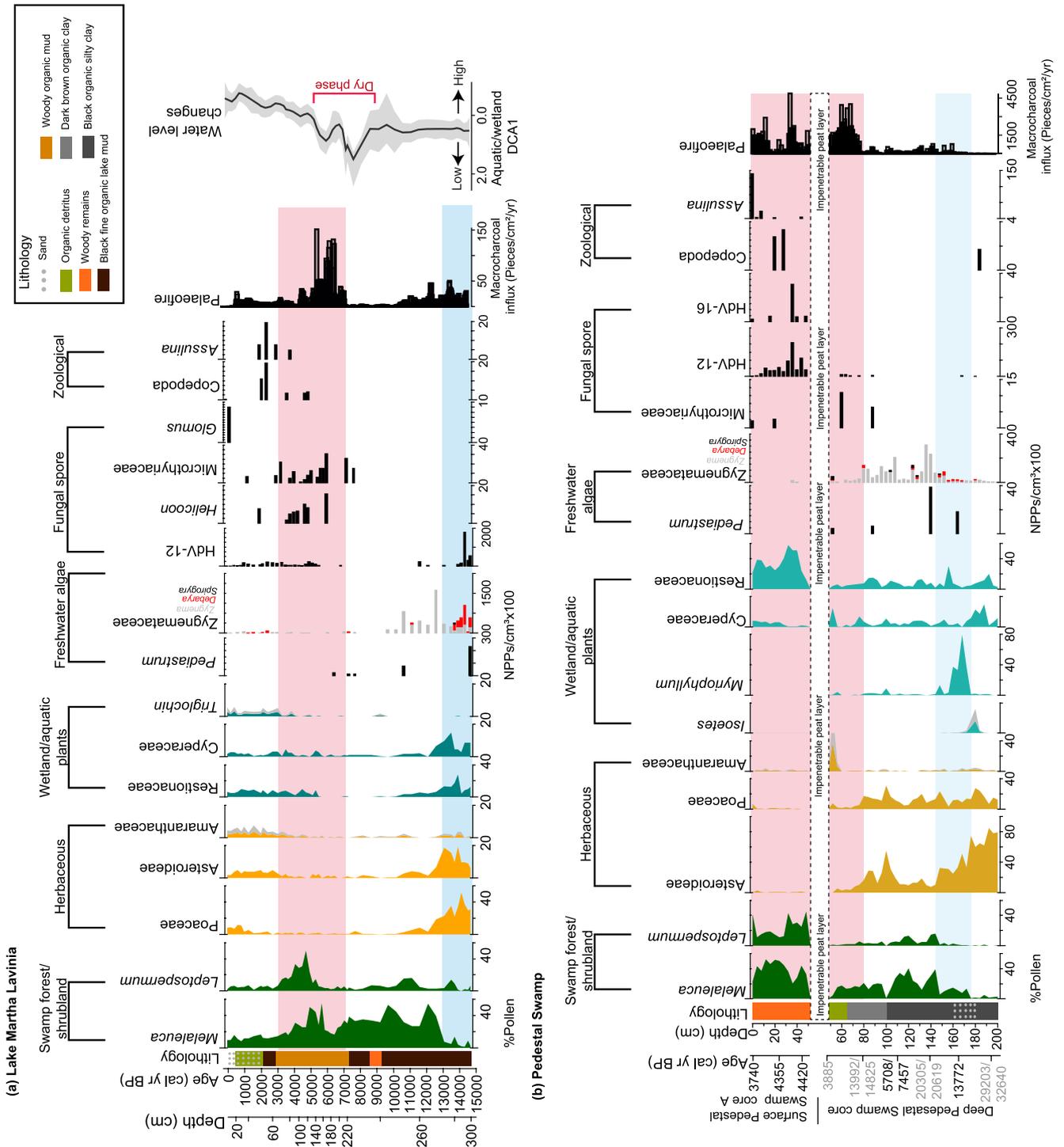


FIGURE 4 | Pollen, non-pollen palynomorphs (NPPs) and charcoal records for studied sites on King Island, Bass Strait, Tasmania. Also shown is the DCA1 curve for Lake Martha Lavinia.

corresponds with the onset of woody deposition in the lake and possibly the onset of peat formation in Pedestal Swamp and across the Lavinia State Reserve in general (Figure 4a). Mesophilic woody taxa (*Melaleuca* and *Leptospermum*) likely replaced herbland around the lake shore during this period, with woody deposition in the lake, which is supported by the occurrence of *Helicoon* in Lake Martha Lavinia, a fungus specifically associated with submerged leaves, twigs and barks of trees (Abdullah et al. 1998). The abundance of HdV-2 fungal type in Pedestal Swamp at ~4.5–3.7 ka indicates woody shrubs growing

in the swamp as well during the Mid-Holocene (Van Geel 1978; Van Geel et al. 1980) (Figure 4).

The recovery of aquatic herbland after 5 ka suggests water level recovery in the lake after the Mid-Holocene dryness (Figure 4a). The presence of copepod remains between 4 and 2 ka, which are associated with temporary standing waters (Van Geel 1978), suggests the increases in water levels were likely gradual. A Restionaceae peak around this time in Pedestal Swamp also suggests increased wetness at the site and sustained decline in

Zygnemataceae at both sites indicates a more stable water level as well (Figure 4b).

5.2 | The Impact of Fire and Peat Loss in Lavinia State Reserve Wetlands

Despite the difficulty of dating the Pedestal Swamp sedimentary sequence, our biostratigraphic comparison with the Lake Martha Lavinia sequence suggests that both sites continued to accumulate organic-rich sediments from at least the Mid-Holocene through to the Late Holocene. Wetlands, especially ones with deeper water depths and larger catchments such as Lake Martha Lavinia, may have been less affected by the Mid-Holocene dry conditions and increased fires. Wetland water levels may have dropped with woody encroachment at this time but were likely still high enough to keep accumulated peat wet, and this is reflected by the occurrence of wet peat fungi fruiting body Microthyriaceae (Van Geel 1978) in the deeper Lake Martha Lavinia (Figure 4a). The expansion of *Leptospermum* at both Lake Martha Lavinia and Pedestal Swamp in the Mid-Holocene may reflect some degree of localization of the fire, at least near the catchments (Figure 4). *Leptospermum*, especially *Leptospermum scoparium*, is known to colonise peat after fires, and ages of cohorts can be used to estimate the time since the last fire (Bowman et al. 2023; Corbett 2010a). Early European

surveys of King Island also show the tea tree (*Leptospermum*) to be abundant in burnt forests, indicating widespread burning in the early 19th century (Scott 1850).

Pedestal Swamp is one of the most fire-damaged wetlands in the Lavinia State Reserve today (Figure 5) and our dated peat sequence from the wetland suggests at least two major peat fires or fire episodes in the recent past. The first resulted in the loss of peat accumulated over the last ~3700 years, which is equivalent to the top ~60 cm of peat accumulated at the margins of Lake Martha Lavinia (Figures 3 and 4). The timing of the fire that burned the entire 60 cm of surface cover on Pedestal Swamp is unclear, though it may most parsimoniously be related to the impact of early European settlement fires and subsequent forest clearance and construction of agricultural drainage networks adjacent to the site over the last 220 years. The second peat fire episode that likely left remnant peat pedestals in the catchment resulted in the loss of > 50 cm of rapidly accumulating peat (representing at least 700 years of peat accumulation loss, Figure 3) in most parts of the swamp. Close examination of the Pedestal Swamp surface in the aerial images from 1946 AD onwards suggests that the pedestals currently present across the swamp surface were not present in the images available from 1946 AD through to 2002 AD (Figure 5). In comparison, Lake Martha Lavinia marginal peat has been protected due to the much deeper water depth, isolation from the impacts of agricultural

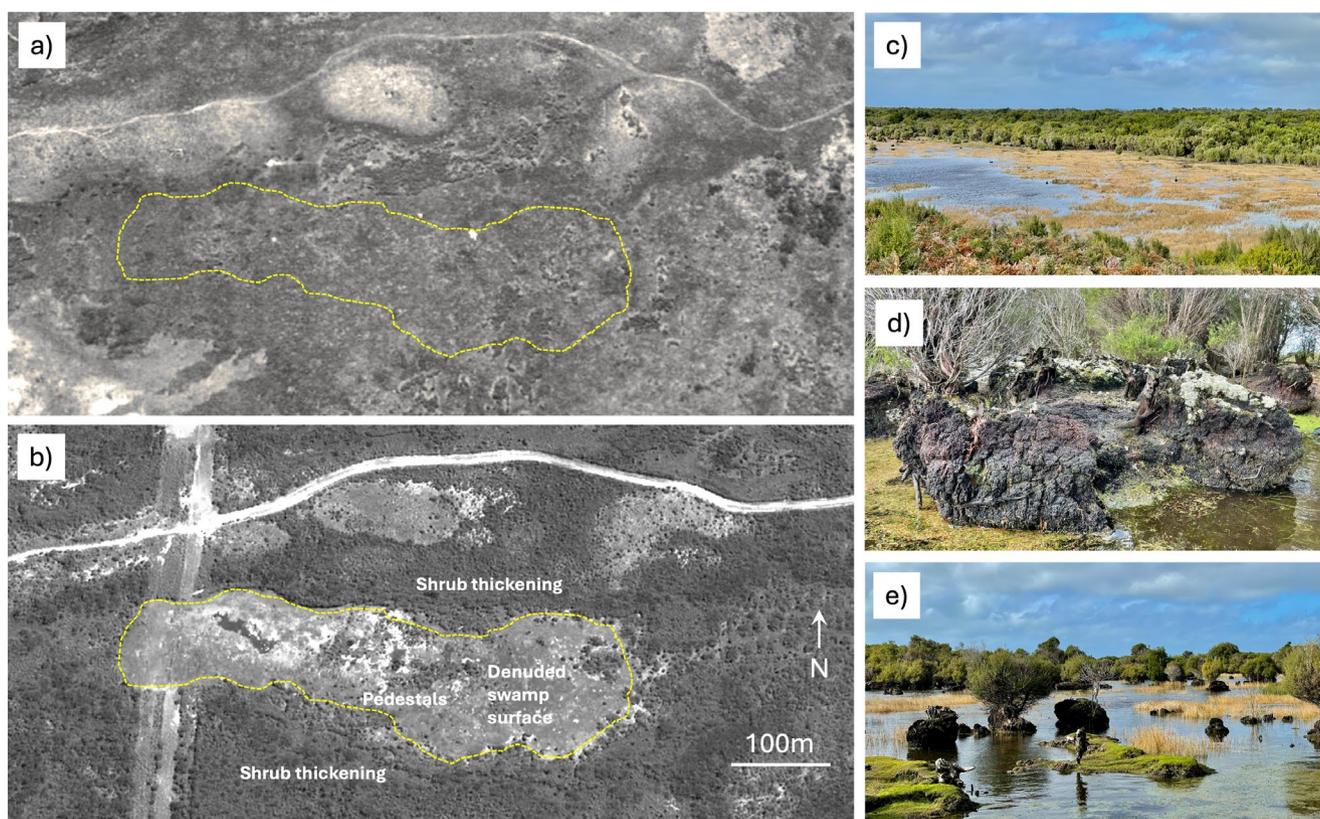


FIGURE 5 | Aerial photographic interpretation of landform changes at Pedestal Swamp (Lavinia State Reserve, King Island) with landscape images of Pedestal Swamp. (a) 1946 Airphoto with continuous vegetation cover across swamp surface (LIST 2024). Yellow dashed area marks 2023 boundary of Pedestal Swamp. (b) 2023 Google earth image of Pedestal Swamp (Google Earth V 6.2.2.6613 2023) showing denuded swamp surface and woody thickening around the swamp margins and nearby slopes. Pedestals are visible as remnant shrubby vegetation (darker spots) in the centre of the swamp. (c) View of Pedestal Swamp from roadside looking south showing standing water on denuded swamp surface. (d) Pedestal formations up to 50cm high in the centre of the swamp. (e) Pedestal formations with and without vegetation growing on top across the centre of the swamp. (colour photos by Simon Haberle 2021).

drainage construction, and forest clearance. Importantly, drainage works may have increased the vulnerability of organic soils to combustion at Pedestal Swamp, as is the case in Borneo (Bowman 2017).

5.3 | Re-Evaluating Corbett's Peat Development Model

A re-evaluation of the conceptual peat development model proposed by Corbett (2010a) using the sedimentary sequence for Pedestal Swamp and Lake Martha Lavinia indicates that wetland development started with the formation of a lake and the system has not always supported peat accumulation (Figures 4 and 6). Peat accumulation generally started in the Mid-Holocene when catchment water levels were low, likely due to a drier climatic episode in the area as previously recorded for eastern Bass Strait (Adeleye et al. 2021), with woody plant encroachment and deposition in the catchment. Our results agree with Corbett's hypothesis that fire has shaped the wetlands, especially Pedestal Swamp over time and show this is not only a feature of the wetland in recent centuries but also in past millennia. However, our results also indicate that fire impact on wetland may vary depending on fire intensity and wetland hydrology. For instance, the first stage of major peat loss to fire in Pedestal Swamp likely

resulted in the loss of the last ~3700 years' worth of accumulated peat in the swamp (Figure 6b,iv) and not a partial loss (Figure 2a, Stage 1). Lake Martha Lavinia appears to have been protected from direct fire impact due to the higher water level over this time. Furthermore, the finding here suggests future dry conditions and fire in Pedestal Swamp may not necessarily result in increased open water area only, but a drier climate could also reduce the existing open water areas, resulting in more swamp terrestrialisation with increased swamp biomass load and availability to burn (Figure 6b,vii). Corbett's hypothesised model was based on different swamps of different fire-impact stages and while this provides an overview of the state of wetlands in the reserve, by contrast our results highlight the importance of individually investigating long-term changes in swamps to better help prioritise further conservation actions.

Fire management on King Island is currently primarily focused on protecting infrastructures and commercial assets (King Island Fire Management Area Committee 2009). While this is important, fire management planning also needs to more effectively protect biodiversity from controlled wildfires (King Island Fire Management Area Committee 2009); issues that remain in the policy formulation stage (King Island Landcare Group 2023). Given the potential future impact of climate (drought and fire) in the Lavinia State Reserve wetlands as indicated by our findings,

Adeleye et al. peat swamp development model

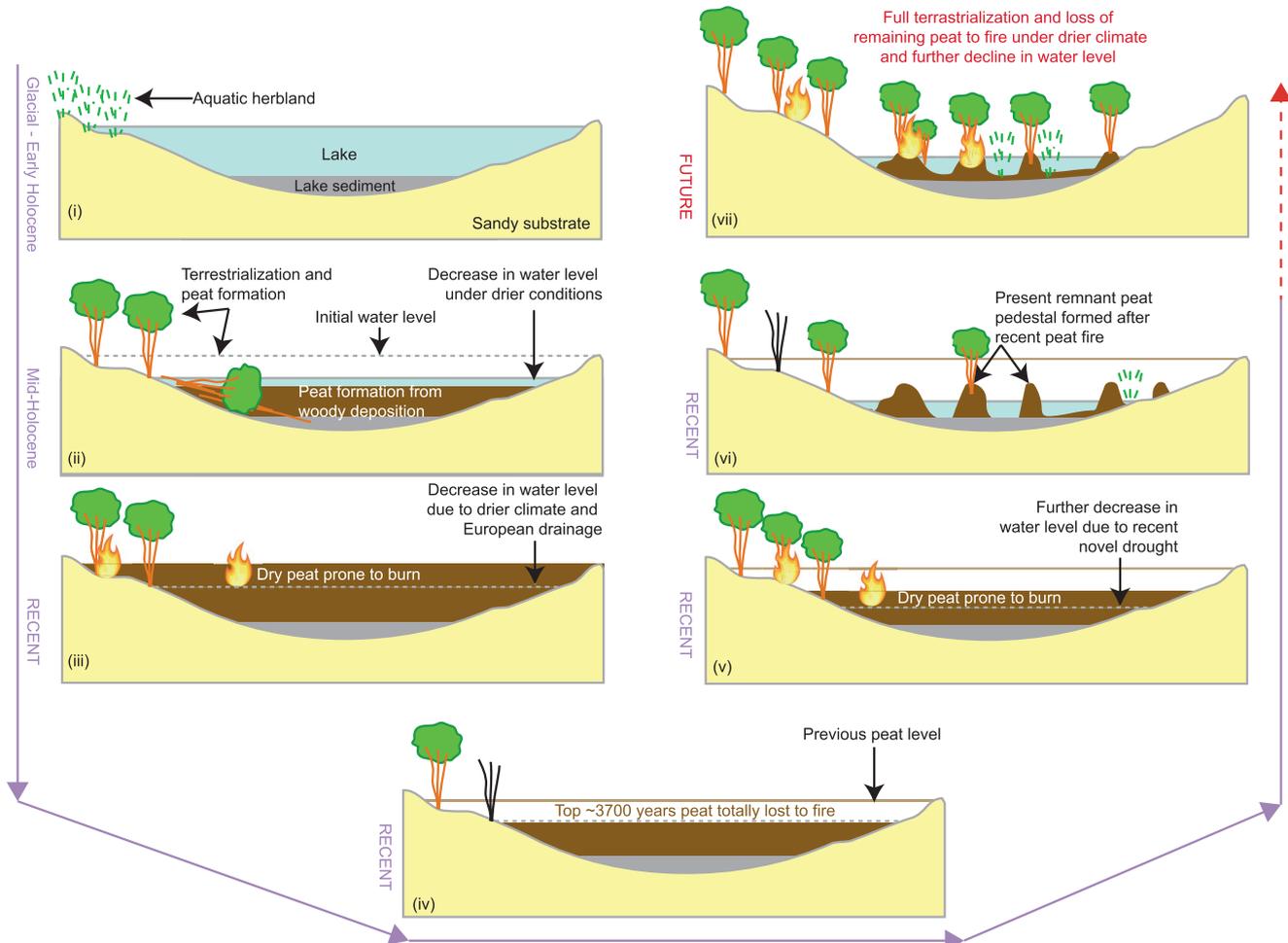


FIGURE 6 | Pattern of peat swamp development in the Lavinia State Reserve inferred from the present palaeoecological study.

a more targeted fire management strategy is urgently required to effectively protect wetland integrity and preserve remnant peats in the reserve. Management options could potentially include planned wetland rewetting, mechanical or prescribed burning to reduce fire hazards, more effective management of anthropogenic ignition sources near and in the reserve (e.g., permanent recreational fire ban), and greater public education about the value of the reserve and its vulnerability to uncontrolled landscape fires. Given the scale of the management challenge of managing threats to the reserve in a warming and drying climate that increases the risk of catastrophic peat loss, an adaptive management approach is required, including monitoring the short-term effect of management actions and comparing them to relevant baselines to assess the effectiveness of adopted strategies.

6 | Conclusion

We present the first long-term ecological assessment of Tasmania/Lutruwita's largest Ramsar wetland reserve located on King Island (Lavinia State Reserve) and our results provide insights into the long-term history and process of peat formation and loss, driven by changing vegetation, climate, and fire regimes over millennia, and exacerbated by European settlement and agricultural development impacts over the past 220 years.

Our findings agree with the existing interpretations that the Lavinia State Reserve wetlands geomorphology has identified deep peat deposits and the importance of fire in shaping wetland vegetation structures (Corbett 2010a). However, we found that the wetlands have not always been solely peat-forming as previously thought (Figure 5). We show that the wetlands at our study sites, and likely other sites, were previously lakes developed during the last glacial period and peat formation only began as a result of wetland terrestrialisation and woody deposition in the catchments during a period of low water levels linked to a possible dry episode in the Mid-Holocene.

We identified two phases of peat loss in Pedestal Swamp, which is the more centrally located peat-forming wetland on King Island and is one of the most fire-damaged swamps in the Lavinia State Reserve (Corbett 2010a, 2010b). The first phase of peat loss is identified by the removal of potentially up to 60 cm of surface peat across the entire swamp. The second phase is related to a further > 50 cm peat loss leaving unburnt peat pedestal remnants across the remaining swamp surface. The timing of these peat loss events is difficult to discern from the current sediment core chronologies, but we suggest the first stage of peat removal occurred at the time or sometime after the early occupation of the island by European settlers around 220 years ago. The second stage of peat loss is likely linked to summer fires in the current millennium.

Climate change impact is evident on King Island, with 2024's drought being the most extreme ever recorded on the island, with large areas burned by peat fire. Such smouldering fires release stored peat carbon into the atmosphere and degrade agricultural production through surface soil losses. Our palaeoecological study highlights the vulnerability of King Island

peat-forming wetlands to the impact of climate change, underscoring the urgent need for effective hydrological and fire management program in the Lavinia State Reserve to better conserve remnant peat and wetland dependent biodiversity. Monitoring the effectiveness of these interventions and comparing to baselines is also important for tackling the adverse climate-change impacts. Further research involving additional coring of burnt and unburnt peat-forming wetlands along with radiocarbon dating of surface samples. Ongoing monitoring of fire impacts are also prerequisites to fully understand long-term peat-fire dynamics on King Island, as well as gauging their vulnerability to drought induced climate change.

Author Contributions

Matthew Adesanya Adeleye: conceptualization, data curation, formal analysis, investigation, methodology, visualization, writing – original draft, writing – review and editing. **Simon Graeme Haberle:** conceptualization, funding acquisition, resources, supervision, writing – review and editing. **Quan Hua:** data curation, formal analysis, methodology, resources, writing – review and editing. **David M. J. S. Bowman:** investigation, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Datasets will be made available upon request.

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