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Tasmanian reserve geoconservation inventory assessment using Geographic Information Technology (GIT)

Mark Andrew Williams *, Melinda Therese McHenry

School of Geography, Planning, and Spatial Sciences; University of Tasmania, Churchill Avenue, Sandy Bay, 7001 Tasmania, Australia

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ABSTRACT

Geoconservation is, at its foundation, a grass-roots movement with geoheritage represented by geosites containing the most scientifically significant and valuable geodiversity elements. Problems arise in the assessment and communication of inventory due in part to inconsistent and traditionally time-consuming, ‘snapshot’ assessments that are difficult to spatially monitor.

The case study of kunanyi/Mount Wellington and the encompassing IUCN Category II Wellington Park Reserve (18,250 ha) (42°53′24″ S 147°13′48″ E, Tasmania, Australia) was chosen to explore the complexities of geosite and geodiversity site assessment, detection and communication. Using digital tools, we revised a 25-year-old snapshot inventory, configuring the ESRI ‘Collector for ArcGIS’ app for in-field data collection. Putative geosite and geodiversity site attributes were assessed for scientific value, potential touristic use, and potential educational use, using the Brilha (2016) method. Additional digital tools supported spatially accurate, engaging and interactive online inventory.

Our findings suggested that many of the putative geosites in the park had low or moderate scientific values, but higher additional educational or touristic use values, especially in the urban-facing park zones. Though site degradation risk was low-moderate, sites in closer proximity to City of Hobart might experience additional impacts from visitation.

The Wellington Park is a significant protected area that aims to tell an important story about the evolution of the periglaciated terrain and the endemic fauna and flora that depend upon it. In this sense, the possibility that not all putative geosites have high scientific value (and instead, might be better classed as geodiversity sites) is of limited concern, because the myriad geodiversity elements and additional value rankings (including 50% being highly ‘representative’ elements) provide an opportunity for all who visit the park to observe a coherent story about Tasmania in an easily accessible location. The opportunities realised in the creation of the digital inventory and assessment process remedy many issues that currently hamper practical Geoconservation, improving cost, consistency and standardisation of the inventory assessment and the quality of geotouristic and educational products. This digital approach could assist protected area managers and geoconservationists to monitor, protect and communicate inventory over the long-term.

* Corresponding author.
E-mail address: mark.williams@utas.edu.au. (M.A. Williams).

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1. Introduction

Geoconservation is the management of geosites and geodiversity sites by means of specific inventory, evaluation, conservation, valuing, and monitoring procedures (Henriques, dos Reis, Brilha, et al., 2011). Many geoconservation researchers and practitioners have indicated that they experience difficulties when collecting and constructing inventories, due to problems associated with scale, practical issues associated with field survey and assessment, boundary detection and logistics and financial constraints of accessing difficult terrain (Pellitero, González-Amuchastegui, Ruiz-Flaño, & Serrano, 2010; Reynard & Coratza, 2013; Westoby, Brasington, Glasser, et al., 2012; Williams & McHenry, 2020).

Successful management of potential geoheritage is dependent on the capacity to understand, assess and classify geodiversity elements and values (Serrano & Ruiz-Flaño, 2007). Although geoheritage is conceptualised at a national or international scale (Brilha, 2016), geoconservation has, at its roots, a local level of understanding and interpretation (Tavares, Henriques, Domingos, & Bala, 2015). This interplay between heritage and grass-roots conservation can result in specific areas of interest being audited and valued for a range of purposes (including tourism and education), with appropriate actions for protection of prospective geoheritage arising from these activities through law or practice (Burek & Prosser, 2008). Zones of potential management and interpretation include geosites (zones of notable geoheritage), and geodiversity sites (geosites with comparatively lesser scientific values that possess higher additional geotouristic and/or geo-educational value) (Brilha, 2016). Both geosites and geodiversity sites require careful and often, time-consuming management, which could be greatly aided by digital tools (including Geographic Information Technology (GIT), sensu Williams and McHenry (2020)).

Understanding the relevant significance and/or comparative significance of elements in geosites and geodiversity sites at a national or global scale, has been hampered by many factors such as inconsistency in the classification and assessment of geoheritage (Brilha, Gray, Pereira, & Pereira, 2018; Williams, McHenry, & Boothroyd, 2020), poor understanding of geoheritage and geotourism due to a lack of promotion and awareness in some countries (Robinson, 2015), and inadequate cost-effective tools for the communication of inventory. Field data, for instance, is still frequently recorded on data sheets and manually entered into a database (Camp & Wheaton, 2014), leading to a proliferation of isolated, 'one-time-only' collection strategies that cannot be replicated nor communicated across time and space. Even seemingly more experienced practitioners and researchers have recently suggested that they lacked insufficient experience and capacity to undertake robust assessments of parks and reserves (Williams et al., 2020). Finally, even when assessment methods and approaches to inventory curation are adhered to at the regional or state level, geosite and geodiversity site boundaries are challenging to delineate in practice and often the boundary is over or underrepresented, introducing problems with land tenure, land management, and legal protection (Brilha, 2018).

The potential cumulative outcome of issues with assessment, protection and management is that when there is eventually a global (or broadscale) consensus on approaches to assess, rank, and assign significance to geosites and geodiversity elements, existing inventory may no longer be considered to be of the same importance or value that it previously was, creating issues for communication and protection. Previous geosites may be, in light of improved communication and comparative assessment, 'downgraded' to geodiversity sites - with high Potential Touristic Use (PTU), and/or high Potential Educational Use (PEU) (sensu Brilha (2016)). The 'downgrade' shifts interpretation and site usage into a potentially very different human values domain, from formalised conservation of superlative natural values, to expectations of frequent use, and the subsequent degradation that comes with this.

Tasmania, Australia, is one such place in which issues associated with scale and simplicity of inventory ranking can be explored. It has a range of protected areas of overlapping significance from local to wilderness World Heritage area scale. Tasmania possesses many sites of significant superlative periglacial geodiversity, and has remarkable diversity of paleoendemic plants relative to latitude. Management of geodiversity in Tasmania is challenging due to the lack of resources to adequately manage such a substantial estate, and Tasmania's reputation as a premier 'natural' tourist destination threatens the integrity of the myriad natural values found on the island. In this paper, we demonstrate the use of digital tools used in the collection, boundary determination and communication stages of geo- and geodiversity site assessment to undertake a rigorous review of a local geosite inventory in a specialist IUCN Category II reserve notably situated in state and continentally significant periglacial terrain.

Specifically, we aim to:

a. Identify scientific, tourism and educational values associated with Wellington Park putative geosites and delineate these from apparent geodiversity sites; and,
b. Identify and describe degradation risks of geosites and putative geodiversity sites arising from human activities

in the Wellington Park, Tasmania. As part of the inventory process, we use self-developed digital tools that could be employed by any practitioner or assessor to improve understanding, measurement and communication of local, regional or supra-regional scale inventories.

2. Geographic and management context of the study area

Wellington Park (42°53′24″ S 147°13′48″ E) is located in south eastern Tasmania, a state in Australia, extending 25 km from the foothills west of Hobart, the state capital, and the Derwent River containing the prominent doleritic peaks of kunanyi/Mount Wellington, Collins Bonnet, Trestle Mountain, and Mount Marian (Fig. 1) which link to the Snowy Range and Tasmanian

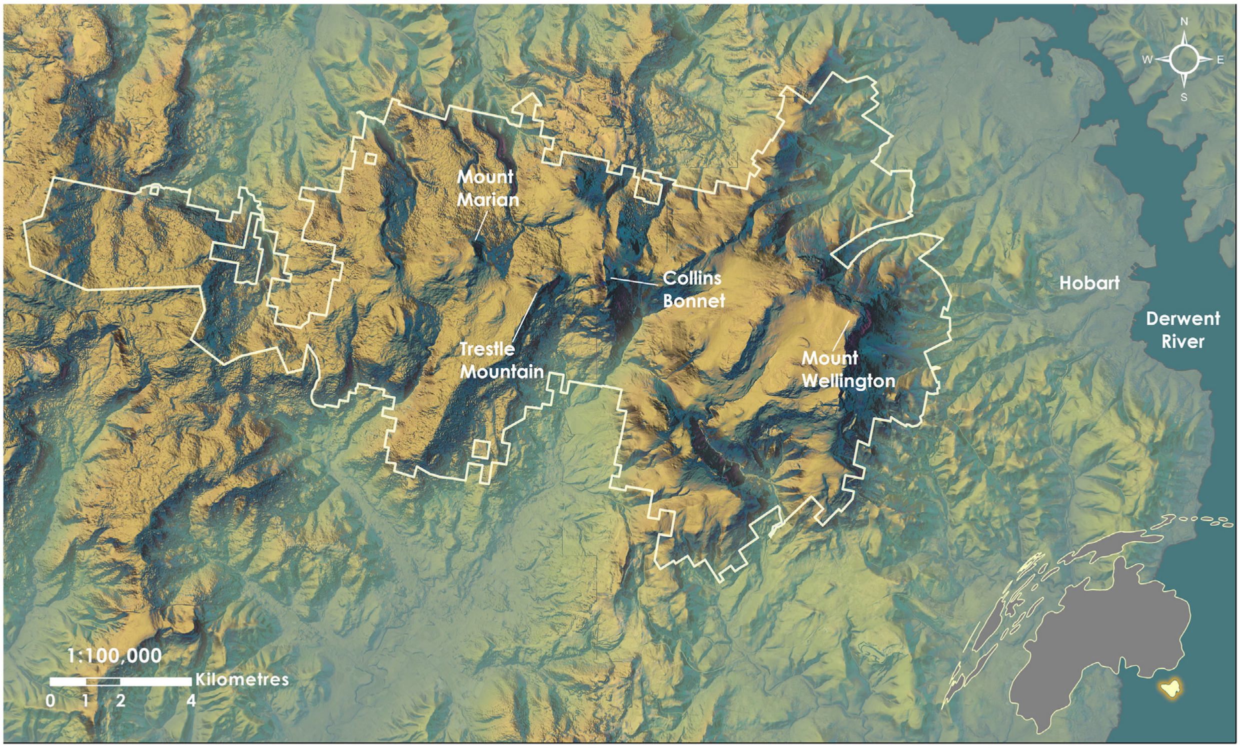

Fig. 1. Location of the Wellington Park in Tasmania, Australia.

Wilderness World Heritage Area (TWWHA) as a continuous natural feature. Tasmania as a whole is the second-most geodiverse place in the world (Manchestor, 2013), and features rock and landform types from every rock class and landform process. The state has an excellent inventory of more than 1300 listed geosites (some of which do not possess geoscientific significance at the national or international level) (the Tasmanian Geoconservation Database – hereafter 'TGD'), that are selected by geoscientific professionals on the basis of geoscientific novelty, rarity, and spatially-defined representativeness (Bradbury, 2014).

The previous geosite inventory for the Wellington Park was prepared by reviewing available geoscientific research, consultation with the Wellington Park Management Trust (the management body associated with the IUCN Category II reserve with which the inventory is associated with) and educated interest groups, and a public consultation for the Wellington Range area. Time and resource constraints only allowed a one-day field trip through the Wellington Park with a heavy reliance on the study team's professional judgement (Hepper & de Gryse, 1995), subsequently leading to some geosite boundaries being delineated using a 1:100,000 topographic map. A number of these sites are listed on the TGD for scientific value at a state level including an extensive periglacial terrain that has never been glaciated (NVA, 2021). Some members of the original inventory reconnaissance team are geoscientists who serve on the TGD reference group that curate the state's geosite inventory, so the short-survey period, though limited temporarily, was sufficient to establish the location and likely status of putative geosites at that time. However, a notable consequence of this approach was that it was "likely that other values may exist than those (geosites) identified within this report; and the information related to the current or potential condition of values could not be precisely assessed in the field" (Hepper & de Gryse, 1995). Essentially, it can be deduced from the initial assessment that geoscientific knowledge of inventory sites and points of interest was potentially very-well expressed in the subsequent first inventory, but additional values associated with educational opportunities, tourism, culture and aesthetics, were not.

Wellington Park is considered one of the most significant outdoor recreation venues in Tasmania (Hepper & de Gryse, 1995) and is now the third-most visited 'attraction' in Tasmania with 341,699 visitors recorded between April 2019 and March 2020 (Wellington Park Management Trust, 2018). In 2019, Tasmania had 1.35 million unique tourist visitors (Tourism Tasmania, 2019), and more than half of these visitors flew into, and were accommodated in the nearby capital, Hobart (population 236,136 (Australian Bureau of Statistics (ABS), 2020). Most tourist visitors to Tasmania indicate that they are seeking to enjoy the aesthetic beauty of Tasmania, which includes a high standard of boutique land and food products (Ooi & Hardy, 2020). Many others come for natural or semi-natural experiences including remote wilderness hiking, remote-area camping, kayaking, hunting, climbing, surfing, trail riding and MTB, four-wheel driving, fishing and adventure sports.

The Tasmanian standard of environmental stewardship in geotouristic infrastructure and trail construction is considered above-average by world standards (Department of Primary Industries Parks Water and Environment (DPIPWE), 2019), but 55% of the state is protected in nature reserves and a UNESCO World Heritage Area – typically, places that do not permit extensive leisure sites, hospitality or fixed-accommodation options. Therefore, where fixed visitor and geotouristic infrastructure is permitted to be situated in reserves (such as the Wellington Park), it is situated near park boundaries, subjecting local areas to edge effects and geophysical degradation associated with high population density in a small area. It is therefore expected that prospective geosites and geodiversity sites within the park will be progressively less exposed to human impacts and associated land degradation with increasing distance from single road entrances and small visitor viewing areas, car parks, and track entrances.

The reserve has a long history of usage, has been visited by Charles Darwin and is valued by the Tasmanian community for its intrinsic and aesthetic values (Wellington Park Management Trust, 2015). Over 500 native flora species and a diverse range of native fauna are protected in the Wellington Park, an IUCN Category II reserve (Wellington Park Management Trust, 2015) aimed to protect natural biodiversity (plant and animal species) and geodiversity sites that are of scientific, educational, recreational and tourist significance (Dudley, 2008). Though the region is well-managed, there is still a risk of threats to specific features by development, vehicular access and even walking tracks in some cases (Bradbury, in NVA, 2021).

3. Landscape evolution and geological context of Wellington Park

Due to its complex landscape evolution, billion-year-long geo-climatic history (in places) and extensive tectonic activity into the Paleogene - Neogene, many of Tasmania's prospective large-area geosites are of significant scientific value at a national or international level. The Tasmanian exposure of Jurassic dolerite (diabase) at the land surface is the most extensive in the world (Seymour et al., 2013). In the Wellington Park, doleritic and basaltic exposures, organic soils, and extensive sedimentary sequences are incorporated into a large, state-significant listing of periglacial terrain that has never been glaciated (NVA, 2021). The Wellington Range periglacial terrain presents significant geohistory, dolerite sill and dyke intrusions into Permian sedimentary layers, uplifted due to crustal extension during the breakup of Gondwana (Morrison, Baillie, Davidson, & Quilty, 1989).

This has led to the lithologies and structures evident in the Wellington Park which have played a major role in influencing the development of geodiversity elements and landforms (Fig. 2). The oldest geological units are inferred to be Precambrian dolomites and Cambrian volcanics, separated by an erosional unconformity from Permian glacio-marine sedimentary sequences on the lower slopes of the range (Leaman, 1990). These sequences comprise mudstones siltstones, limestones, and sandstones containing glacial dropstones transported from adjacent glacial subunits during the Pleistocene glacial period, and some marine fossils including brachiopods and bryozoans from what is now Antarctica. An interglacial period in the late Permian resulted in marine sediments being deposited across a broad floodplain which include coal seams in carbonaceous mudstones, shales and erosion resistant sandstones which commonly feature sedimentary benches and cliffs (Hepper & de Gryse, 1995). Younger, Triassic sandstones have been uplifted and largely eroded, exposing a large Jurassic dolerite ('diabase') intrusion, which is widely featured

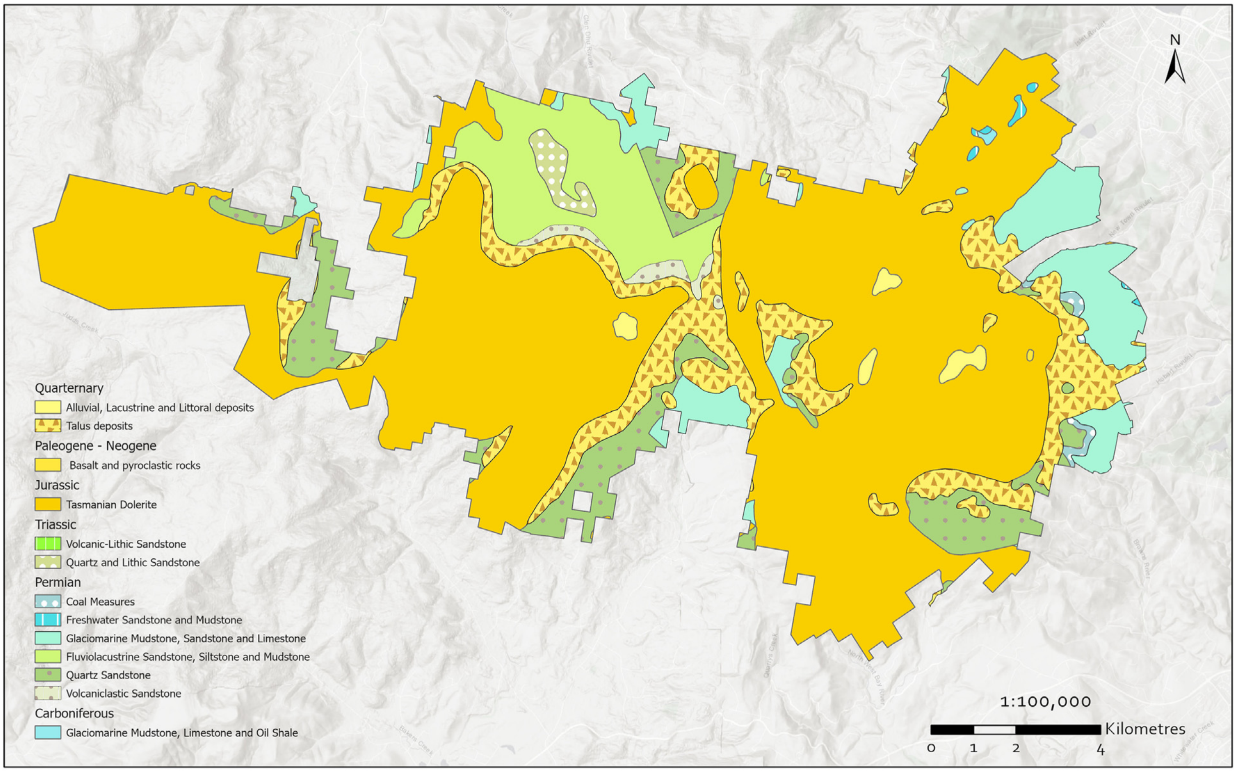

Fig. 2. Simplified geological map of the Wellington Park.

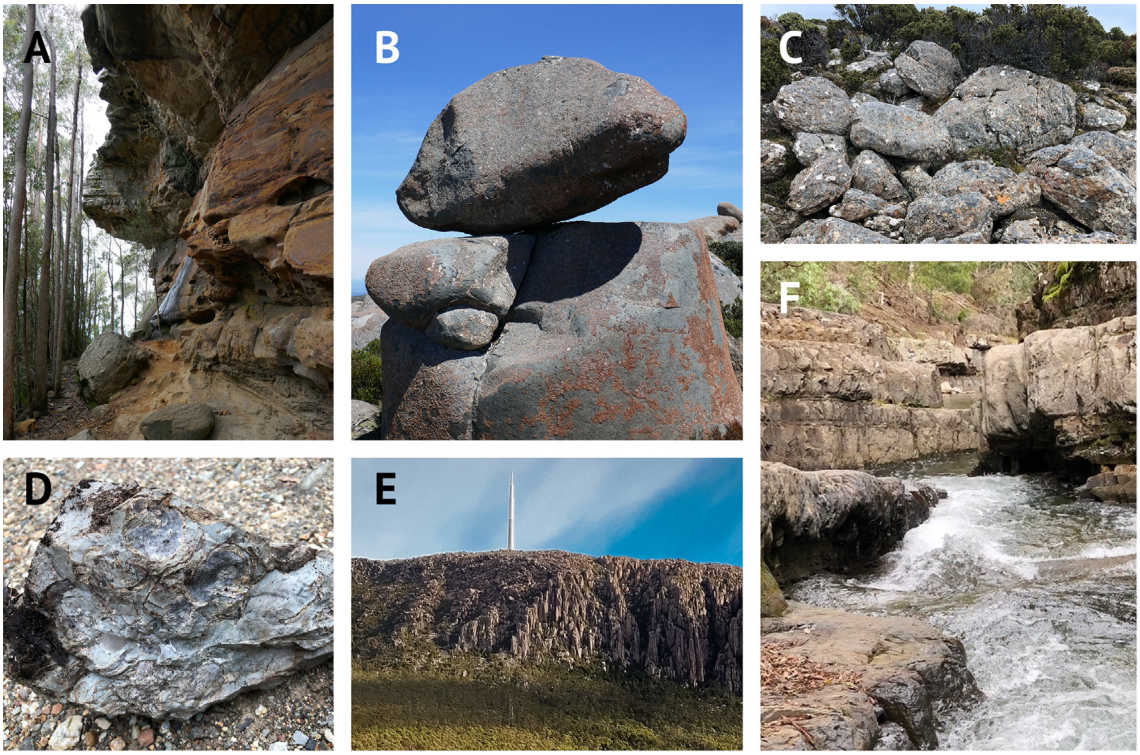

Fig. 3. Geosites and geodiversity sites in Wellington Park. A: Sphinx Rock sandstone cliffs; B: Rocking Stone dolerite tor; C: Hawaiite basalt from Pinnacle Volcanic Plug; D: Limestone embedded with molluscs from Merton Fossil Site; E: Organ Pipes - columnar-jointed dolerite cliffs; F: Mudstones at Mountain River Canyon.

across the Wellington range as a number dykes and sills on the upper slopes and mountains tops that are likely to have occurred at different times (Leaman, 1975). Locally-charismatic, columnar jointed dolerite cliffs and tors are found within the Wellington Park, including the well-known 'Organ Pipes' on kunanyi/Mount Wellington, rising to 1271 m above sea level and viewable from the south, east, and north of Tasmania's capital city, Hobart. Despite the dominance of non-volcanic rocks, there is a small volcanic plug close to the summit of kunanyi/Mount Wellington containing olivine rich basalt of Paleogene – Neogene age, containing fragments of dolerite.

The evolution of the geosites and geodiversity sites in Wellington Park (Fig. 3) has been dominated by block faulting and periglacial freeze-thaw cycles at higher altitudes, and fluvial processes at lower altitudes, evident from extensive quaternary deposits including colluvium, landslips, and slumps.

4. Methods

4.1. Assessment of Wellington Park putative geosites and geodiversity sites

A revised **inventory** of the Wellington Park was conducted using a geosite and geodiversity site assessment method (Brilha, 2016) and newly-developed GIT tools (section 4.3). The Brilha (2016) mixed-methods approach removes some of the subjectivity inherent in the assessment stage (White & Wakelin-King, 2014) of geosites (and geodiversity sites). It recognises three values - scientific value (SV), educational value (EV), tourism value (TV) - against well-defined criteria-sets and ranks these against degradation risk (DR) from natural and anthropogenic hazards and processes (section 4.2).

We constructed a revised inventory**,** by consulting the original inventory document (Hepper & de Gryse, 1995), local experts and a conducting a literature search of studies and technical documents related to geoheritage, geomorphology and geology in the Wellington Park. Grey literature was also analysed including tourism pamphlets, guidebooks, blogs and tourism websites to provide background on perceived community educational or touristic values.

A geological framework was then developed and incorporated into the inventory design, which facilitated putative geosite interpretation within themes that related to the dominant geomorphological process or type of geological landform within the park. This was considered necessary to enable ease of communication about the potential SV of putative geosites at the regional scale (as per the existing 1995 inventory) versus the significance of the entire Wellington Park periglaciated terrain at the state level (NVA, 2021). A candidate list of putative geosites was derived from seven themes and a list of landforms in the geological framework (Fig. 4) based on typical landforms found in similar geomorphological environments (Bradbury, 2014; Davies, 1969; Sharples, 2014; Wellington Park Management Trust, 2015).

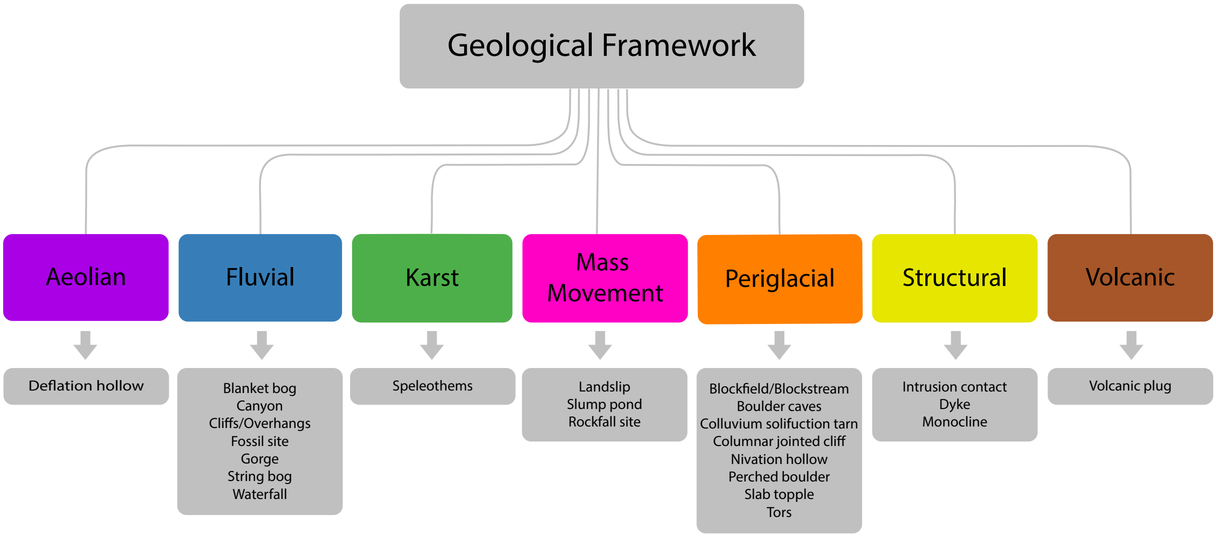

Fig. 4. Geological Framework represented by 7 themes and 24 landforms (after Bradbury, 2014) in an inventory of periglacial geosites and prospective geodiversity sites in Wellington Park, Tasmania.

The potential 53 geosites were visited in the field (Fig. 5) and data required for assessment was collected using the preconfigured 'Collector for ArcGIS' app (hereafter referred to as 'CollectorApp'). Some geosites were excluded due to being colonised by vegetation, considered to be insignificant, or not found in the field. Of the remaining 49 geosites, some were located on steep, inaccessible terrain and were surveyed from a distant vantage point and the boundary was drawn using satellite base maps in the field or as a desktop exercise.

The resulting candidate list of 49 putative geosites (and/or geodiversity sites) were examined in situ over 55 days between November 2017–September 2019 using the CollectorApp (section 4.3) to support in-field data collection.

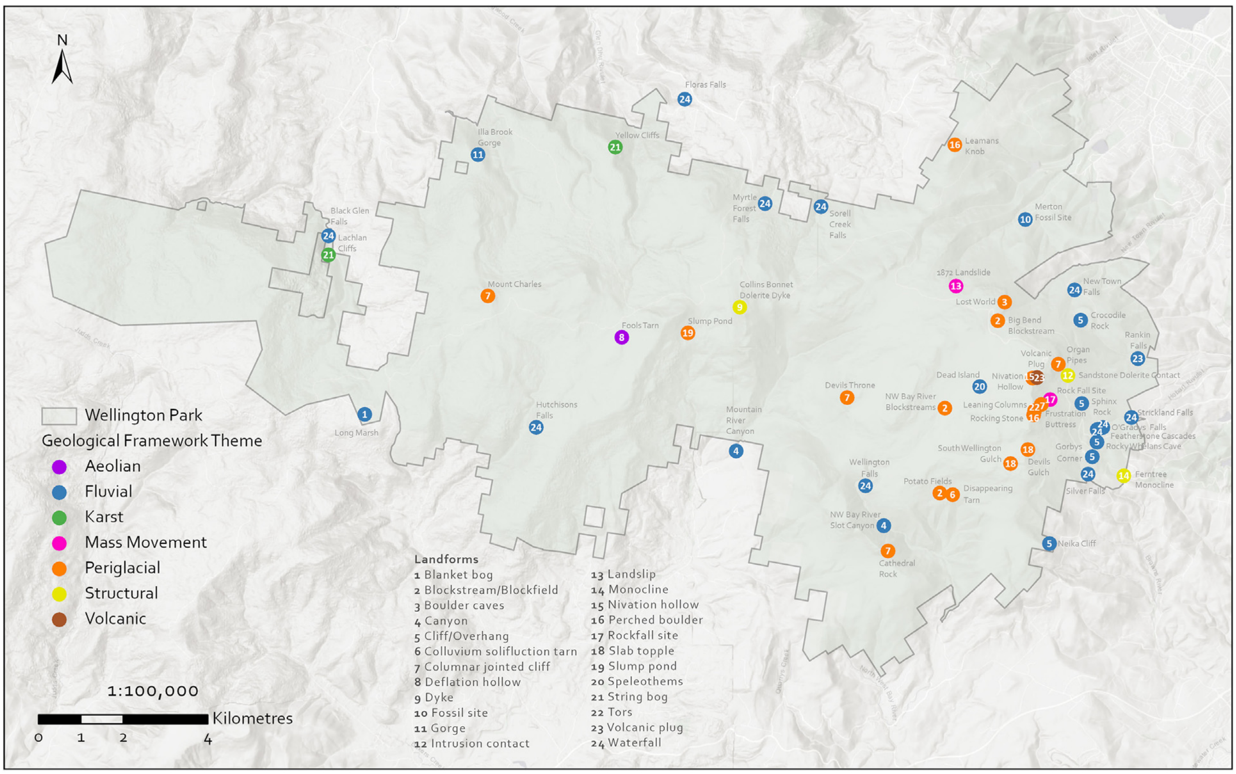

Fig. 5. Map of geosite and geodiversity site location, with reference to geological thematic framework.

The **assessment criteria** from the Brilha (2016) method measured SV by evaluating representativeness, integrity, rarity and scientific knowledge – which was used to determine the amount of regional *geosites* within the park. Once the most highly-rated geosites were established and listed in inventory, assessment of EV by evaluating potential educational use (PEU) and TV by evaluating potential touristic use (PTU) was conducted, so as to determine the extent of *geodiversity sites* within the park.

4.2. Degradation risk and prospective management issues

Both putative geosites and geodiversity sites were assessed and scaled against their DR by evaluating vulnerability, fragility and other factors, and were then ranked according to conservation goals in the inventory (to preserve originally suggested geosites where possible and identify the extent to which original geosites were now geodiversity sites given enhanced criteria and tools for assessment).

The final assessment and ranking of the inventory for **conservation** purposes was conducted using a quantitative ordinal-scale approach. Each criterion was subdivided into sub-criteria and assigned points between 0 and 4, with 0 being of no value or usage and 4 being of high value or usage. The sub-criteria were then weighted according to importance and the final score for each geosite was between 0 and 400. To identify geosites with the greatest SV, PEU, PTU, the classification used by Lima (2008) was adopted: low (≤200), medium (201−300) and high (301–400). Degradation risk was similarly classified following Brilha (2016) and all geosites and geodiversity sites were sorted in descending order by SV, PEU and PTU and further sorted by DR to understand the capacity of the geosites' to support different types of use and of the geosites' risk of degradation.

We conducted additional statistical analyses on the weighted and individually-assessed values. Quantitative weightings associated with the determination of SV, PEU, PTU and DR were ranked and visually depicted using histograms to identify the proportion of geosites and geodiversity sites with specific scores and values. Correlation and regression analyses were employed to identify relationships between overall assessed values, where appropriate. This information, along with a completed inventory, was designed to aid nature conservation managers specifically in making decisions related to the touristic/recreation uses of the park. Through the visual depiction of the distribution of park and site values, park managers were able to distinguish between sites of high representative or educational value that might be at risk of significant degradation.

The Brilha (2016) method suggests final steps involving **interpretation and promotion** of the geosites and geodiversity sites, as well as a protocol for **site monitoring.** Our approach to assess and interpret inventory was conducted through the quantitative ranking undertaken within the assessment stage (number of representative geosites versus new geodiversity sites) and the subsequent promotion of the inventory using a web app. Though not featured within this paper, a protocol for site monitoring was supported by the determination of DR baseline values, photography obtained during this re-assessment using an Unmanned Aerial Vehicle (UAV) and communication with the Wellington Park management body.

4.3. Geographic Information Technology tools for inventory assessment & communication

We developed and used the following geographic information technology (GIT) tools when conducting a revised inventory of the Wellington Park:

a. A mobile collection app, configured with custom attribute fields which served the purpose of being able to be easily uploaded to a web-GIS and cross-corroborated with other datasets in the field in real time.
b. Employ of UAV's and enhanced image processing to accurately determine and visualise landform and prospective geosite boundaries.
c. A web communication tool for the presentation of a geolocated, dynamic and interactive inventory that could be used to communicate values, share 3D models derived from UAV footage and post-processing, and other geoscientific information to managers and the public.

To setup the **mobile data collection** for the prospective Wellington Park inventory, a file geodatabase was created with ArcGIS Pro 2.4 software and a geosite feature class for data collection was created and shared as a web map to ArcGIS Online (Williams, 2020a). The fields of this feature class were designed to characterise a geosite and attribute domains (Williams, 2020b) to reduce human data entry error and increase the speed of field data collection. A geology layer (Calver, Forsyth, Clark, & Latinovic, 2011) and a state listing of geosites (NVA, 2021), clipped the extent of the Wellington Park, were added to the web map to provide background information during field surveys. The web map was configured with a World Topographic Map basemap (ESRI, 2021) and enabled for editing and offline synchronisation, and photo and video attachments were enabled to capture media directly in the field (Williams, 2020c). Data collected from the CollectorApp became readily available in the Inventory Web App (https://arcg.is/158T4K0), allowing real time access of photos and field data (Fig. 6). Erroneous data collected in the field was removed or corrected prior to geosite assessment.

The boundary of each geosite was surveyed by walking the extent, if possible, using the streaming data capture function of the CollectorApp, configured to capture a data point every 3 m, allowing for accurate delineation of geosite boundaries (Williams, 2020d). In cases where walking the boundary was not possible, due to difficult or steep terrain, the geosite boundary was surveyed from particular vantage points and the boundary was drawn with the assistance of satellite base maps available on the CollectorApp (e.g. Organ Pipes, Fig. 7 – data collection).

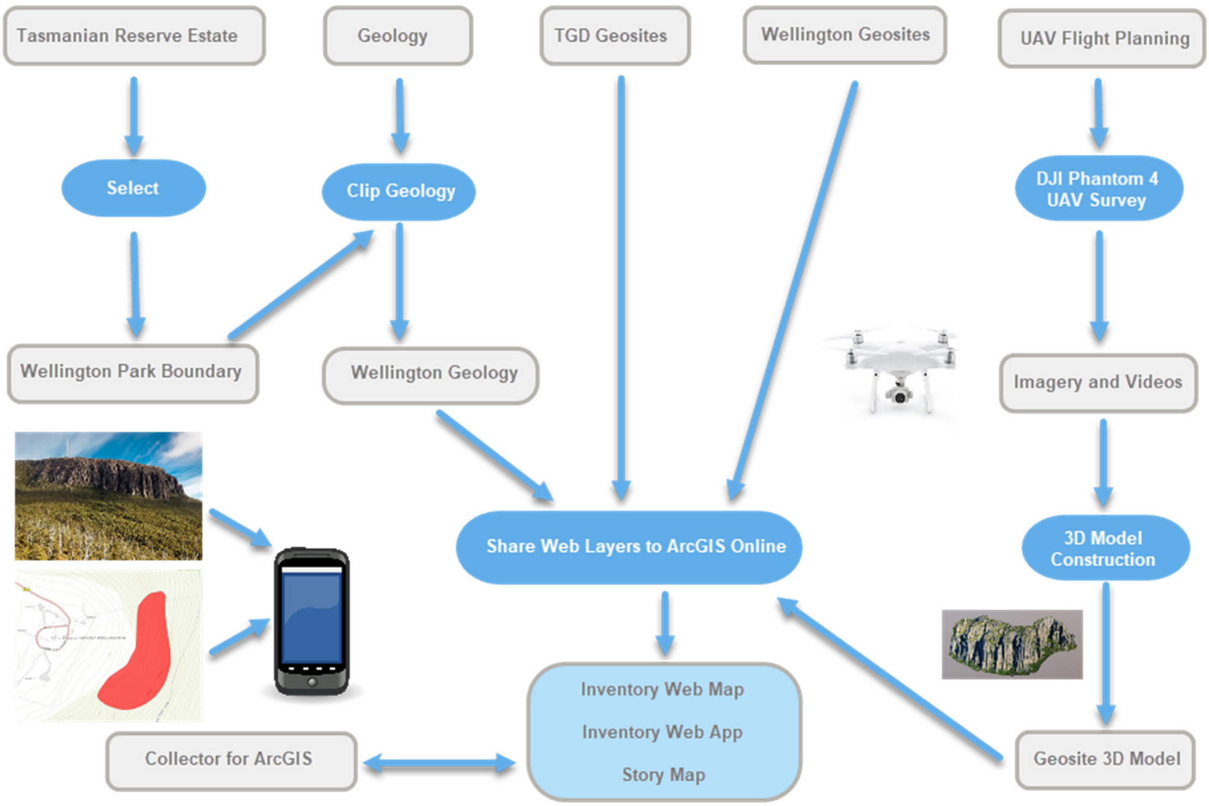

Fig. 6. Web-based inventory using a UAV, Collector for ArcGIS and ArcGIS Online Web Maps, Apps and a Story Map.

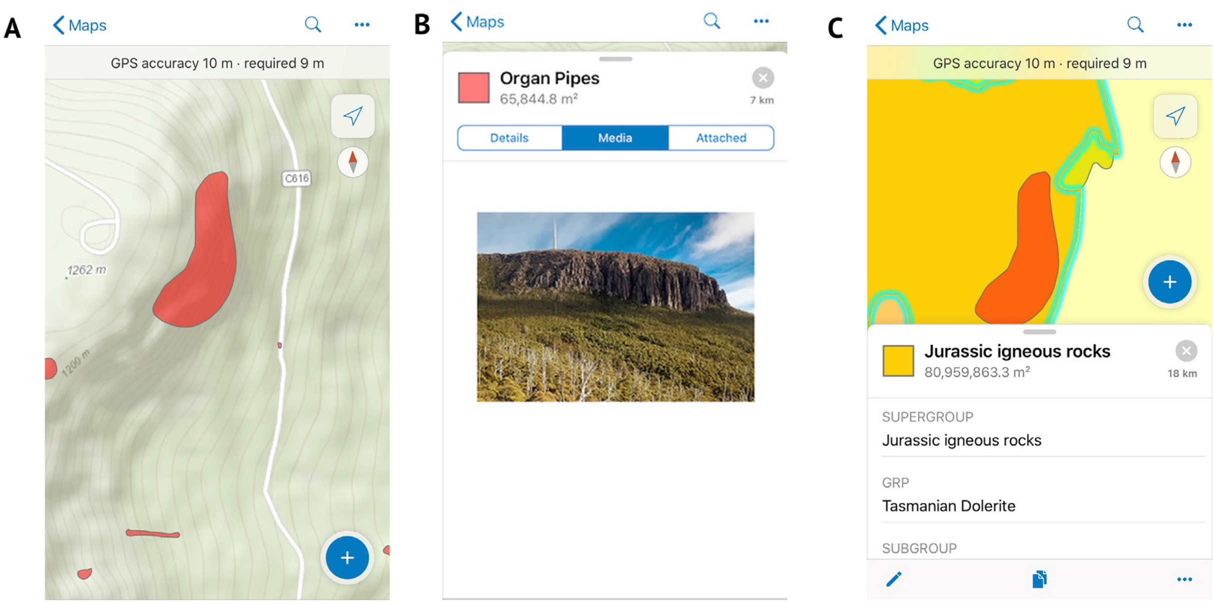

Fig. 7. Mobile Collector app showing (a) the boundaries of geosites, (b) photograph of the Organ Pipes geosite and (c) geology of the surrounding area.

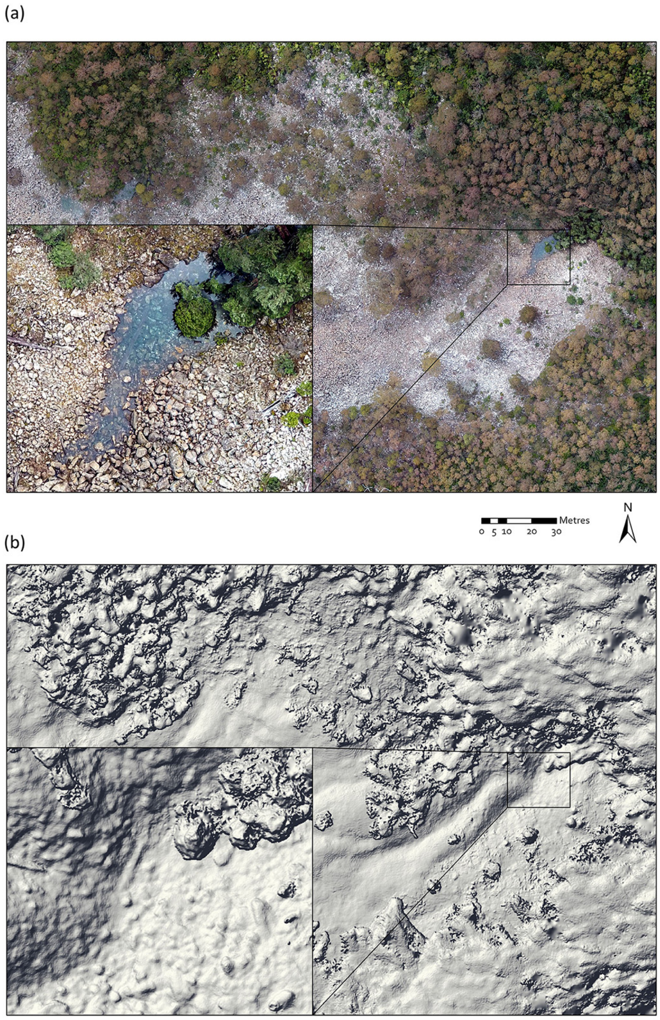

Fig. 8. UAV products: (a) Orthomosaic imagery captured at 10 cm resolution with 2 cm inset, (b) 20 cm resolution hillshaded 3D surface with 5 cm inset at Disappearing Tarn geosite. From Williams and McHenry (2020).

A DJI Phantom 4 Pro **UAV** was used to collected images and video at 10 geosites, harnessing the capability to capture data across large- and small-scale features from different perspectives. The high-resolution data captured from UAV flights was used to create 11 3D models, used for visualisation of geoheritage and assisting in the delineation of geosite boundaries (Fig. 8). Geographic delineation of each site was necessary because in a legislative environment, this information would be used to establish land tenure regimes and/or boundaries, so as to provide an adequate level of legal protection (Brilha, 2018) for geosites and natural values. Agisoft Metashape Professional 1.5.3 software was used to process the data from UAV flights and create high resolution Digital Elevation Models (DEM), orthophotos and 3D models using Structure from Motion (SfM) photogrammetry techniques. The 3D Models were uploaded to Sketchfab (e.g. Wellington Falls https://skfb.ly/6Dt7X and Disappearing Tarn https://skfb.ly/6XxyC), a web-based 3D content viewer, for visualisation and public communication (Williams, 2020e). Additionally, 3D models and videos were attached to the appropriate sites within the Inventory Web App for public and management visualisation.

The **web inventory** was setup using an ArcGIS Online template for a web application, designed with the aim to support decision making and support. The web application is built on top of the mobile data collection web map and was further customised to include usage information, metadata and the ability to search for geosites. Additionally, the web inventory was also used to construct a Story Map that could be used as a communication tool for stakeholders and the general public to raise awareness of the geoheritage values and geodiversity of the Wellington Park.

5. Results

Of the 49 potential candidates, assessment and classification (after Lima, 2008; Brilha, 2016) revealed a total of 1 high, 28 moderate and 20 lower-value putative regional geosites based on scientific values (Williams, 2020f). Additionally, there were 0 high, 38 moderate and 11 low; and 1 high, 32 moderate and 16 low geosites, based on educational and tourism values

Table 1
Range and 'mean' score (in brackets) for overall scientific value (SV), potential touristic and educational use (PTU and PEU, respectively) and risk of degradation (DR), as clustered by landform class, in Wellington Park, Tasmania. Landform theme was the 'geological framework' used for clustering sites in the park, which, geologically, was comprised primarily of Jurassic Dolerite ('diabase') and Permian sedimentary sequences.

Landform theme	Count	SV	PTU	PEU	DR
Aeolian	1	240	145	145	155
Fluvial	23	95–300 (205)	120–295 (218)	120–280 (217)	50–260 (178)
Karst	2	270–270 (270)	193–195 (193)	225–230 (228)	190–195 (192)
Mass Movement	2	280–295 (288)	200–210 (205)	195–250 (225)	165–285 (223)
Periglacial	17	115–310 (253)	185–310 (232)	185–275 (218)	50–340 (218)
Structural	3	230–265 (253)	185–310 (230)	200–245 (220)	50–380 (175)
Volcanic	1	170	170	210	85

respectively, that could be further developed as geodiversity sites so as to meet both tourism and geoconservation management objectives. When organising by landform theme (which was more informative than representation by geological type), it was revealed that a large proportion of sites were created by fluvial and/or periglacial processes (Table 1). Organising inventory by geological subunit did not reveal any additional information about values as most sites were either derived from Jurassic dolerite or Permian sedimentary sequences. A full explanation of the assessment criteria and a summary of findings can be found online (Williams, 2020g).

5.1. Geosite and geodiversity site values

Circa 98% of geosites were assessed as being of moderate to low SV (Fig. 9a-b). The highest ranked geosite for SV was the Organ Pipes, which in addition is also a unique, accessible geodiversity educational reference site. The lowest ranked geosite was Gorbys Corner (http://arcg.is/144SDS) which was not considered to be a reference site and has never been used as a study site for educational usage. Additionally, there were many representative geosites with modest geodiversity that were well preserved. Many geosites were not well-studied or recognised and most geosites had usage limitations due to permits required for sampling or difficult access (low scores for 'Key Locality' and 'Scientific Knowledge' criteria). Conversely, many sites had high integrity scores and over half were 'representative' geosites.

The overall PEU of putative geosites and geodiversity sites in the park was lower than that of PTU of the same sites (Fig. 10).

Two additional criteria differentiated PEU from PTU assessment - 'Didactic Potential' and 'Geological Diversity'. Only two sites had moderate to high didactic potential ('Pinnacle Volcanic Plug' and 'Merton Fossil Site') and just five had high geological diversity ('Pinnacle Volcanic Plug', 'Lost World Cliff and Boulder Cave Complex', the 'Organ Pipes', 'Lachlan Cliffs', and 'Yellow Cliffs') (Fig. 11). The mode of rankings for both criteria was 2 – moderately low. There were no significant differences between level of access, landform type, geological type and either didactic potential or geological diversity.

The Organ Pipes also had the highest PTU (Williams, 2020h), providing easy access through a network of trails, possessing moderate interpretability and some safety facilities, and good proximity to other attractions. Sphinx Rock (http://arcg.is/1W9a5b) had the highest PEU, providing easy access, high didactic potential through the display of a range of geodiversity elements and had good safety facilities. Long Marsh (http://arcg.is/1OzqT5) had the lowest PTU and PEU due to difficult access, difficult interpretability, limited scenery potential. Additionally, any access could result in degradation because the site is considered fragile.

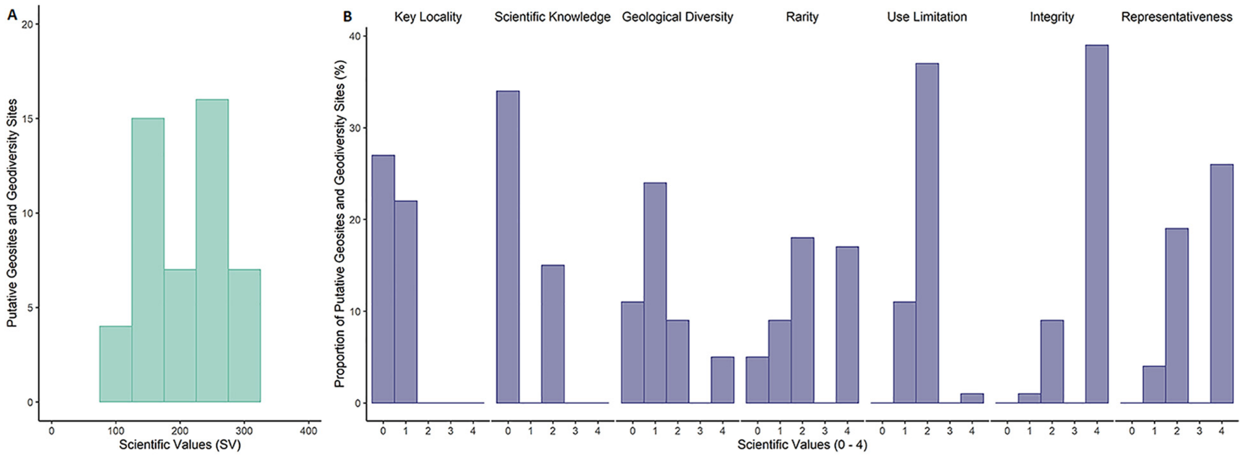

Fig. 9. (a). Assessed overall scientific values scores for putative geosites and geodiversity sites, and (b) proportion of sites meeting specific scientific values criteria as per the Brilha (2016) method in the Wellington Park, Tasmania.

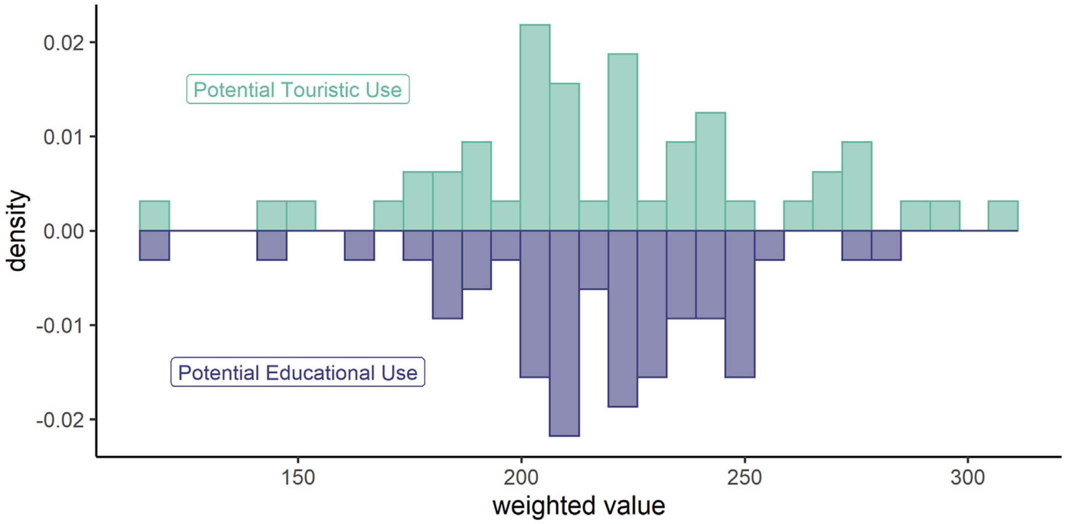

Fig. 10. Weighted overall PEU values were lower than weighted PTU values in the park.

Many sites had at least moderate geodiversity site potential because they contained moderate levels of PTU and/or PEU (201–300). Approximately 35% (17/49) of the sites had the highest interpretive potential and other values associations (16/49) (Fig. 12). Sixty-nine percent (34/49) of the sites had the best observational conditions and 76% of sites were in close or very close proximity to recreational areas, and 71% possessed at least moderate economic levels. Twenty-eight percent (14/49) of sites were at least somewhat unique (ranked 2 or 4/4). However, many sites had poor accessibility (28/49), lower levels of safety (41/49), no or limited scenery (36/49), many use limitations (22/49) and moderate to high vulnerability (35/49). Nearly all sites possessed excellent observational conditions (34/49).

Some of the more scenic sites – Silver Falls, Sphinx Rock, Myrtle Forest Falls and O'Grady's Falls – had high or very high safety scores. Silver Falls and Sphinx Rock additionally had the highest interpretive potential for sites with a 4/4 for safety. The most vulnerable sites in the park were often the most accessible (Ferntree Monocline, Pinnacle Road Sandstone/Dolerite Contact, Rocky Whelan Cave, Pinnacle Volcanic Plug – vulnerability = 3–4/4; accessibility = 3–4/4). Many of the moderately scenic sites (2/4 - there was only one site scoring 4/4, The Organ Pipes) also had the highest interpretive potential (4/4). These sites were Rankin Falls, New Town Falls, Sphinx Rock, Strickland Falls, Lost World Cliff and Boulder Cave Complex, Wellington Falls, O'Grady's Falls, Myrtle Forest Falls, and Silver Falls (Fig. 13).

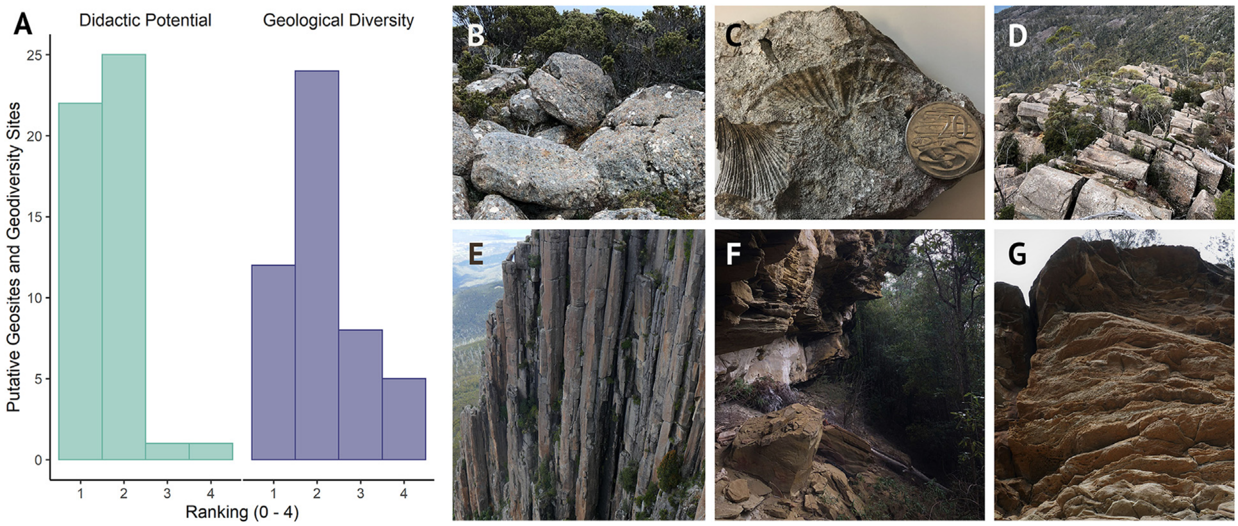

Fig. 11. (a) Sites in the Wellington Park had low to very low didactic potential, with two exceptions (b: 'Pinnacle Volcanic Plug' and c: 'Merton Fossil Site'). Sites in the Wellington Park had slightly higher geological diversity, with five sites deemed to have excellent geological diversity (also c: 'Merton Fossil Site', d: 'Lost World Cliff and Boulder Cave Complex', e: the 'Organ Pipes', f: 'Lachlan Cliffs' and g: 'Yellow Cliffs').

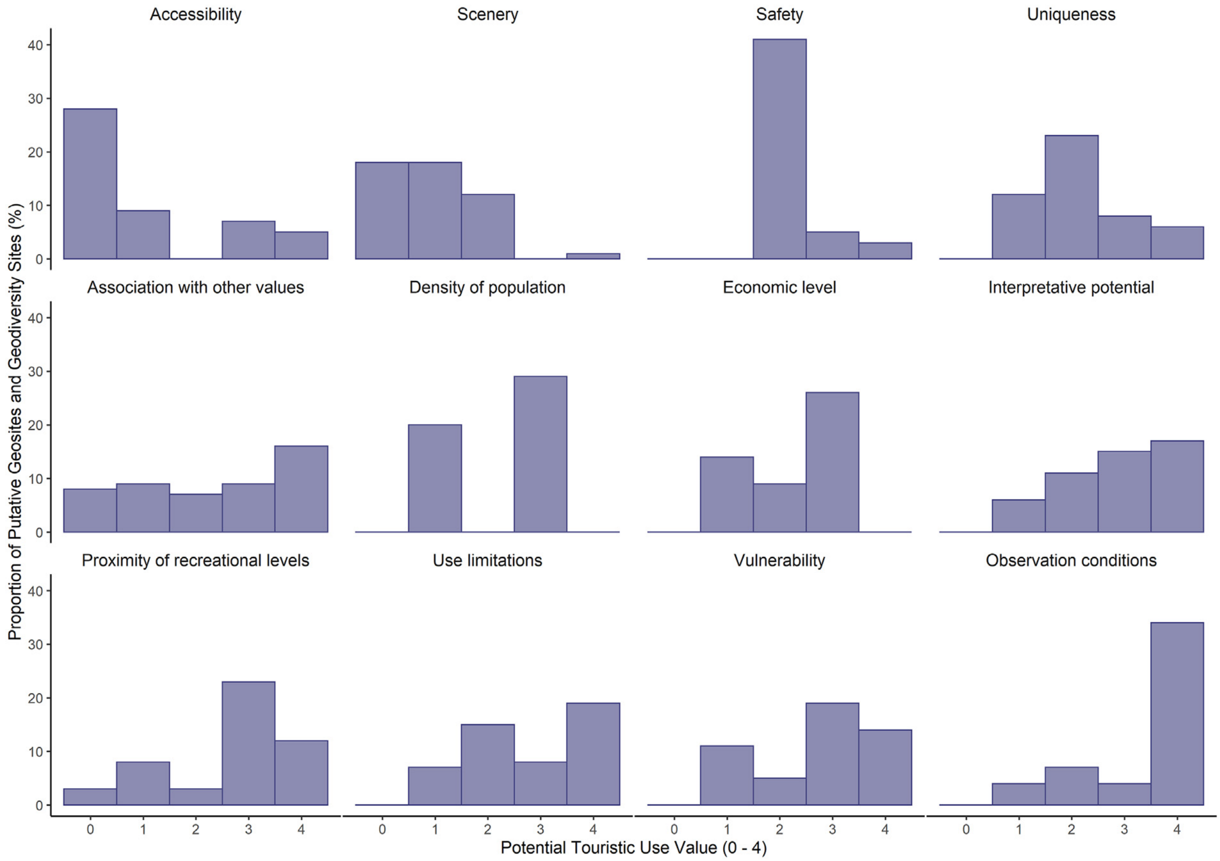

Fig. 12. Potential Touristic Use Value criteria, each of which are common to the assessment of Potential Educational Use Value (PEU). Logistics criteria not shown (48% of sample had a logistics score of '3' and 52% had a logistics score of '4'). Values criteria are ordered from lowest scores to highest scores from top-left to bottom-right.

5.2. Geosite and geodiversity site degradation risk

Most geosites in the Wellington Park were at low (59%) to moderate (37%) risk of degradation. Many putative geosites were more than 1 km away from a source of degradation, possessed reasonable legal protection and had low or difficult accessibility (Fig. 14). Wellington Falls (http://arcg.is/0X9uHr), for instance, had the lowest risk of degradation due resistant geology, its relatively remote location and good level of protection. Conversely, the Ferntree Monocline (http://arcg.is/jnLm5) had the highest degradation risk because it is located directly on a road with no legal protection or access control (Williams, 2020i).

There were no significant correlations between overall PTU, PEU and SV rankings and DR, however, sites with higher integrity values from SV assessment generally had the lowest DR. Examples of sites with an integrity rank of four with the highest DR scores (200–250) were Flora Falls, the Organ Pipes, Strickland Falls, Sorrel Creek, the Nivation Hollow, Silver Falls, the Merton Fossil Site, Leamans Knob, Rocking Stone, Neika Cliffs and Mountain River Canyon (Fig. 15). Finally, despite there being a general association between lower levels of rarity and degradation risk, the sites of highest rarity were just as likely to have low DR as high DR.

5.3. Assessment and communication of inventory using GIT

A *GIT product* arising from the analysis was the production of a geosite evaluation map (Fig. 16) which spatially confirmed that many geosites close to Hobart and towards the perimeter of the Wellington Park possessed relatively high PTU and PEU due to good access and close proximity to Hobart. The map also revealed that geosites of high SV were generally present around the periphery of the reserve or near access points or readily accessible via a network of trails. High DR geosites were generally spatially located adjacent to roads or the main thoroughfare of the reserve.

Additionally, a Story Map was created to communicate research in the Wellington Park and educate the public about geodiversity (https://arcg.is/14nm8T), highlighting the geohistory of the reserve and showcasing some of the geodiversity sites with embedded multimedia and 3D models.

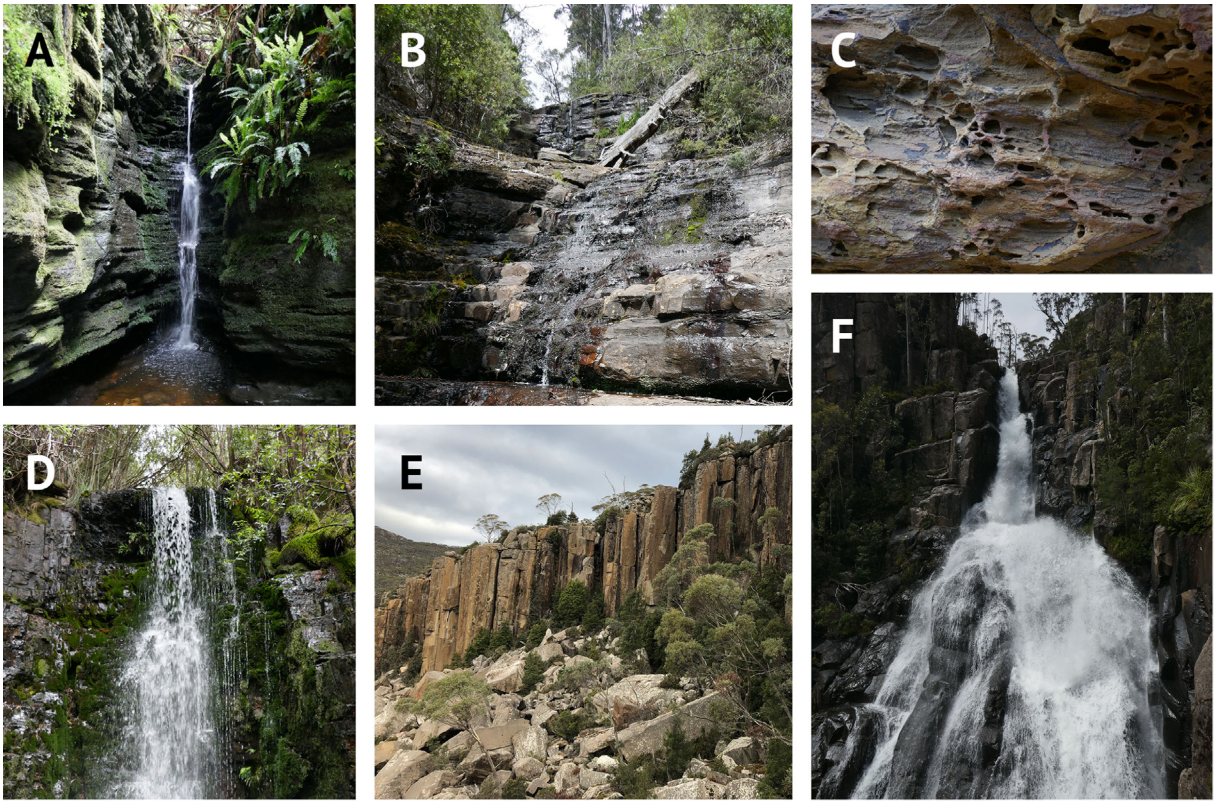

Fig. 13. Geosites and Geodiversity sites with high interpretive potential. A: Rankin Falls; B: New Town Falls; C: Sphinx Rock; D: O'Grady's Falls; E: Lost World Cliff and Boulder Cave Complex; F: Wellington Falls.

6. Discussion

The Wellington Park is a spectacular example of periglaciated terrain in Tasmania that co-occurs with a high concentration of endemic (to Tasmania) biota and paleoendemic plant communities. In this study, we found that almost half of the putative geosites from the original inventory (Hepper & de Gryse, 1995) were representative (53% of 49 assessed) which demonstrates the wide range of landforms and geomorphological processes evident in the Wellington Park. Nearly all were of high integrity.

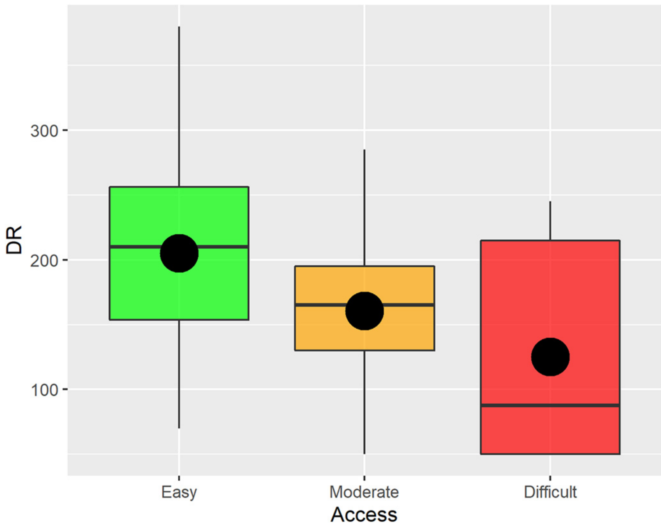

Fig. 14. The more accessible a site in the Wellington Park, the more likely it was to be of high risk of degradation.

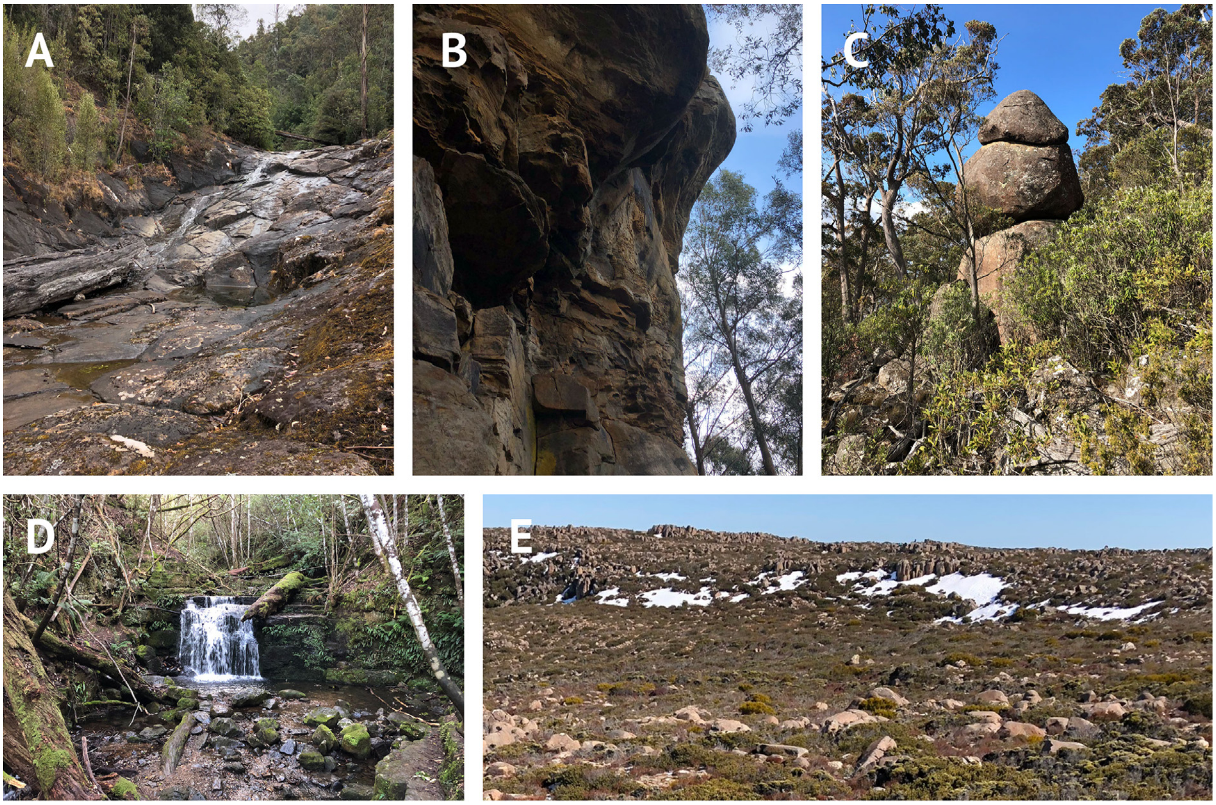

Fig. 15. Selected Geosites and Geodiversity sites with high degradation risk and high integrity scores. A: Sorell Creek Falls; B: Neika Cliffs; C: Leamans Knob; D: Strickland Falls; E: Nivation Hollow.

However, very few putative geosites scored high SV overall. This is due to the situational context of Tasmania and the original objectives of the park management strategy and inventory goals.

Firstly, less than a quarter of the putative geosites were rare. Though the Wellington Park inarguably has one of the highest concentrations of periglaciated landforms and terrain that has never been glaciated in Tasmania – there are indeed many other places in Tasmania with periglaciated terrain that are recognised in state inventory (NVA, 2021). Dolerite, as a geological subunit, is extensively expressed across Tasmania – in fact – it is the largest expression in the world (Seymour et al., 2013). Therefore, whilst the Wellington Park has many outstanding examples of such geomorphosites in one place, not all are of similar scientific value.

Additional reasons for the lower SV score for many of the putative geosites is that use limitations and key locality scores were low, as was scientific knowledge. The latter is reflective of the small population size of Tasmania (>510,000) and the short history of European occupation in Australia more broadly (just over 250 years). The only university in the state (The University of Tasmania) has been open for 175 years, and has a world-class, but small, geology and geography department to account for the entirety of the state's extensive geodiversity. It therefore may be possible that, as new information becomes available through extensive scientific study, the SV of putative geosites in the Wellington Park may increase.

Clearly, a challenge for managers of the inventory is to ensure that sites are protected from degradation until further, more detailed descriptions can be made. As we discuss hereafter, the proximity of the park to Hobart, increased visitation to the park, and this first examination of additional values of putative geosites from the original inventory, suggests that descriptions and management goals might need to be expanded to acknowledge the existence of a number of putative geodiversity sites within the park.

6.1. Putative geosite values

Despite the high proportion of representativeness, only 11 geosites from the Wellington Park are recognised on the state inventory (the 'TGD'). The TDG recognises these outstanding scientific values at a state level, in some cases, grouping putative geosites from the original Wellington Park inventory into a larger 'meta' site covering a broad area. This difference in representativeness can be explained in the way that geosites are classified and the aims of the inventories. The TGD classification of landforms operates at a state-wide level where geosites are grouped under broad themes. This was unsuitable for the regional Wellington Park inventory since this approach only captured a small selection of landforms disregarding the various types of

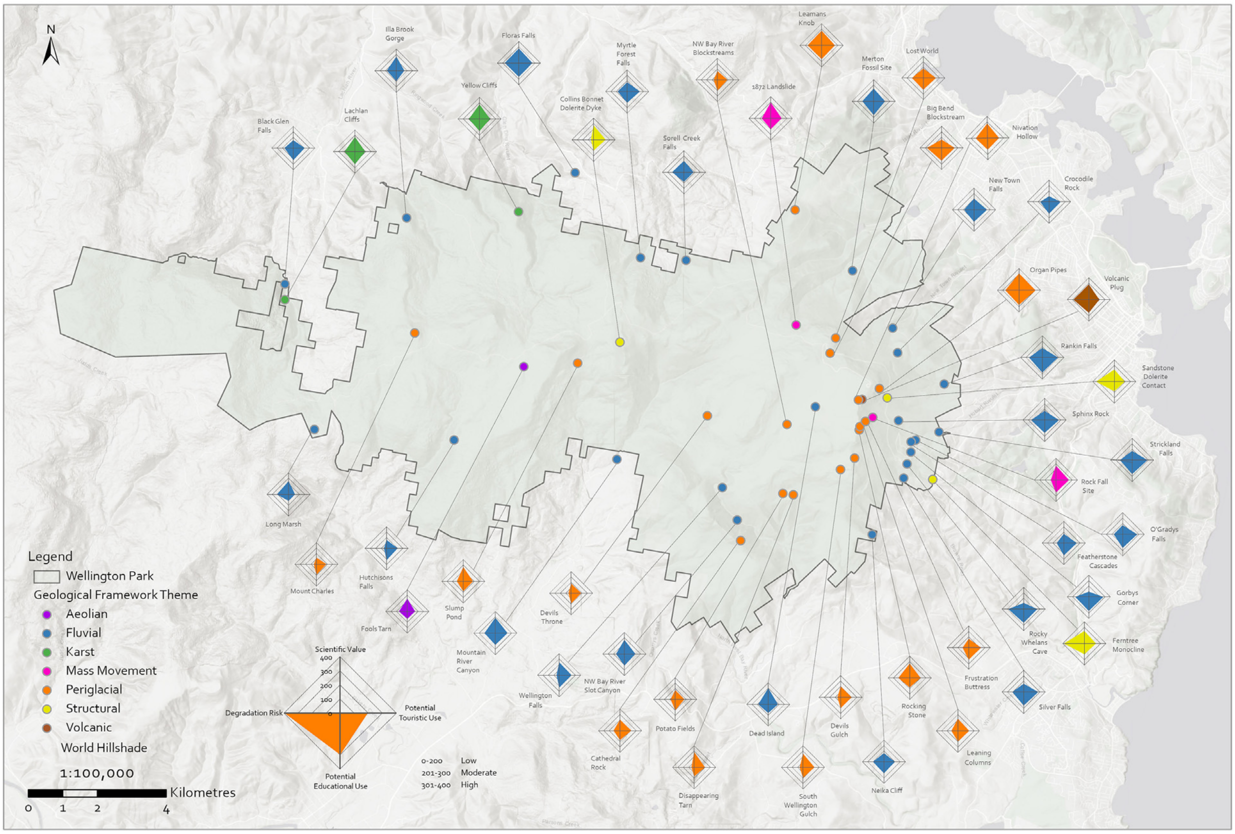

Fig. 16. Radar chart overlaid on Wellington Park boundaries showing domains 'Degradation Risk' (left apex of diamond), 'Scientific Value' (top apex of diamond), 'Potential Touristic Use' (right apex of diamond) and 'Potential Educational Use' (bottom apex of diamond) of sites grouped by landform classification (after Bradbury (2014)), as assessed using the Brilha (2016) method.

landforms in the large park. The high proportion of representativeness is also in part due to the design of the original inventory 25 years ago. Sites were *intentionally* selected for their representativeness in order to conserve the best examples of a geodiversity element or geomorphological process in the park, and secondly the wide range of processes through the evolution of the Wellington range has led to a large number of landforms types. Although the dominant geomorphological processes in the park are periglacial and fluvial, there are also relict volcanic (e.g. Pinnacle Volcanic Plug https://arcg.is/1qG9r90), aeolian (e.g. Fools Tarn https://arcg.is/0WyCy1), and karst (e.g. Lachlan Sandstone Cliffs https://arcg.is/1L5fH1) processes.

In most cases there are better representations of a particular landform type in the state-based TGD, but the Wellington Park geosites represent an important part of the world's largest exposure of dolerite that tell a significant story of the evolution of Tasmania and Antarctica through the Gondwanan breakup. Sites that generally scored high to moderate SV were periglacial and fluvial due to the abundance of these types of landforms and often exhibited good geological exposures that allowed scientific studies to be undertaken. Similarly, landforms that scored low were also of the fluvial and periglacial variety that were often degraded from overuse or the access to these sites constrained scientific studies of these sites. Perhaps the best way to resolve differences in scale-based interpretations of the SV of putative geosites in the Wellington Park is to value these in terms of their role as geodiversity sites instead. Geoheritage, after all, is assigned exclusively to the sites of highest SV at a national and international level. If putative geosites of our most recent update of the inventory are lower in SV than other places on the TGD inventory, then attempting to represent them as geosites would be a misrepresentation akin to 'local science' (Brilha, 2016).

It is additionally worth noting that spatial trends of SV show that geosites with high SV are well distributed and are not as affected by proximity to large populations, although some of the easy to access locations have been studied more which increases the SV. It is also clear from the evaluation map that the far western part of the Wellington Park has received little attention and warrants further exploration to enhance the inventory.

6.2. Additional values and the potential for a range of putative geodiversity sites

Despite the challenges of assessment, sites in the Wellington Park exhibited high scenery value with 63% of geosites being advertised as a hiking destination in walking books, blogs, published maps and advertised directly through tourism websites. This is bolstered by a large local bushwalking community in Tasmania and many tourists come to visit the Wellington Park for hiking recreation and scenery. Additionally, most geosites are in areas with moderate populations with good accommodation options for tourists and were also close to other tourist attractions. Many geosites were regionally unique, displayed good scenery and many potential belvedere points (after Kubalíková, 2014), possessed reasonable geological diversity and exhibited good interpretative potential. Although some interpretative information about geosites exists at various places in the park, there is further potential to develop mobile apps that could use technologies such as augmented reality to further educate people about the important geodiversity in the park.

During the PEU and PTU assessment of the Wellington Park, information was limited or missing for some criteria and other sources of information, such as grey literature and existing geotouristic promotional and educational products were used as a proxy for the required information. For example, information was missing for the scenery criterion, based on the level of tourism advertising for a geosite, hence the assumption was made by the assessor to use advertising material available on websites, blogs, and hiking websites as well as formal brochures and handouts. In many parts of the world, the required information to undertake a geotourism assessment is likely limited, and therefore the possibility to develop readily-accessible mobile GIT for initial reconnaissance, and inventory guidance, could be quite useful in parts of the world where promotion of prospective geodiversity sites may be occurring ahead of sufficient inventory for geosites and SV in general.

Furthermore, most (71%) of the sites in Wellington Park are close to local population with above average national socioeconomic status, increasing the probability of visitation given the appropriate access and promotion. Despite the high PTU and PEU, quite a few geosites are quite vulnerable, many geosites had poor access (> 1 km), no safety facilities and limited promotion. These sites would need to be managed accordingly so as not to increase the DR. The analysis suggests that more study should be undertaken to further understand these putative geosites considering many of these geosites are representative types (in terms of SV), but yet have higher PTU or PEU than SV.

The high additional values could potentially warrant the conversion of many geosites into geodiversity sites, based on the PTU and PEU values previously discussed and the high level of observation conditions of many putative geosites. The potential for 'exclusive' geosite status cannot be conclusively discounted, however, because many geosites have not been studied sufficiently to validate their scientific knowledge ranking. Ultimately, most sites will possess a number of values, as the purposes of the Wellington Park are to provide recreational and tourism uses consistent with protection of biodiversity, preservation of scenic interest and features of the land, including scientific and geomorphological interest (Wellington Park Management Trust, 2018). Thus, it might be possible that putative geosites that have low SV and high PTU and PEU could be categorised as geodiversity sites and be suitably managed under the existing management structure and reserve classification, but until sufficient knowledge is obtained about these sites, conclusions cannot yet be drawn about their specific status.

6.3. Geosite and geodiversity site degradation risk

Indeed, after 25 years since the first Wellington Park inventory, degradation is now evident across many of the originally-proposed geosites (Hepper & de Gryse, 1995) still present in the existing inventory. Geosites with the highest degradation risk are close to major roads in the Hobart region. Generally speaking, fluvial landforms (e.g. waterfalls and sandstone cliffs/overhangs) tend to have higher DR which is explained by their proximity to populations and the softer lithology in which they exist. In contrast, periglacial landforms are harder to access and are generally made of dolerite, an erosion resistant lithology. Sites with lower SV and higher DR values (Fig. 17) across much of the park may need monitoring, but also suggests that new opportunities could be explored where PTU and PEU values are largely moderate or high.

6.4. Inventory using GIT tools

The CollectorApp attributed more precise boundary delineation of prospective geosites. During fieldwork in the Wellington Park, geosite boundaries were determined by walking the extent of the geosite, if practical, otherwise satellite photos were used to describe the boundary of geosites. The accuracy of delineation was limited by the difficulty of traversing the terrain and the clarity of boundary delineation, but in many areas that otherwise would have been too hazardous to sample, the combined use of CollectorApp and a UAV as GIT tools facilitated clearer delineation (e.g. Fig. 18). Alas, there are situations where you wouldn't want an accurate boundary for land management or sensitivity reasons, and in this case a buffer could be added to the boundary collected in the field to accommodate for this requirement.

This study has demonstrated that at least for the more rapid and accurate assessment of inventory, the use of the GIT tool, CollectorApp, was useful and streamlined processes. The assessment of semi-wilderness geosites in Wellington Park was performed at an average of 1 site per day in sometimes extremely rugged and hazardous terrain, with no formed tracks, by a single person in a 18,250 ha protected area. Twenty-five years ago, when the first inventory was performed, it required multiple experts to undertake simultaneous field trips to perform the same task (Hepper & de Gryse, 1995), with many sites not receiving a visit due to the already-specialist local working group having visited and managed specific areas previously (Dr. Chris Sharples, Geoconservation expert, 2019, pers. Comm). One might therefore argue that in some situations, it might be preferable for one assessor to visit all sites, so as to provide consistency in surveying and assessment – and that GIT tools such as the CollectorApp, 'Fieldmove Clino' and other mobile apps facilitated this possibility. Of course, there are many other situations where a group reconnaissance is preferred, and in these situations, the GIT tools just described could be used for communication and be configured to improve consistency across multiple in-field assessors.

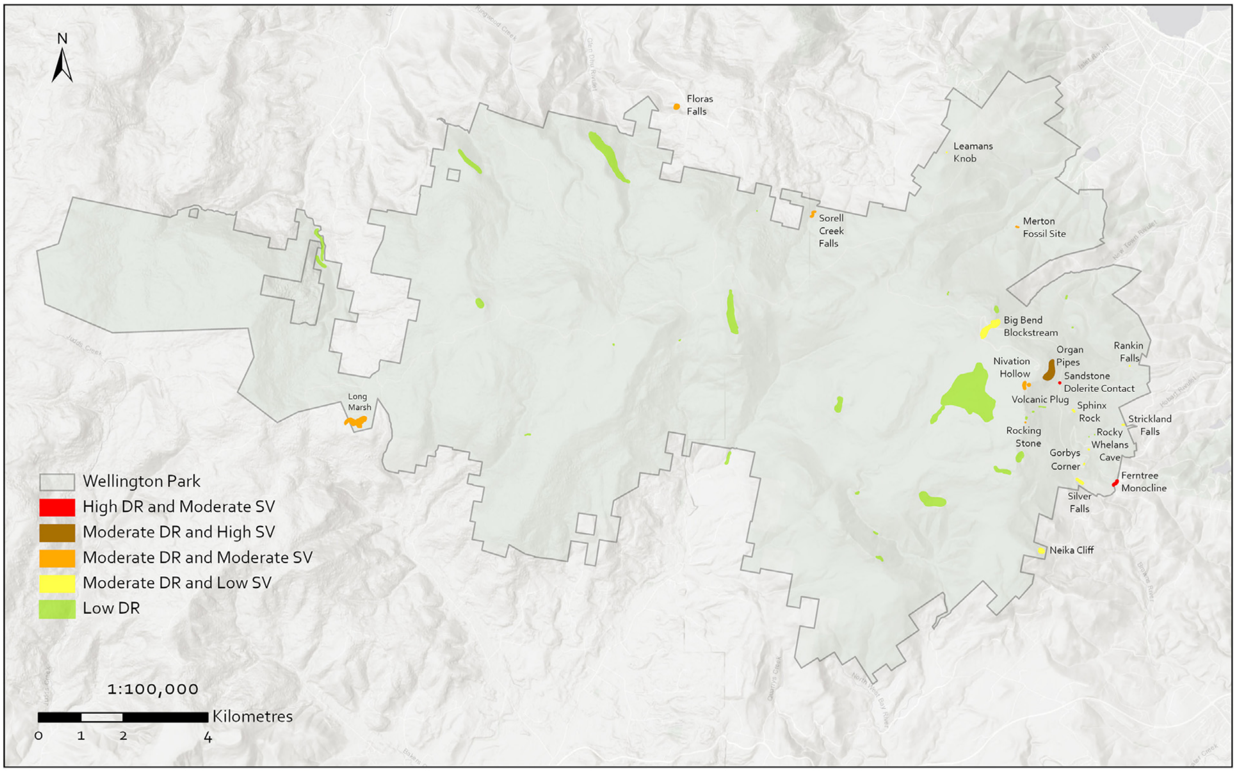

Fig. 17. Degradation Risk Map showing sites with high and moderate DR categorised by SV as assessed using the Brilha (2016) method.

In addition to inventory compilation, monitoring geosites for degradation caused by natural and anthropogenic sources is another considerable challenge, particularly in areas that are well developed for tourism such as Geoparks. Like the problems related to boundary delineation, the challenges are related to scale and accessing difficult terrain as well as obtaining accurate data in a cost-effective manner. In addition, it is important to have current and historical data so that changes can be detected, and appropriate action can be put in place if unwanted changes occur. Monitoring is a time intensive and often impractical task for park managers, requiring regular field surveys. The data collection stage of this paper required 55 days of fieldwork in the Wellington Park, mostly by the author, presenting consideration time and financial challenges. Fieldwork is clearly a necessary component in compiling an inventory and is also a key part of monitoring geoheritage for degradation and making sure geosites are managed effectively, and hence the use of GIT tools provide a standardised and comparative method of in-field assessment. Furthermore, a subset of the inventory data can be shared with the public through the use of web and mobile apps and there is potential for this data to be incorporated into a geotourism experience using web-apps, 3D models, virtual reality experiences or a Story Map, or an in-field experience using augmented reality.

7. Conclusions

The assessment of the original inventory has suggested that many geosites in the Wellington Park may in fact be better classified as geodiversity sites (sensu Brilha (2016)). Nonetheless, in an attempt to update the Wellington park regional inventory, a geological framework was adapted based on others found in the literature (Bradbury, 2014; Davies, 1969; Reynard, Perret, Bussard, et al., 2016) and a list of representative landform types was determined for the study area. This is problematic in that a different geological framework and list of representative types could have easily been determined and this would have significant impacts on the evaluation of representativeness, rarity and uniqueness criteria related to SV, PEU and PTU. Despite the use of a quantitative assessment method by Brilha (2016), there were many interpretations of sub-criteria made, introducing subjectivity. The methodological approach, however, in this inventory review, was to use a list of geodiversity elements based on Serrano and Ruiz-Flaño (2007) and count geodiversity elements consistently across different scales i.e. terrane to crystal. Such a criteria set is useful for specifying and delineating local-global geodiversity-geoheritage boundaries by defining the spatial extent of geodiversity elements and prospective geodiversity sites, whilst recognising that geoheritage significance (and thus, the recognition and protection of geosites) can only be recognised at a much coarser spatial and territorial scale.

This study has shown how GIT tools can be used to identify regional scientific, tourism and educational values and hence potential regional geosites and geodiversity sites, and how geosites can be assessed for degradation risk and monitored for any

Geosite	Area using traditional method (m^2)	Area using CollectorApp method (m^2)	CollectorApp proportion (% of traditional method)
A - Yellow Cliffs	3402712	451250	13.3
B - Organ Pipes	422381	122752	29.1
C - Disappearing Tarn	249696	1113	0.4
D - Rocking Stone	43590	538	1.2

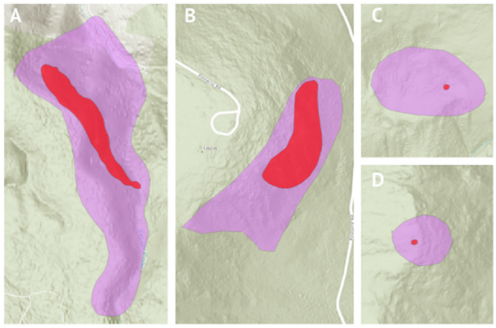

Fig. 18. Selected Geosites showing the geosite boundary (purple) using traditional methods and the boundary determined using the CollectorApp. A: Yellow Cliffs; B: Organ Pipes; C: Disappearing Tarn; D: Rocking Stone.

unwanted changes. Furthermore, GIT tools can be used for the more rapid and accurate assessment of inventory, and an in-field, consistent data collection and monitoring process.

Ultimately, many problems associated with geoheritage and geotouristic assessment and recognition exist because methods to assess are not ubiquitous nor simplistic in their determination of quantitative or qualitative values and elements (Boothroyd & Henry, 2019). The use of GIT can dramatically aid in improving these situations, because, once developed, online inventory tools and in-field mobile apps allow experts and amateurs from around the world to view their local areas as part of a global context. Currently, assessment methods are often site, and context specific, which may be necessary – but also allows individual research groups to develop vastly different criteria and value sets that are not translational. The use of GIT might enable discussion, comparison and reflection across broader spatial and cadastral contexts than ever before. The number of ways in which GIT tools could be used to support data collection, and knowledge transfer in geoconservation and geotourism at existing geographic scales (local/regional; state/provincial/national; international) - appears to be considerable. Between the initial reconfiguration of the CollectorApp, to the results, imagery and hyperlinks contained within this article, three GIT tools were used, at reasonable cost using standard software. The potential for use of GIT to simplify workflow for geosite and geodiversity site identification and degradation assessment was just one example of what could be possible for places new to the ideas and principles of geoconservation and natural values assessment, and poorly-conserved regions will now be able to produce spatially-explicit inventories, enhancing global knowledge of geoconservation and appreciation of geoheritage and geodiversity.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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