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Time, justice, and urban nature: procedural barriers to multi-species flourishing

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This paper explores the ways in which urban green and blue spaces are beset by problematic governing processes that reinforce an unrepresentative and unjust environmental narrative. In efforts to operationalise Nature Based Solutions this is problematic for, ultimately, law may act to 'freeze' the environmental narratives that shape our urban ecosystems. In many cases the results will not adequately recognise multiple species or provide an adequate basis to learn from the self-organised resilience of ecosystems with a long history in place. In this paper we use an Australian case study to demonstrate that a once extensive plant community that was extirpated over the past 150 years is now unknown and unrepresented in environmental law and policy, despite its value for Nature Based Solutions. We suggest that modest regulatory change can act as a vehicle for more-than-human representation within existing decision-making processes. Improved representation of disrupted and marginalised ecologies may achieve the functionality needed for effective Nature Based Solutions and allow urban ecologies to flourish.

In the context of increasing urbanisation globally, there is a growing awareness of the importance of building or conserving articulated terrestrial, aquatic and wetland systems in cities (here referred to collectively as urban green-blue spaces or UGBSs), due to the key role they play in public health and well-being[1], climate disaster mitigation[2], stormwater and water quality management[3], biodiversity protection[4] and diverse cultural and aesthetic benefits[5]. This awareness is reflected in the United Nations Sustainable Development Goal 11, which aims to future-proof cities with improved green public spaces. Relatedly, the UN Decade of Ecosystem Restoration (2021–2030) has led to projects such as UNEP's (United Nations Environmental Program) 'Generation Restoration Cities' (https://www.decadeonrestoration.org/cities) The UNEP project (2023–2025) is 'dedicated to reversing the tide of ecological degradation in urban areas' through implementing urban nature-based solutions (NbS)[6–10]. NbS learn from, or mimic, the self-organising functionality of 'natural' systems to address socio-ecological challenges and create resilient, adaptable environments that are sustainable over the long-term[6]. The holistic aim of these programs is to enhance urban biodiversity, meet obligations under the Kunming-Montreal Global Biodiversity Framework (GBF) and, simultaneously, build resilience in cities. We emphasise the distinction between resilience and sustainability, the latter of which here is taken to mean the adaptive processes of creating and maintaining ecosystem services through integrated social, environmental, economic and governance actions[11]. It follows that urban sustainability is dependent on resilient UGBS, and that UGBS are important locations in which NbS interventions are likely to yield significant co-benefits[7].

Co-benefits of NbS are frequently expressed as ecosystem services that benefit humans. This has resulted in distributive inequalities, whereby the benefits and disadvantages of NbS are not shared equally between human and more-than-human stakeholders. Multi-species justice (MSJ) becomes an important perspective for identifying and addressing these distributive injustices at a conceptual and practical level[12–16]. MSJ sees humans as part of, and dependent upon, urban ecologies that incorporate more-than-humans. This is relational and holistic, reflecting the complex reality of the socio-ecological systems we, as a species, have helped create and now must manage sustainably in the face of systemic change[16,17]. Despite this, the aegis of justice has, traditionally, not covered more-than-humans or their communities, in large part due to practical and conceptual challenge of giving adequate voice to their interests (agency) in human decision-making processes[18]. How more-than-human representation and agency might be achieved in urban environments where 'nature' is disrupted and contested, is an area of active and vigorous experimentation[19,20].

Australians are among the most urbanised people on earth: 90% of Australians live in cities[21]. Because of this, the challenges associated with conserving, restoring or creating resilient, sustainable and just UBGS are acute. UGBS are critical to human wellbeing and enhance the vibrancy and resilience of city environments. These spaces provide crucial environmental services for human communities and a habitat refuge for more-than-human

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communities[22]. While progress from research in urban biodiversity has been significant, there is still much to do, including improving our understanding of ecological connectivity in space and time and the flow-on impacts for species abundance[4]. For some vulnerable species, cities are a refuge. A recent assessment of the distribution of threatened species in Australian cities indicates that urban locations can be veritable 'hotspots' for many species, including many threatened species[23].

There are many national, state and local strategies that aim to increase the viability of biodiversity within Australian cities. One example is the 'Biodiversity-in-Place' initiative of the New South Wales state Government Architect to improve urban biodiversity in NSW[24]. 'Biodiversity-in-Place' suggests that one key element in efforts to rethink UGBS habitat renewal in an Australian setting is to avoid ideas associated with 'rewilding' that influences some narratives about urban greening globally. As they point out, in an Australian setting, Indigenous communities have been managing land and waterscapes for tens of millennia. Biodiversity initiatives in Australian UGBS, and particularly restoration efforts as one aspect of the NbS framework, can be challenged by a lack of foundational data and the degree to which the systems have been modified by urbanisation. UBGS are often heavily degraded, highly contested and vulnerable to projected environmental change[25]. Restoration to achieve NbS requires a baseline assessment of ecosystem status and identification of evidence-based targets against which progress toward biodiversity conservation outcomes can be assessed [8, Criterion 3]. This can be problematic in urban environments as most ecosystems are heavily modified from their baseline condition and knowledge of baseline condition is either inadequate or missing[26,27]. This raises specific questions about what 'success' looks like in urban NbS, who decides what belongs, and how such decisions are made. These questions are critical, because NbS approaches require adequate integrated institutional and legal frameworks and governance structures[7–9].

In this paper we draw attention to the ways in which UBGS configurations are beset by problematic procedural and institutional frameworks that do not adequately address distributive injustices or permit multi-species representation in decision making. Such a lack of representation can compromise efforts towards achieving inclusive and sustainable NbS in cities.

We argue that a critical problem in efforts to address UGBS renewal is the lack of integration between procedural decision making by key bodies, in turn informed by law, and long-term environmental data that enable us to discover what 'flourishing' ecosystems look like, how they are composed, and how they function over the long-term. Using a case from a former 'natural' but now highly modified wetland environment of inner-eastern Sydney, Australia, we consider two critical elements for policy reform. The first is to consider the role of law in appointing experts to determine 'what' belongs 'where' in efforts to secure NbS for UGBSs. In a similar way to Mata[28] we urge more inclusive decision-making processes and point out the limitations of existing regulatory obligations that restrict this endeavour. Our second consideration outlines how environmental histories can provide an evidence-based assessment of ecosystem status in highly degraded urban ecosystem, and act as a form of multi-species representation for marginalised, disrupted ecologies. Again, Mata[28] in relation to 'bringing nature back' to cities, also call for a longer-term perspective. With these twinned considerations in mind, we explore problems associated with a rigidity in regulatory processes which emphasise a narrow scientific perspective, which do not provide adequate agency or representation to more-than-human stakeholders, and which are not consistent with global standard for nature-based solutions (Criteria 5.3, 8.2)[8].

The Botany Wetlands are a network of modified coastal freshwater wetlands in the inner suburbs of Sydney, a remnant of a formerly extensive wetland system that was significantly reduced in area and character during the 19th century (Fig. 1)[29]. The wetlands were an important component of the landscape and played a central role in Sydney's industrial and domestic water supply until the 1880s[30].

Today the wetlands are surrounded by urban green space, including Centennial Park, and several private and public golf clubs that lease the land from Sydney Water Corporation, the managing authority. The lower end of the system, where the system discharges into Kamay Botany Bay, is partly built over by Sydney Airport and is managed by the Commonwealth Government. The value of this system is primary expressed in terms of ecosystems services for humans and, indeed, there are significant human health and wellbeing benefits associated with access to open space[31]. Accordingly, public access to Botany Wetlands has been identified as a priority project by the Office of the Government Architect of NSW in the Sydney Green Grid report, part of the Greater Sydney Region and District Plans. In addition to the human health benefits, the wetlands act as a natural filter for stormwater runoff from a highly urbanised catchment, improving surface water quality and acting as a passive flood detention basin.

These diverse ecosystems services meant that Sydney's UGBS are valued highly by human users and thus contested. Green spaces absorbed by golf clubs have been a particular flash point[32], reflecting the long-standing global frustration regarding public access to urban green spaces[33,34] and, more conceptually, the contest between alternative 'urban imaginaries'[35]. The exclusive use of UGBSs by 'elite' club's cleanly exposes differential power dynamics in urban politics, of social/spatial exclusion, and issues surrounding 'rights' to the city[36,37].

Results

The role of law and the appointment of scientific committees

Current environmental management policy and practice within the Botany Wetlands is dominated by the requirement to protect and regenerate two endangered ecological communities: Eastern Suburbs Banksia Scrub (ESBS) and Sydney Freshwater Wetland (SFW) and the removal of invasive plant species. These plant communities are listed as endangered or critically endangered under national and states laws, being the *Environmental Protection and Biodiversity Conservation (EPBC) Act 1999* (Commonwealth) and the *Biodiversity Conservation Act 2016* (NSW) ('the Act'). Protection and regeneration actions are identified as 'high priority' (i.e., 'action required to avoid possible breach of legislation and prosecution') in the 2018–2028 Plan of Management for the Botany Wetlands[38]. Plans include strategic expansion of these protected communities. Importantly, the characteristic species composition for these protected plant communities is defined by the New South Wales Threatened Species Scientific Committee (NSW TSSC, 'The Committee'), based largely on extant examples of these communities and estimates of historical distributions[39,40]. We return to the problem associated with inadequate scientific knowledge to support the regulatory and policy framework below. In this section our aim is to consider how the Committee is composed, and the ongoing influence the committee's composition has for enabling or disabling MSJ.

The NSW TSSC is established pursuant to legislation, particularly Division 7 of Part 4 of the Act. Under this provision the Committee is established as a NSW Government Agency (s.4.38(2)), and is "not subject to the control or direction of the Minister" (s.4.39). The Committee's core function is to determine which species or ecological communities are to be listed under the Act as extinct, extinct in the wild, or 'threatened' (that is, vulnerable, endangered or critically endangered) (section 4.40(1)).

The Committee consists of 11 members (s.4.41), four of whom are scientists employed by the appropriate state or federal government departments (at the time of writing these were the Office of Environment and Heritage, the Royal Botanic Gardens and Domain Trust, the Australian Museum Trust, CSIRO, provisions 4.41(2)(a) – e)), as well as four scientists who are employed by a NSW tertiary education institution (s.4.41(2)(f)(1) or have been "nominated by a professional body principally involved in ecological or invertebrate research"(s4.41(2)(f)(ii)). Expertise of the persons appointed to the Committee is strictly prescribed in the Act, and exclusively relates to aspects of either ecology or biology (Division 7 Part 4, section 3 (a – i)).

The procedure for listing species and ecological communities to a threatened list is set out in Division 3 of the *Biodiversity Conservation Act 2016* (NSW) (aside from provisional listings which are dealt with pursuant to Division 4). It is the responsibility of the Committee to determine the

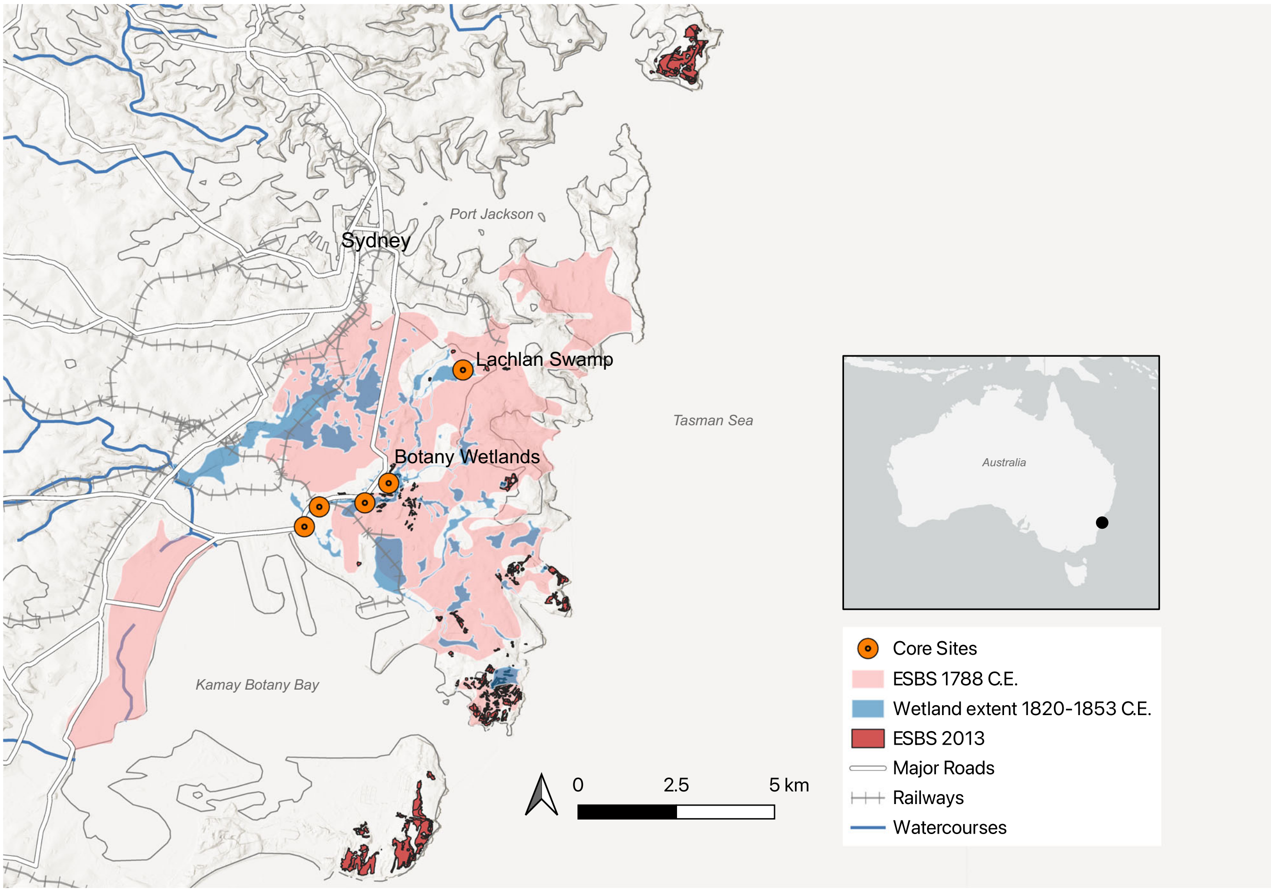

Fig. 1 | Map of Eastern Sydney, Australia. Modern distribution of Eastern suburbs Banksia Scrub (ESBS) as at 2013 is shown in dark red, © State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water 2015. Presumed pre-European ("1788") distribution of ESBS between Kamay Botany Bay and Port Jackson, shown in pink, is based on Figure 4 p. 685 of Benson and Howell[40], scanned and geo-registered using QGIS 3.40.0. Sample locations ('core sites') from which materials were collected for this analysis are also shown. Estimated extent of wetlands 1820–1853 shown in blue[29]. The stark difference between the 'pre-Industrial' distribution and the current distribution of this plant community is claimed to reflect severe range collapse, as described in the main text. Base layer data ©State of New South Wales through Regional NSW 2021.

listing of species and ecological communities (Division 3, s.4.9) which are set out in Schedules 1, 2 and 3 of the Act. Assessment is based on the available data and the Committee can, if necessary, make use of consultants or obtain advice outside of the Committee, although there is no obligation to do so. In cases where there is insufficient data, the nomination is considered to be 'data-deficient', not accepted for listing, and may be referred to the data-deficient management stream[41]. In determining nominations for listing, the Committee makes both a preliminary (s.4.13) and final determination (s.4.15) and must provide reasons for their determination (s.4.15(1) and (2)). It is the Committee that determine which species or communities 'belong'. They thus play an influential role in the character of land and waterscapes.

Understanding *how* the law determines *who* decides *what* is protected is often an overlooked element in thinking about how land and waterscapes take shape. In outlining the regulatory framework for the appointment to and processes of the Committee, who as a group, are ultimately responsible for deciding what 'belongs' in this case in a highly modified urban green space, it becomes clear that there is an 'expertise bottleneck'. By virtue of Division 7 Part 4, section 3 (a – i), the composition of the Committee is dominated by biologists and ecologists. We are not suggesting that this is an erroneous approach or that any individual or group nominations are problematic, and we want to maintain that these specialist scientific perspectives are vital to the conservation evaluation process. Ecologists can advocate for more-than-human species and communities as well as any other human could. However, the current disciplinary focus of the Committee does encourage abstraction of species from the larger socio-ecological systems in which they exist and away from the deeply relational perspective required to achieve multi-species justice in decision making. The strict legislative limitations on the core expertise available to the Committee can act as a potential constraint upon inclusive, transparent and empowering governance processes as required under the Global Biodiversity Framework (Targets 21-23) by the IUCNs global standard for Nature Based Solutions (Criterion 5, particularly 5.3, 5.4).

In terms of improving multispecies representation, widening the terms of appointment to the Committee would allow complimentary and contradictory perspectives, including better multi-species representation within the decision-making processes as an example of the sort of deliberative, institutionalised multi-species justice advocated by Celermajar and others[12]. This might take the form of an advocate for more than human stakeholders as a standing member of the Committee, akin to the advocacy provided by the Birrarung Council on behalf of the Birrarung Yarra River in Melbourne, Australia[42]. We suggest that achieving MSJ is predicated on ensuring more diverse representation and, in the practice of this, in attending to who decides what belongs is a small first step. While much of the MSJ literature has considered theoretical and conceptual problems, including the important concern about not replicating past injustices, especially in relation to silencing minority voices (particularly Indigenous voices, see for example[13–15,18]) our concern is more pragmatic as we reflect on how existing regulatory and policy settings can be re-drafted with more inclusivity in mind. Inclusive conservation in contested UGBSs requires a more critical and thoughtful approach and, in this one example, movement towards wider expertise/perspectives in the appointment of Committee membership is warranted. Legislation can be changed. Making the committee membership less restrictive in the Act opens opportunities for better recognition of a range of interests. Many more voices could, or should, be heard, including potentially the voices of plants and animals of the present (through their representatives) and of the past through, for example, integration of historical ecology[29], palaeo-ecological data and the broader environmental and earth sciences[30,43–49]. Legislative change (specifically, to Division 7 Part 4, section 3 (a – i) of the Act) might enable more diverse perspectives including representatives of more-than-human stakeholders, that may facilitate the institutionalisation of MSJ concerns and better (more just) outcomes in UGBS. The potential to improve representation in decision-making processes is vital for UGBS managers in steps towards incorporating multispecies considerations. It will not be easy, but the first step is opening up the chance to be heard.

In this section we are pointing out that potential multi-species representation in decision making process is stifled by the Act, which emphasises one particular form of scientific knowledge and valuation in decision making. Once listed under the Act following recommendations from the Committee, those species/communities are protected by law and all subordinate policy that relates to them must conform to this. In this way, some species or communities are permitted to remain, while others are actively excluded or prevented, reinforcing a particular perspective or narrative about what belongs in highly modified UGBS. A collateral outcome of this phenomenon is to 'freeze' urban ecologies and to prevent successional change toward, for example, novel or hybrid ecosystems that might be more resilient to climate change[50]. It is well established that governance arrangements can engender a 'regulatory sclerosis' that can compromise adaptive responses to disruption or shock[51–53]. In this highly contested, modified and urbanised setting, we further argue that vegetation communities with a long history in situ are potentially more resilient than those that have been identified by the Committee because they have persisted through natural and anthropogenic perturbation for thousands of years and are better able to tolerate future change in those locations. This century of disruption is making urban renewal toward a more-resilient state both necessary and desirable. One way of unpacking what belongs where is to turn to the past. Long-term historical ecologies are called for[44–49]. In the next section we expose how the Committee can work to freeze UGBS through nomination and listing processes that do not take adequate account of environmental histories.

The missing environmental history story or 'How the Eastern Suburbs Banksia Scrub Became Protected'

The listing of ESBS by the Committee as Critically Endangered under NSW law was based on an assessment that the plant community had suffered a very large reduction in distribution since the pre-Colonial period (which the Committee refer to as the 'pre-industrial era'). The pre-Colonial distribution of this plant community is not known, and estimates rely heavily on the mapped distribution of soil landscapes as proxies for its former distribution[40].

The Committee note in their final determination (2017)[54] however that, while the current disjunct distribution of ESBS is strongly correlated with particular soil types, it is not restricted to them. Uncertainty with respect to the 'pre-industrial' distribution of ESBS led the Committee to propose a very large possible range, from a minimum of 5355 ha to a maximum of 9643 ha. This is significantly greater than the estimate of c. 2500 ha[55,56]. Benson and Howell[40] also used soil landscapes as a proxy for the "presumed 1788" (p. 685) distribution of ESBS but noted with some caution that some 1788 community ranges are "essentially land units made up of several groupings of plant species, termed plant communities associated with a particular geologic or physiographic type" (p.681). Whatever the case, the current distribution represents a significant decrease from the pre-industrial distribution, in the order of a 91.2–97.4% reduction[54] (Fig. 1). It is based on this hypothesised reduction in geographic distribution (Clause 4.9 of the *Biodiversity Conservation Regulation 2017*, a subordinate instrument under the obligations of the Act) that ESBS was listed as Critically Endangered.

ESBS is difficult to describe (or proscribe) precisely, with many of its characteristic plant species occurring in similar communities in adjacent areas, such that the Committee describe it as "one of a complex of related communities"[54] that vary in composition and structure in response to (*inter alia*) soil depth, fire regime, soil nutrient status, and maritime influence. This makes precise mapping of contemporary community distributions problematic[40] and pre-Colonial distributions virtually impossible. Yet, the listing of threatened ecological communities does not permit such ambiguity, and the Comittee were, perforce, required to stipulate a species assemblage that propagated to all subordinate policy and, ultimately, to on-the-ground actions that encourage certain species and exclude others.

These approaches to defining the composition of 'pre-Industrial' vegetation communities (based on heavily degraded vegetation communities as they appeared in the latter part of the 20th century), and former ranges based on the conflation of degraded remnant communities with specific soil types is obviously problematic and reflects a critical lack of information on historical conditions and environmental history. This is, in part, a reflection of a lack of appropriate empirical data when the decisions were made, and in part a reflection of the 'expertise bottleneck' forced upon the Committee by the Act.

Our geo-historical data (see Fig. 2, Methods and Supplementary Information) suggest that ESBS as a community or species assemblage, and indeed some species listed by the Committee as dominant within ESBS, were not apparent in eastern and southern Sydney prior to the 20th century. The titular genus *Banksia* (the Committee list four species as dominant in most forms of ESBS[54]) contributes an average of 0.7% of the total pollen sample population at a wetland site that was hydrologically connected to the Botany Wetlands (Lachlan Swamp[29,57]) up to the 20th century and there are only four occurrences of the pollen from the genus prior to ~1856. Approximately 4 km south in the proposed pre-Colonial range of ESBS, in the Botany Wetlands, *Banksia* is even more poorly represented (an average of 0.2% of the total pollen sample), with the first occurrence in ~1849. Under-representation of the genus in community-level pollen signatures might be anticipated given its conservative pollen dispersal strategies[58] but the sporadic appearance of its pollen in sediments deposited in the centre of the pre-Colonial range of ESBS is noteworthy.

Of more significance is the former dominance of Ericaceae (heath) pollen at both sites into the 19th century, most probably derived primarily from the heath genus *Sprengelia* (*S. incarnata* Sm., or pink swamp heath, based on taxonomic analysis of the pollen; Wang et al., under review). Pollen from this family is abundant in the sediment at both sites, dominating the pollen assemblage until 1832 in the Botany Wetlands (an average of 25.8% of the total pollen assemblage until that time), and until 1856 at Lachlan Swamp (an average of 18.7% of the total pollen assemblage) (Fig. 2). *Sprengelia* is not listed by the Committee as part of the characteristic ESBS species assemblage, yet its clear dominance within the 'pre-Industrial' range of ESBS to the middle of the 19th century appears to indicate the widespread occurrence of an ecological community that was floristically and structurally different from ESBS. Pollen derived from rushes (Restionaceae) follow a similar pattern over time to the swamp heath, suggesting that the wetlands and drainage lines – much more extensive in the early 19th century than they are today[29] - supported a community that was floristically different from the sedge-dominated (Cyperaceae) Sydney Freshwater Wetlands threatened ecological community that occurs there today. Pollen from grasses (Poaceae) increase in abundance toward the present day, particularly after the early-mid 20th century. This is particularly notable in the Botany Wetlands, where a dramatic increase in grass pollen (modelled from c.1935) likely coincides with the establishment of The Lakes golf club and course – which demarcates the western edge of the wetlands - in 1928.

Our data demonstrate the presence of one or more floristically and structurally distinct ecological communities within the core range of ESBS that were extirpated during the 19th century and are now unknown and unrepresented in conservation and management strategies. There are three

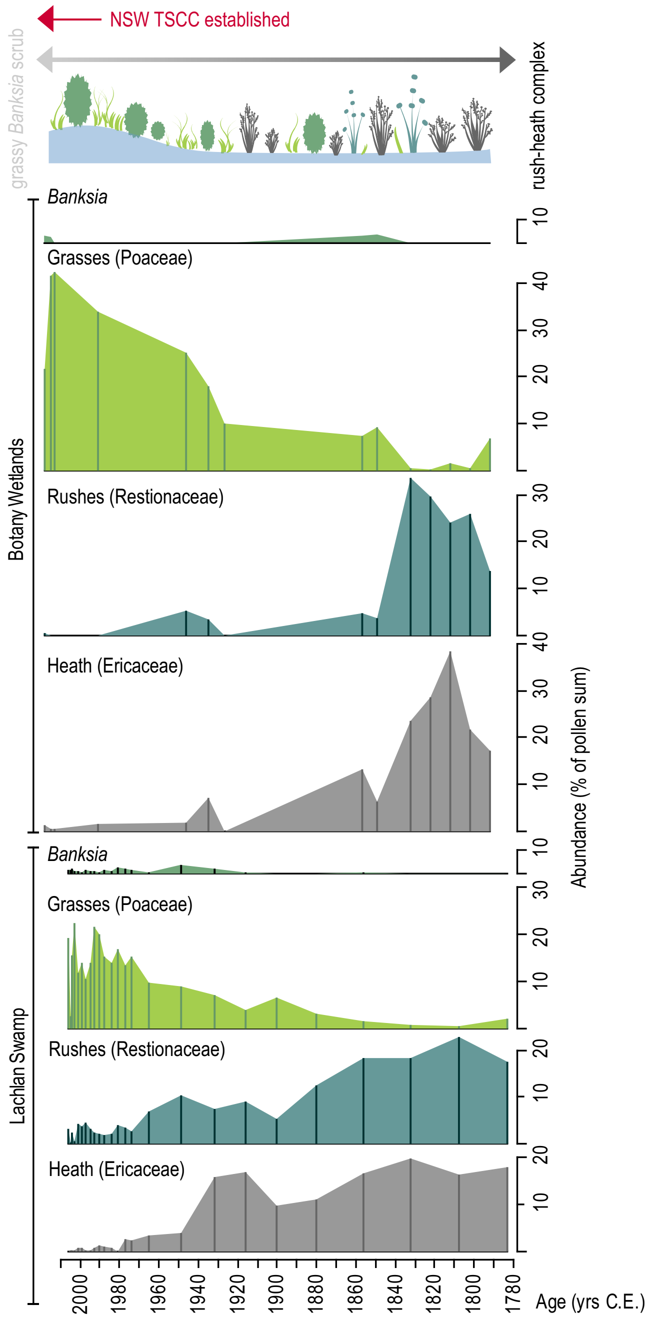

Fig. 2 | Plot of selected pollen taxa against time from two sites within the pre-colonial range of Eastern Suburbs Banksia Scrub. See Method and Supplementary Information.

points of significance: first, any attempt to restore 'resilience' to these inner UGBSs by adopting NbS approaches to land management that mimic, or are inspired by, self-organising natural systems will fall short of expectations if long-term ecological data are not available or are ignored by policy makers whose expertise may be too narrowly defined by law. Second, degraded and disrupted remnant vegetation communities in urban spaces should not be accepted as an adequate baseline or reference condition on which to base nature repair or ecological restoration policy. Third, the assumptions that underpin 'range collapse' in this specific threatened ecological community (particularly the use of soil types or landscape units as proxies for the presumed 'pre-impact' distribution) can be empirically disproved, threatening the basis used by the Committee for listing the community as endangered or critically endangered.

Management operations can become compromised by inadequate data. In our example, the characteristic species composition of the endangered plant communities extant in the Botany Wetlands has been defined by the NSW Threatened Species Scientific Committee. This decision is based largely on extant examples of these communities and partial and largely descriptive historical accounts (particularly Benson and Howell's highly generalised 1994 map of the 'pre-European' flora[40]). This map appears to be profoundly compromised by a simplification of community diversity and presumptions of continuity over space based on the mapping of native vegetation as it was in 1982[39,40]. Long-term ecological and environmental data of adequate fidelity to be meaningful for management practice do not exist, and narrative descriptions of 'pre-impact' ecosystems are not supported by empirical evidence. In this context, palaeo-ecological data could act as form of representation in decision making for ecological communities that have been disrupted and marginalised by urbanisation over the past century. Equally, this information can guide NbS interventions that truly learn from the self-organising capacity of ecosystems with a long history of flourishing in place.

Discussion

The benefits of resilient UGBS in Australia's cities are well-known, well-established, and permeate all relevant policy and practice at all levels of government. UGBS are thus important locations in which NbS interventions can yield multiple co-benefits to many stakeholders. The capacity to mimic or learn from nature in these settings is, however, compromised by the profound transformations they have experienced. Here, we demonstrate that ecological communities that have been spatially marginalised, degraded or extirpated by urbanism offer valuable guidance for NbS interventions in high-value UGBS. However, current regulatory settings prioritise particular scientific perspectives and do not make space for deliberative multi-species justice representations. We suggest that palaeo-ecological data, such as those presented here, might be used to represent more-than-human interests in decision making, and suggest modest regulatory change that widens the range of voices considered in decision making to institutionalise MSJ perspectives. Such an approach can support the restoration and sustainable conservation of urban ecosystems within a NbS framework that is coherent with MSJ perspectives. Ultimately, this ensures sustainable management of key environmental services for humans and enables more-than-human species to flourish.

Adaptive management informed by NbS's will benefit the community now and into the future. In Australia it is recognised nationally, and throughout the states and territories, that resilient UGBS are crucially important for successful urban futures. In our case study site, urban development in the suburbs surrounding the Botany Wetlands will make this area the most densely population part of Australia, with population densities located less than 1300 m from the wetland corridor exceeding that of Hong Kong[59]. Increasing tension over exclusion from and access to UGBS in the context of high and rising population density makes management of these sites complex and may encourage management authorities toward conservative approaches that emphasise stability and precedent in policy settings. Sustainable management of UGBSs such as the Botany Wetlands becomes both challenging and crucial under these circumstances. Globally, there is a broader recognition that UGBSs are disproportionately important in conserving threatened species and that cities can be hotspots of biodiversity[23].

As we move further into a century of environmental disruption, it is necessary to reevaluate sustainability in our cities. Thinking is shifting toward new ways of occupying our cities through a coming century of climatic disruption. In this paper we draw attention to a twinned problem for actioning NbS in UGBSs - law's operational rigidity and the importance of understanding places according to their spatial and temporal pasts. We argue that this case study shows that better representation of the past and greater stakeholder input via reform to existing regulatory mechanisms might enable society to give greater consideration to the MSJ implications in UGBS renewal projects.

Methods

Field sampling procedure, laboratory pre-treatment for pollen extraction, and protocols for data analysis and decomposition follow[30] and[57].

To construct an independent chronology for the pollen sequence from the Botany Wetlands, the pollen sequence (based on core A of the replicate set) and absolute radiometric dates (based on core B of the replicate set), two cores had to be objectively correlated. A sequence slotting approach was used to correlate the two cores[60] based on the magnetic susceptibility profiles for both cores. Magnetic susceptibility was measured using a Bartington MS3 meter with a MS2E sensor[61] at 1 cm resolution (P5_04_19_A $n = 119$, P5_04_19_B $n = 116$) via the Bartsoft platform (v. 4.2.16). Instrument accuracy was evaluated using a supplied reference material (#331, agreed value = 460×10^{-5} SI). Nine measurements yielded an average value of 448.43×10^{-5} SI, 97.48% accuracy. Triplicate measurements were taken at each depth level in the cores (2 second measurement time for each measurement), with blank measurements before and after each triplicate and auto drift correction enabled. The average of those measurements for each depth level is shown in Supplementary Fig. 1 and was used as the basis for the core correlation.

CPLSlot v. 2.4b[62] was used for sequence slotting. In addition to the magnetic susceptibility data, stratigraphic boundaries common to both cores were imposed as constrains on the slotting procedure (Supplementary Table 1). From this, known position (depth) of dated horizons in Core B were then used to identify estimated position in Core A, which act as a basis for chronological modelling of Core A (Supplementary Fig. 2).

Chronological modelling was performed with Bacon[63] using R version 4.4.1[64] in R Studio 2024.09.0 + 375[65]. The chronological model for P5_04_19_A (Supplementary Fig. 4, Supplementary Information) was based on six ^{210}Pb ages and one bio-stratigraphic age (consistent appearance of pollen from exotic plants in the sequence) at 80 cm depth and given an age of 1852 ± 12.5 years C.E[30]. Several stratigraphic hiatuses were imposed for this core, corresponding to stratigraphic boundaries at 22.5 (lower boundary Unit 1), 73 (lower boundary Unit 2) and 80 cm (lower boundary Unit 3) depth in core. The chronological model for core LSB2 (Supplementary Fig. 3) was based on eight ^{210}Pb ages, one ^{137}Cs marker horizon (first appearance of this isotope at these latitudes in the southern hemisphere), two bio-stratigraphic ages based on the appearance of pollen from pine (1865 C.E.) and fig (1888 C.E.), and one ^{14}C age (Beta-284319) calibrated using the SHCal20 curve[57,66]. Pollen data[30,57] were replotted with the updated chronological models using C2 1.7.7[67].

Data availability

Data that supports the findings of this study are available in the supplementary information of the article, with the exception of previously published data which are reanalysed here.

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Author contributions

J.G., D.P., and R.H. wrote the main manuscript text. J.G., D.P. and R.H. conducted fieldwork. D.P. and R.H. conducted laboratory analysis and prepared figures and supplementary information. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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