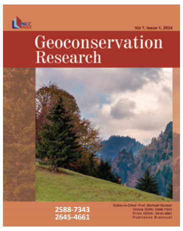

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Geoconservation Subjectivity Evaluation: A Case Study of a Management Toolkit

Jake RA Crisp[1*], Joanna C Ellison[1]

[1]School of Geography, Planning and Spatial Science, University of Tasmania, Launceston, Tasmania, 7250, Australia

***Corresponding author:** Jake Rex Albert Crisp Email: jracrisp@utas.edu.au

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Abstract

Conservation efforts, such as geoconservation, involve some degree of subjectivity, compromising the objective data and verifiable evidence required for effective decision-making. Geodiversity, which comprises the non-living components that underpin life, is increasingly at risk from human activities and is frequently overlooked in conservation initiatives. Here, we develop a novel subjectivity evaluation tool and management framework, implemented as a case study at a Tasmanian mountain site using a geoconservation toolkit approach. Our assessments show that Mounts Dial (102) and Gnomon (124) are highly geodiverse, while Mount Duncan (31) is moderately geodiverse. Further, scientific, tourism, and conservation values are determined to be most representative of geoconservation significance, with Mounts Duncan and Gnomon ranking highest. However, the novel subjectivity evaluation tool reveals highly subjective data and outcomes for geodiversity and geoconservation assessment (25) attributed to a lack of scholarly literature, limited interdisciplinary engagement, and evaluator input into criteria ranking. Therefore, the subjectivity framework recommends measures to mitigate this subjectivity, by enhanced interdisciplinary engagement of expert stakeholders using objective hierarchical methods, combined with remote sensing or GIS statistical validation. Overall, the study demonstrates the usefulness of the subjectivity evaluation approach to identify parameters hindering geoconservation outcomes. The novel subjectivity approach has global implications, in improving subjectivity management in geoconservation assessment and allowing better alignment of comparisons between practitioners and sites.

Keywords: Geodiversity, Conservation, Geoconservation, Subjectivity, Assessment

Introduction

Overview

The non-living framework that supports life on Earth – geodiversity – is under increasing threat from degrading human influence (Orsi 2014; Hjort *et al*. 2015; Bétard and Peulvast 2019; Garcia 2019; Crisp *et al*. 2022a). Geodiversity is defined as including geomorphological (landforms, topography, physical processes), geological (rocks, minerals, fossils), pedological (soil) and hydrological features (Gray 3). Measuring the significance (Barančoková *et al*. 2023), distribution (Özşahin 2017; Manosso *et al*. 2021), or more commonly the richness of geodiversity (Hjort *et al*. 2022; Crisp *et al*. 2022a; Crisp *et al*. 2022b) through its evaluation or assessment can benefit conservation decisions and outcomes (Anderson *et al*. 2015; Comer *et al*. 2015; Lawler *et al*. 2015). In the first stages of a geodiversity assessment, a number of methods are used to source geodiversity data, such as geological maps (Zakharovskyi and Németh 2021; Elkaichi *et al*. 2021; Scammacca *et al*. 2022), remote sensing information (Stepišnik and Trenchovska 2018; Zakharovskyi and Németh 2021; Rong *et al*. 2023), or field surveys (Stepišnik and Trenchovska 2018; Bajala *et al*. 2022; Crisp *et al*. 2022a; Crisp *et al*. 2022b), and in subsequent stages, qualitative, quantitative, or qualitative-quantitative methods are used to evaluate the data sourced (Forte *et al*. 2018).

Qualitative methods include grading scales of values and benefits (Gray 2008; Ellis 2011; Ahmadi *et al*. 2022). Quantitative methods use algorithms and parameters to determine a georichness value, which refers to the quantity or sum of geodiversity elements in a study area (Stojilković 2022; Tukiainen *et al*. 2022) or can be referred to as the abiotic equivalent of species richness used in biodiversity assessments (Bétard and Peulvast 2019). For example, Zakharovskyi *et al*. (2023) adopted a qualitative-quantitative geodiversity assessment approach based on an arithmetic average equation attributed to abiotic values to facilitate enhanced geosite determination, while Pereira *et al*. (2013) adopted a GIS grid-based approach to quantify geodiversity on a set of geological maps.

Geoconservation is the action of conserving geodiversity for its intrinsic, ecological, and geoheritage value (Sharples 2002; Prosser 2013). A geoconservation strategy is the process used to achieve geoconservation outcomes, such as inventorying, evaluation, conservation, interpretation, and promotion (Brilha 2016). There are conceptual and methodological challenges constraining geoconservation outcomes, such as the prevalent state of methodological development in the relatively recent geodiversity concept (Serrano and Ruiz-Flaño 2007; Soms 2017; Crisp *et al*. 2021; Nemeth *et al*. 2021), the exclusivity of geodiversity assessment from geoconservation strategies (Brilha 2016; Crisp *et al*. 2022b), funding constraints, and the lack of substantive information and conflicting priorities (Chakraborty and Mokudai 2018).

Geoconservation is still a recent concept, with the term 'geoheritage' initially mentioned at the First International Symposium on the Conservation of our Geological Heritage in 1991 (Németh *et al*. 2021), and geodiveristy studies emerged earlier in the late 1970s and 1980s (Ibáñez *et al*. 2019). However, studies in biodiversity have a longer history spanning from as early as the 1700s and 1800s; hence, biodiversity and biological conservation are supported by centuries of methodological development by comparison (Ibáñez *et al*. 2019). Therefore, progress is still needed in geoconservation and geodiversity to improve standardization in terminologies and processes to avoid misuse and unconventional application of defining concepts, such as the inclusion of irrelevant sites and the exclusion of important geosites (Brilha 2016). However, standardization of concepts and processes in geoconservation is not progressing ideally, especially as geoheritage still tends to favor Western values (Brilha 2016). This warrants further consideration to establish consistent terminologies and processes in geoconservation. For example, a novel subjectivity evaluation and management approach could help mitigate this Western bias in geoheritage by encouraging more diverse cultural perspectives in the assessment of geosites.

Subjectivity in Geoconservation Strategies and Geodiversity Assessment

Subjectivity in methods can present challenges to geoconservation outcomes (White and Wakelin-King 2014; Brilha 2016; Micić Ponjiger *et* *al*. 2021; Crisp *et al*. 2022a). Some criteria and methods are inherently subjective (Brilha 2016), requiring allocation of values to criteria based on evaluator input (Pereira *et al*. 2007; Dede and Zorlu 2023). This study refers to the 'degree' of subjectivity as intrinsic subjectivity need not indicate weak methodological approaches, inferences or conservation outcomes. For example, in the case of geodiversity assessments which are quantitative and objective (Crisp *et al*. 2021), some still exhibit intrinsic subjectivities (Ahmadi *et al*. 2022), such as the need for judgment of geological, geomorphological, or soil maps often require, with different levels of expertise and experience probably resulting in different interpretation outcomes. In other conservation efforts, the subjective experiences, well-being, and perspectives of individuals and communities are evaluated to assess the social or cultural impact of protected areas such as marine reserves (Bryce *et al*. 2016) or are used to shape the success of conservation outcomes, with subjective involvement in conservation efforts potentially shaping positive behaviors and stewardship in individuals and communities (Chmara-Huff 2014; Bennett 2016; Swaim *et al*. 2016). However, it is generally accepted that methods involving subjectivity, such as those based primarily on personal opinions – satisfaction, feelings, and individual preferences – can hinder conservation outcomes (Burgman 2001; Margoluis *et al*. 2009; Cook *et al*. 2010; Cook and Hockings 2011; Carranza *et al*. 2014; Datta and Sarkar 2019; Datta 2020). For example, ambiguous criteria, varying personal values, and poorly defined criteria and methods can lead to the exclusion of important geosites in geoconservation planning and management (Brilha 2016; Mucivuna *et al*. 2019).

Subjectivity in geoconservation assessment can depend on the experience and knowledge of the evaluator (Reynard *et al*. 2016; Zwoliński *et al*. 2018), the relevance of their training and experience (Andrade *et al*. 2014; Elliott *et al*. 2018), transparency of criteria and methods (Mucivuna *et al*. 2019), objectivity of methods used with indirect spatial or statistical techniques commonly used to remove subjective evaluator input (Crisp *et al*. 2021), or limited human resources and training (Williams *et al*. 2020), such as the absence of scholarly literature to support objective decision making in conservation decisions. Other intrinsic factors also influence subjectivity (Brilha 2016), such as:

• Values and beliefs shape perceptions and interpretations of criteria and methods (Pereira *et al*. 2007; Brilha 2016; Dede and Zorlu 2023). For example, an expert evaluator who values the aesthetic potential of an area may prioritize preserving geodiversity for its scenic beauty, while another who values its scientific value may promote its preservation for exploration by other scientists.

• Cultural values can also influence attitudes and opinions around geoconservation protection (Reynard and Giusti 2018). For example, more direct types of cultural significance, such as caves preserving paintings and inscriptions, could be prioritized for conservation over less tangible aspects of cultural history, such as the spiritual significance of an area (Crofts and Gordon 2015; Gray 2019).

• Economic and political considerations can also influence geoconservation outcomes (Crisp *et al*. 2021). For example, the priorities of a government could promote the economic value of a prospective geosite over its geoconservation values.

Therefore, there is an opportunity to evaluate and report on the degree of subjectivity in future geoconservation. For example, qualitative methods depend mainly on the evaluators who use subjective decisions to select a score for each criterion in a geosite assessment (Ahmadi *et al*. 2022). Assessing geomorphological sites using subjective geoheritage criteria (Pralong 2005; White and Wakelin-King 2014) depends largely on the evaluator and their expertise and resources. Some scholars acknowledge the degree of subjectivity in their assessments, such as Ahmadi *et al*. (2022), who state that the qualitative-quantitative method of questionnaires and analysis of geomorphologic and tectonic structures data had overall low subjectivity.

Techniques have been developed to alleviate subjectivity in geodiversity and geoconservation studies (Bruschi *et al*. 2011; White and Wakelin-King 2014; Ferrando *et al*. 2021). For example, Ferrando *et al*. (2021) included the analytical hierarchy process and input from 12 experts to assign weightings to parameters used to calculate a geodiversity index, which eliminated subjective personal opinions (Datta and Sarkar 2019; Datta 2020). Stepišnik and Trenchovska (2018) used morphographic mapping and a variety of spatial analyses to evaluate geodiversity, which were combined using an automated modeling approach to reduce subjectivity.

Therefore, evaluating and reporting on the degree of subjectivity could help facilitate the identification shortfalls in methods and opportunities for improvement, and therefore help shape geoconservation management priorities and outcomes. For example, the experience and level of knowledge of authors can be linked to the misuse of concepts and methods (Brilha 2016), and indicating this in a subjectivity evaluation and reporting process could help to identify the need to further validate the application of criteria or value assessments by other experts (Reynard *et al*. 2016; Zwoliński *et al*. 2018). For example, expert geomorphologists assessing the cultural or geotourism value of a geoconservation site might overlook key insights informing relevant criteria determinations, and in a worst-case scenario result in the misuse of criteria and exclusion of important geosites from global databases (Brilha 2016), and conversely, the same would be true if experts in geotourism or cultural assessments assess the core scientific values, such as geodiversity, underpinning geoconservation sites. Therefore, evaluating and reporting on varying factors contributing to subjectivities in geoconservation could lead to more informed decision-making and enhanced protection of critical geosites.

Objectives

Here, we develop and explore a novel technique for determining the degree of subjectivity in conservation efforts, with a focus on geoconservation, through development of a subjectivity evaluation tool and a subjectivity management framework. The 'subjectivity evaluation tool' was supplemented with a previously developed 'geoconservation toolkit' (Crisp *et al*. 2022a; henceforth referred to as 'the tool') to demonstrate the tool's potential to supplement current strategies and enhance conservation management priorities and outcomes.

Materials and Methods

Study Sites

Mountain environments are usually high in geodiversity and species richness (Antonelli *et al*. 2018; Gordon 2018; Flantua *et al*. 2020; Wang and Dai 2020; Chakraborty 2021). Therefore, many researchers have endeavored to study and conserve mountain environments through assessment of their geoheritage and geodiversity value (Williams and McHenry 2021; Ahmadi *et al*. 2022; Somma 2022; Bollati *et al*. 2023). The Dial Range Residual Ridges geoconservation site (DRRR) near Penguin, Tasmania (Fig. 1) has high scientific, aesthetic and conservation value. In 1996, the DRRR was granted geoconservation status by Tasmanian geologist Chris Sharples (Sharples 1996), but no further studies have been conducted since to assess its status (NRE 2021). DRRR comprises several mountain peaks, with Mt Duncan (680 m, 419140E, 5439189N), Mt Dial (480 m,

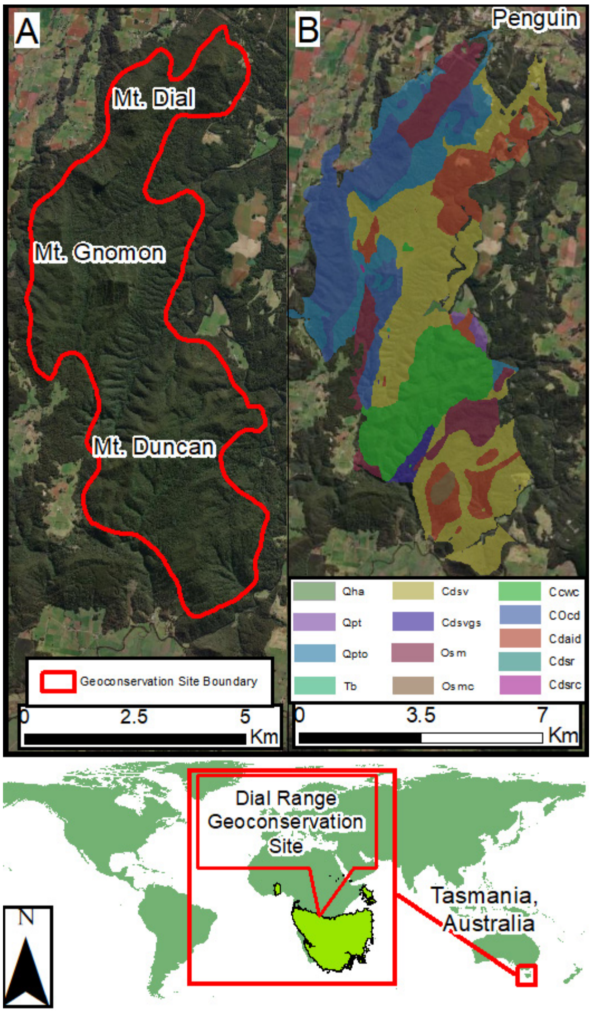

Figure 1. A) Current Dial Range Residual Ridges geoconservation boundary (Data source: (NRE 2021). B) Distribution of geological units across the Dial Range Residual Ridges geoconservation site (Data source: Mineral Resources Tasmania 2014).

419663E, 5442252N), and Mount Gnomon (490 m, 418926E, 5441386N) the focus of this study (Fig. 1A). Geological data from Mineral Resource Tasmania (2014) shows a range of diverse geological elements (Fig. 1B; Table S3). Given the importance of mountain environments and the need for their conservation, the DRRR site with its potential high scientific, aesthetic, and conservation value (Sharples 2002), diverse geological features (Fig. 1B; Table S3), and lack of recent assessments (Sharples 1996; NRE 2021), provides an ideal location to explore and implement the novel subjectivity evaluation tool developed in this study.

Subjectivity Evaluation Tool

The null hypothesis posits that subjectivity cannot be effectively evaluated in geoconservation efforts. To test the null hypothesis, a novel subjectivity evaluation tool was developed (Figs. 2, 3, 4) with seven criteria (C1 to C7) to evaluate the subjectivity of the geoconservation toolkit approach (Fig. 2; Table S1):

• C1: Evaluated using study site relevant keyword searches in Google Scholar, such as Dial Range, Mount Dial, Mount Gnomon, and Mount Duncan.

• C2: The type and context of citations were considered. For example, statements in articles or writing with minimal evidence from the literature were assigned a higher overall subjectivity.

• C3: An ORCID search was undertaken, and if unavailable, a background search was completed using the affiliated institutional profiles of scholars. ORCID provides a unique identifier for researchers, ensuring that published works are consistently attributed to the right individual. Therefore, ORCID was used for its standardized approach to verify researcher credentials, publication histories, and experience.

• C4: Information captured from the evaluation of C3, and a count of contributing authors, was used to inform C4.

• C5: The methodological approach was scrutinized for overall subjectivities, with high subjectivity applied when personal judgement or interpretation was required to determine a ranking assessment.

• C6: Evaluated by considering whether components of the methodological approach alleviated some subjectivity, such as the replacement of personal judgment with GIS, statistical, or other approaches.

• C7: In this study, the nature of inferences was

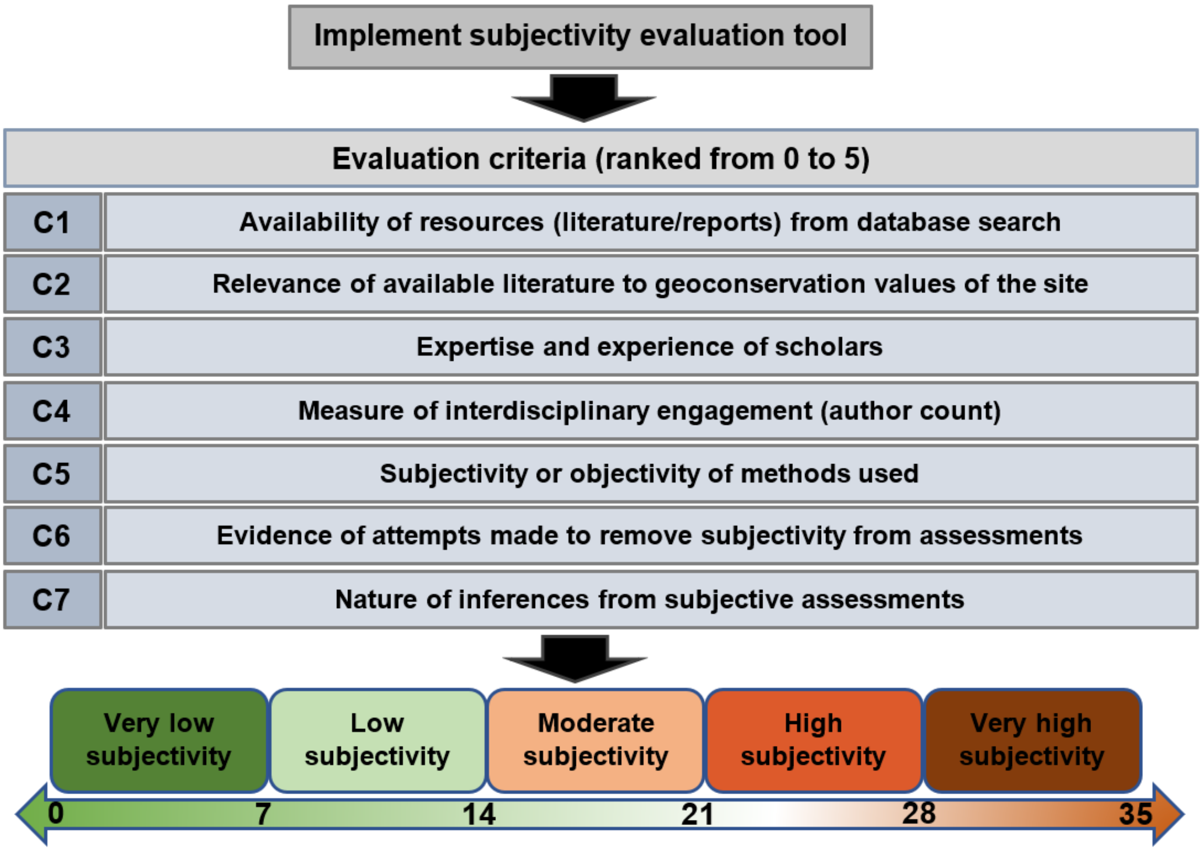

Figure 2. Subjectivity evaluation tool process using evaluation criteria (C1 to C7) for determining degrees of subjectivity in geoconservation strategies or geodiversity assessments.

explanatory and mostly qualitative; hence, higher overall subjectivity was attributed to this criterion.

Subjectivity Evaluation Amalgamation with Geoconservation Toolkit Approach

The tool was amalgamated as an additional step in the Crisp *et al*. (2022a) geoconservation toolkit approach (Fig 3; Fig S1), which used three ArcGIS mobile applications – QuickCapture, Survey123, and Explorer – to consolidate the Serrano and Ruiz-Flaño (2007) geodiversity assessment index and the Brilha (2016) interpretation of a geoconservation strategy to streamline the assessment of geodiversity and geoconservation values. In the geoconservation toolkit approach, ArcGIS Survey123 was used to facilitate both the geoheritage and geodiversity assessments. QuickCapture provided a streamlined interface to capture geodiversity information and locations, while Explorer facilitated field access to pre-established maps and other spatial data.

In this study, the tool replaced the functions of QuickCapture and Explorer with ArcGIS FieldMaps. FieldMaps allowed both viewing and validation of existing geoconservation site boundaries and the acquisition of location data for individual geodiversity components (Fig 4). Like the geoconservation toolkit, in this study Survey123 was also used for the geodiversity assessment, geoconservation strategy, and now the subjectivity evaluation step (Fig 3; Fig S1).

Implementation of the Amended Geoconservation Toolkit Approach

Available sources of information, such as the Tasmanian Geoconservation Database (https://nre.tas.gov.au/conservation/geoconservation/tasmanian-geoconservation-database#AccessingtheDatabase), were explored for relevant information before implementation of the tool (Brilha 2016). A Samsung Galaxy A12 device was used to implement the tool (Fig. 3) given its affordable $150 – $250AUD price range, extended 5000mAh battery life, acceptable camera quality of 48MP, Octa-core CPU and 4GB RAM to sufficiently operate the ArcGIS mobile applications. Future research could benefit from using tablets, such as the Samsung Galaxy Tab series, given their larger screen size for data entry, improved camera quality, and advanced CPU/GPU performance to power applications more efficiently. Details on steps preceding subjectivity evaluation in the tool (Figs 2, 3) are provided by Crisp *et al.* (2022a). The criteria for subjectivity analysis were evaluated at the geoconservation site (Fig. 2); the required detail to rank the criteria effectively (Table S1) was provided in-field by the Survey123 application (Fig. 3).

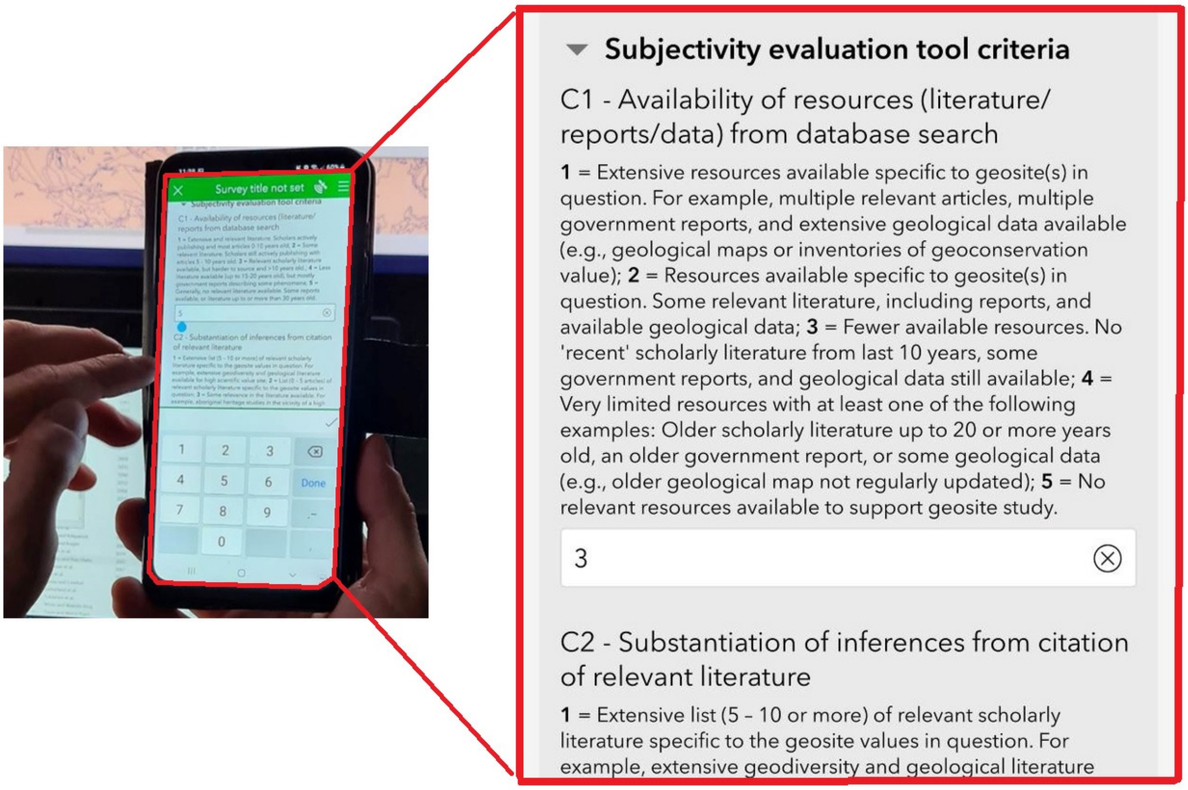

Figure 3. The subjectivity evaluation tool as it appeared using the ArcGIS Survey123 digital application.

The digital version of the Mineral Resources Tasmania (2014) geological map was imported into FieldMaps to help inform attribute population during the in-field spatial acquisition of geodiversity data (Fig. S1). Geodiversity data were captured opportunistically using a randomized observation-based approach previously adopted by Crisp *et al.* (2022a,b), where the sites were explored on foot while simultaneously gathering geological information in the absence of established transects or quadrats. Any incorrect or unverified attributes captured in the field were subsequently amended during analysis (Fig. 4B, C). To assess geoconservation values at DRRR, the geoheritage assessment criteria were ranked from 1 to 5 using the conditions outlined in Table S4.

Subjectivity Management Framework

A subjectivity management framework was developed to provide informed and specific subjectivity mitigation actions for subsequent research

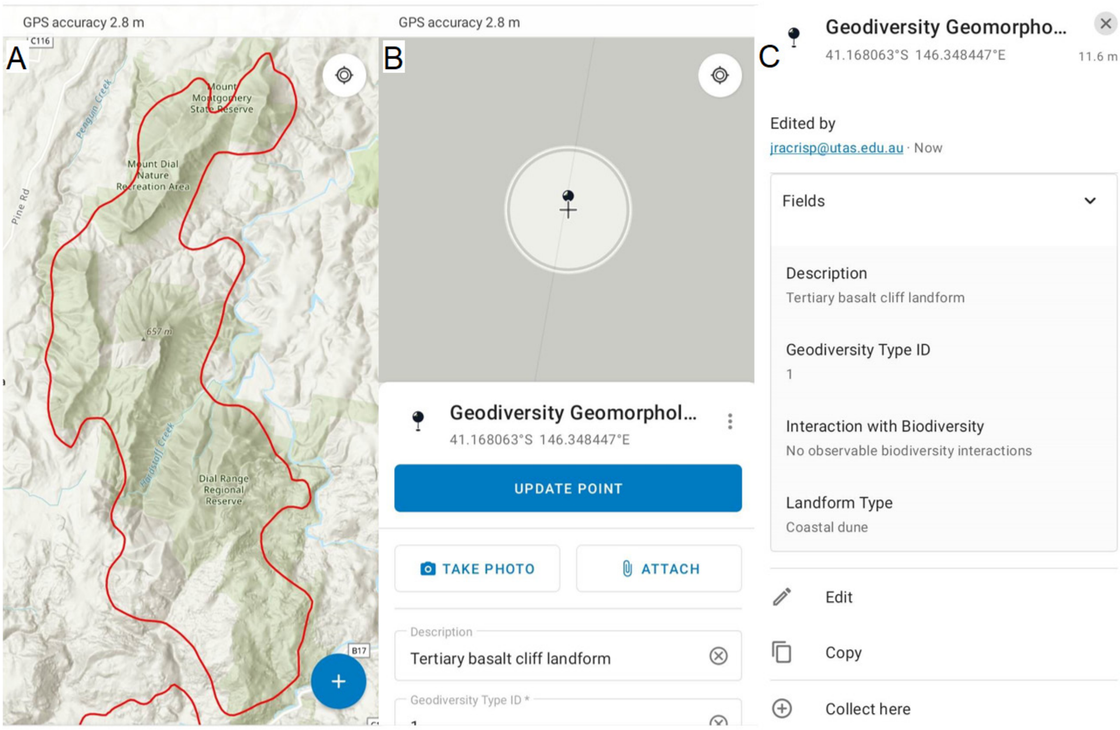

Figure 4. Field Maps used for viewing and validation of existing geoconservation site boundaries and the acquisition of location data for individual geodiversity components A) Geoconservation site boundary as it appeared in the field using ArcGIS FieldMaps B) Screen for capturing geodiversity location and attributes. C) Screen for viewing and editing existing points and attributes.

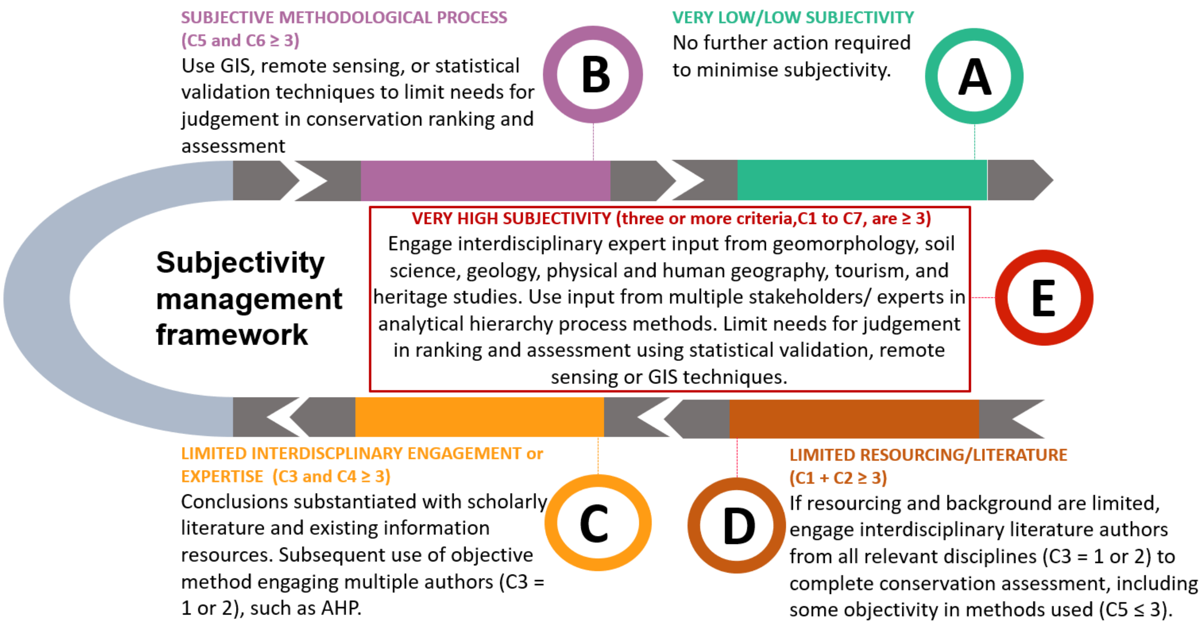

Figure 5. Categorization of management priorities and outcomes for varying degrees of subjectivity based on elevated subjectivity evaluation criteria. Grade E results from three or more subjectivity evaluation criteria exceeding or equal to a ranking value of 3; Grade D results from instances in conservation endeavors with limited relevant resourcing and literature; Grade C results from conservation endeavors with meager interdisciplinary engagement or expertise; Grade B results from conservation endeavors supported by only subjective methodological processes; Grade A results from circumstances were all subjectivity evaluation criteria are below or equal to 2 (Flow chart structure inspired by ©Template Lab design).

(Fig. 5). The grades in the subjectivity framework were developed from the overarching themes observed in the subjectivity evaluation criteria (Fig. 2; Table S1), including subjective methodological processes (C5 and C6 ≥ 3), limited interdisciplinary engagement (C3 and C4 ≥ 3), limited resources or literature (C1 and C2 ≥ 3), or multiple higher subjective factors with three or more high-ranking criteria (C1 to C7 ≥ 3). Mitigation actions for each grade were then proposed. For example, Grade A indicates scenarios with low to very low subjectivity based on all parameters (C1 to C7 in Table S1), with no further management actions suggested. Conversely, Grade E indicates management actions for scenarios with several high-ranking subjectivity parameters (C1 to C7 ≥ 3), including enhanced interdisciplinary engagement or adoption of more objective approaches such as spatial analytical techniques (Crisp *et al*. 2021) or the analytical hierarchy process (Ferrando *et al*. 2021).

Results

Subjectivity Evaluation Tool Outcomes

The subjectivity evaluation tool implemented at the DRRR sites resulted in highly subjective outcomes for geodiversity and geoconservation assessments (Fig. 6; Table S2). There were varying degrees of subjectivity for each criterion, but there was no very low subjectivity or very high

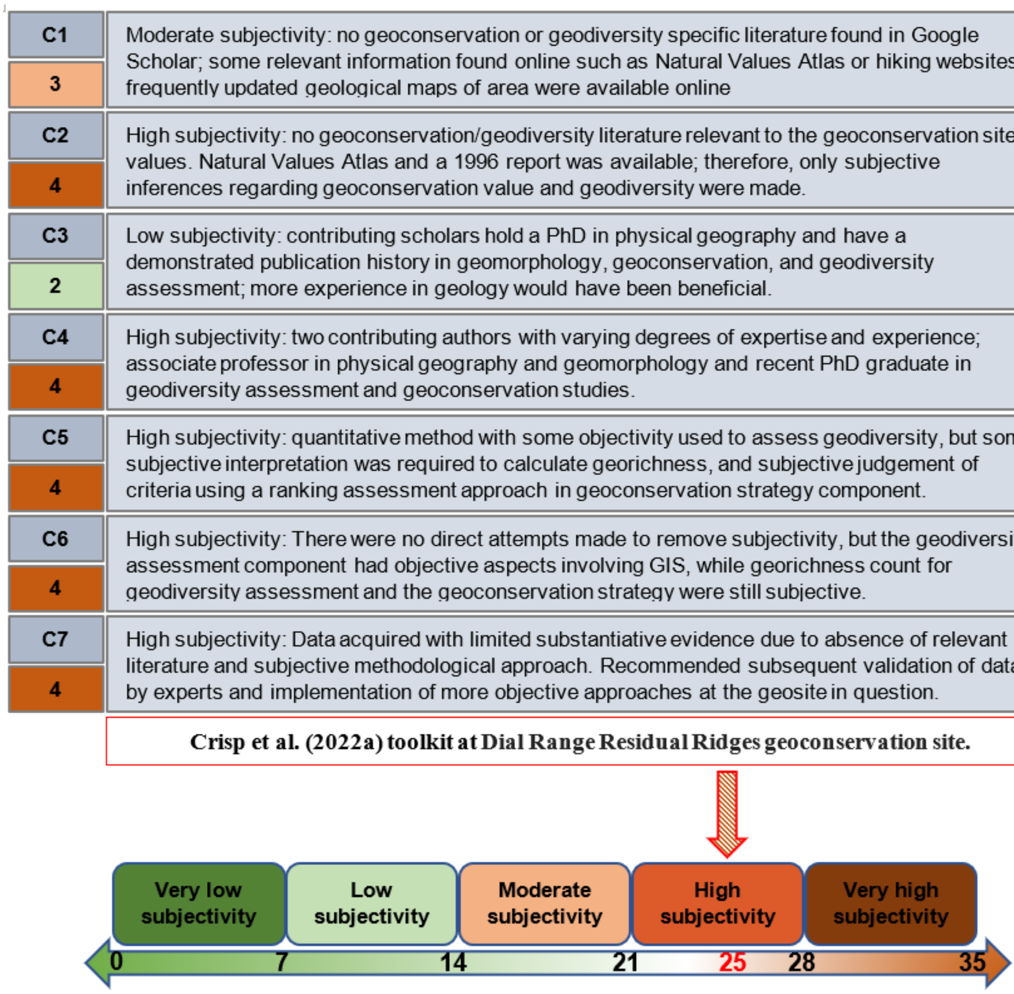

Figure 6. Subjectivity evaluation tool outcome for the implementation of the Crisp et al. (2022a) geoconservation toolkit at the Dial Range Residual Ridges geoconservation site.

subjectivity assigned. C1 and C3 were the least subjective of all other criteria, with relevance of literature (C2), interdisciplinary engagement (C4), and methodological approach (C5–C7) criteria as the most subjective.

Geoconservation Toolkit Outcomes

Geoconservation Value Outcomes The average scientific value was highest for Mt. Gnomon and Mt. Duncan (3.4), and lowest for Mt. Dial (2.1) (Table 1). The scientific value criterion, scientific knowledge, was the lowest ranking for all three sites with a consistent ranking value of 1. Conversely, key locality, was the highest-ranking scientific criterion for Mt. Gnomon, degradation for Mt. Dial, and representativeness and visibility for Mt. Duncan, as its geodiversity features were clear, prominent, and distinctive. Mounts Dial and Gnomon received the highest ranking for the degradation criterion as there was little evidence of human impact, erosion, or weathering, and any degradation would unlikely affect the geoconservation value of the area. Conversely, Mt Duncan exhibited relatively significant degradation attributed to human impacts.

Tourism value was the highest for Mt. Gnomon and Mt. Duncan (3.9) and lowest for Mt. Dial (3.2), related to proximity to tourist facilities, such as other recreational areas, road networks, restaurants or hotels, and urban areas, due to the close proximity of the Penguin township (Table 1). The tourism criteria, safety and availability of information, were the lowest ranking for all three mountains, due to the lack of adequate signage directing tourists to specific paths and information boards about the DRRR site.

The average conservation value was highest for Mt. Gnomon (2.9) followed by Mt. Duncan (2.7) and lowest for Mt. Dial (2.6). The conservation value criteria, settlement proximity and accessibility, were the lowest ranking criteria overall across all sites. Conversely, the level of deterioration and integrity or intactness was the highest ranking. The high value for integrity and intactness at Mt Gnomon reflects the high quality and uniqueness of the features on the mountain that appear relatively unaffected by any human influence.

Geodiversity Assessment Outcomes Mount Gnomon showed the highest geodiversity (Gd) compared to other sites, with a value of 124, followed by Mount Dial with a value of 102 (Table 1). Mount Duncan recorded extensive geological features (Egf) like Mount Gnomon, however, its vast surface area (SA) of 3.92km2 compared to the other sites significantly reduced its geodiversity.

The geographic distribution of Egf across DRRR is illustrated in Fig. 7, with greatest concentration around Mount Gnomon and Mt Dial attributed to their higher overall Gd and low SA. Mount Duncan had all Egf types, with 1 hydrological (H)

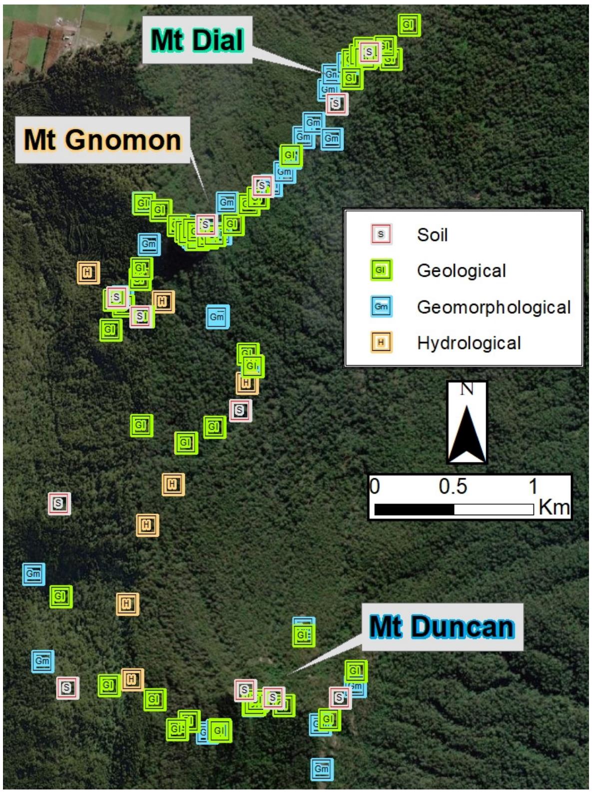

Figure 7. Distribution of geodiversity points at DRRR captured using ArcGIS Field Maps3.3 Subjectivity management framework.

Table 1. Geoconservation assessment criteria ranking outcomes for scientific, tourism, and conservation values for the DRRR.

Value	Criteria	Ranking value		
Scientific criteria		Mt. Gnomon	Mt. Dial	Mt. Duncan
	Representativeness	4	2	5
	Key locality	5	2	3
	Scientific knowledge	1	1	1
	Use limitations	3	2	3
	Visibility	3	1	5
	Ecological interest	4	2	3
	Extensiveness	3	2	4
	Interpretation	4	3	3
	Degradation	4	4	2
	Quality	4	2	4
	Scientific worth	3	2	4
	Average scientific value:	3.4	2.1	3.4
Tourism criteria		Mt. Gnomon	Mt. Dial	Mt. Duncan
	Vulnerability	3	2	3
	Accessibility	4	2	2
	Safety	3	2	2
	Logistics	4	3	3
	Proximity to rec. areas	4	4	4
	Infrastructure and facilities	5	5	5
	Aesthetics	4	2	5
	Viewpoint	4	1	5
	Degradation	5	4	4
	Proximity to restaurant/hotel	5	5	5
	Proximity to urban area	5	5	5
	Proximity to road networks	5	5	5
	Availability of information	2	2	2
	Average tourism value:	3.9	3.2	3.9
Conservation criteria		Mt. Gnomon	Mt. Dial	Mt. Duncan
	Legislative protection	3	3	3
	Ecological influence	3	3	2
	Settlement proximity	1	1	1
	Level of deterioration	4	3	4
	Integrity or intactness	4	3	4
	Accessibility	2	2	2
	Conservation status	3	3	3
	Present use	3	3	3
	Average conservation value:	2.9	2.6	2.7

2 soil and stratigraphy (SS), 4 geomorphological (Gm), and 7 geological (Gl). The two H features counted were the Duncan River (Fig. S2A) and an upstream rock pool (Fig. S2B). Several Gl features were noted around DRRR, including bedrocks of coarse-grained sandstone (Fig. S3B), pebble-cobble siliciclastic conglomerates (Fig. S3A), planar fracturing joints in sandstone

and chert clasts (Fig. S4), and others (Table S3). Various geomorphic features were also observed, including prominent cliffs, mass wasting talus and scree features, fluvial erosion, and evidence of tectonic uplifting events, such as the prominent peaks observed around Mt Duncan (Fig. S5). SS appeared homogenous around DRRR, apparently shallow and rocky in most areas (Fig. S6B) and pale brown with possible low organic matter content (Fig. S6A).

Owing to the high subjectivity of the tool at DRRR based on several high-ranking parameters (Fig. 6; Table S1), the subjectivity framework indicated that Category E management measures were required to mitigate subjectivity for future conservation efforts in subject research. These include interdisciplinary engagement of expert stakeholders using objective hierarchical methods, combined with remote sensing or GIS statistical validation (Fig. 5).

Discussion

We have developed a novel subjectivity evaluation tool and a subjectivity management framework with a focus on geoconservation using the Crisp *et al*. (2022a) geoconservation toolkit approach. As a case study, the novel subjectivity evaluation tool was implemented at a northwest Tasmanian mountain range geoconservation site, the Dial Range Residual Ridges, a previously little studied site.

Exploring Geodiversity and Geoconservation at DRRR

The results of this study indicate that the assessment of geoconservation and geodiversity values at DRRR is highly influenced by subjective factors (Fig. 6), and further research is needed for data validation and substantiation (Fig. 6).

While there is evidence suggesting a connection between geodiversity and biodiversity (Parks and Mulligan 2010; Hjort *et al*. 2012; Bailey *et al*. 2017), and the role geodiversity can play in the functioning of ecosystems and the services they provide (Edwards *et al*. 2014), this relationship remains complex and not uniformly linear across all regions, with other factors like climate and altitude also influencing biodiversity (Read *et al*. 2020; Ren *et al*. 2021). Therefore, the results of the geoconservation assessment (Table 1) could offer reasonable insights into the ecological significance of Mounts Gnomon and Dial, evidenced also by the growing inclusion of geodiversity in conservation endeavors (Comer *et al*. 2015; Pellitero *et al*. 2015; Ren *et al*. 2021). The geodiversity (Table 2) and geoconservation values (Table 1) of an area could also assist stakeholders in making informed management decisions. For example, areas with high geodiversity that are also vulnerable to human influence and degradation warrant priority conservation over regions with high geodiversity but minimal human impact (Crisp *et al*. 2022a).

Subjectivity Assessment and Reporting

The scarcity of recent and relevant literature regarding the DRRR site (refer to C1 and C2 in Fig. 6) heightened the subjectivity of the study (Fig. 6). The lack of reference materials resulted in a strong reliance on individual interpretations and judgments, which may have introduced bias or impeded the ability to compare and validate the results (Pereira *et al*. 2007; Brilha 2016; Dede and Zorlu 2023). The evaluation of geoconservation and geodiversity involves interdisciplinary input from fields such as soil science, geomorphology, geology, hydrology, and physical and human geography. However, the limited involvement of experts from multiple disciplines in the implementation of the tool (refer C4 in Fig. 6) further compounded overall subjectivity. Therefore, further study could benefit from a more diverse range of expert perspectives (Bruschi *et al*. 2011; Ferrando *et al*. 2021). The Crisp *et al*. (2022a) method required

Table 2. Geodiversity parameters and values for Mounts Dial, Gnomon, and Duncan.

Value	Parameter sub-type	Geodiversity parameter
		Mount Gnomon
15		Number of geological features (Egf)
10	Geological	
4	Geomorphological (erosional or accumulation landform)	
0	Hydrological	
1	Soil and stratigraphy	
4		Roughness (R)
1.62		Surface area km2 (SA)
124	Total geodiversity:	Geodiversity (Gd)
		(Very high)
		Mount Dial
10		Number of geological features (Egf)
7	Geological	
2	Geomorphological (erosional or accumulation landform)	
0	Hydrological	
1	Soil and stratigraphy	
4		Roughness (R)
1.48		Surface area km2 (SA)
102	Total geodiversity:	Geodiversity (Gd)
		(Very high)
		Mount Duncan
14		Number of geological features (Egf)
6	Geological	
4	Geomorphological (erosional or accumulation landform)	
2	Hydrological	
	Soil and stratigraphy	
	2	
3		Roughness (R)
3.93		Surface area km2 (SA)
31	Total geodiversity:	Geodiversity (Gd)
		(Medium)

significant personal judgment to rank and evaluate geoconservation criteria (refer to C5 in Fig. 6). To reduce this subjectivity, alternative more objective methods, such as the Bruschi *et al*. (2011) method, which uses statistical techniques to validate experts' criteria rankings in geoheritage assessments, or the Ferrando *et al*. (2021) method, which employs the analytical hierarchy process to incorporate expert insights into geodiversity assessments, could be adopted (refer to C6 in Fig. 6). Therefore, the evaluation tool indicated high subjectivity for all parameters except criterion 2 (refer C1–C7 in Fig. 6), thus reducing confidence in the inferences (refer C7 in Fig. 6) regarding geodiversity and geoconservation values at DRRR. Future research is therefore required to validate data acquired, otherwise there is possibility that high subjectivity (Fig. 6) could result in important areas within DRRR, geoconservation values, or geodiversity elements being overlooked due to ambiguity in criteria, personal biases, and lack of transparency in methods (Brilha 2016; Mucivuna *et al*. 2019).

Enhanced Geoconservation Management and Future Research Directions

The highly subjective tool implemented at DRRR attributed to several high-ranking parameters (Fig. 6; Table S1), necessitates the use of Category E management measures to address the significant subjectivity concerns (Fig. 5). The framework suggests adoption of extensive interdisciplinary collaboration involving experts in Tasmanian geology, geoheritage, and related fields. Furthermore, subsequent research recommends the adoption of more objective methodological approaches. Hence, a comprehensive approach that integrates spatial analytical tools, remote sensing, and field mapping techniques could serve as a reliable and objective means of future research (Stepišnik and Trenchovska 2018). Overall, the evaluation tool (Fig. 2) and framework (Fig. 5) have provided a clear pathway for transition from Category E subjective management measures to Category A in subsequent research. Therefore, achieving Category A in subsequent research at DRRR could mean reduction in the degree of individual judgement and therefore bias in decision-making (Pereira *et al*. 2007; Brilha 2016; Dede and Zorlu 2023), increased clarity in decisions for conservation priorities and planning (Brilha 2016; Mucivuna *et al*. 2019), and increased confidence in data used to substantiate conservation decisions (Burgman 2001; Margoluis *et al*. 2009; Cook *et al*. 2010; Cook and Hockings 2011; Carranza *et al*. 2014; Datta and Sarkar 2019; Datta 2020).

There are several avenues for research related to the subjectivity evaluation tool and management framework. Firstly, further research could explore the impacts of stakeholder engagement on reducing subjectivity in assessments. Secondly, additional studies could examine the impacts of temporal and spatial scales on subjectivity, particularly about the assessment of geodiversity and geoconservation. Thirdly, research could investigate the role of uncertainty in subjectivity in conservation decision-making, particularly in situations where there is limited data or incomplete knowledge of the site. Lastly, future studies could apply the subjectivity evaluation tool and management framework to other fields beyond conservation, such as urban planning or environmental management. In addition, further expert input, in the form of a technical working group or conference, could investigate the intricacies within each parameter and then amend accordingly based on overall consensus. For instance, qualifications and experience are commonly used to evaluate expertise and knowledge, as was also the case in C3 of the evaluation tool (Fig. 2; Table S1). However, such criteria may not always reflect the reliability and consistency of individual judgements (Cooke and Goossens 2008; Martin *et al*. 2012). Thus, seeking consensus and input from experts through further review of the tool could help address any underlying complexities in the criteria used to determine subjectivity, such as the expertise of evaluators.

Conclusion

This study developed a novel subjectivity evaluation tool and management framework with a focus on geoconservation using the Crisp *et al*. (2022a) geoconservation toolkit approach, at the northwest Tasmanian Dial Range Residual Ridges geoconservation site. The results of this study demonstrate that the subjectivity evaluation tool was successful in identifying factors hindering geoconservation management outcomes. The geoconservation toolkit showed high geodiversity values for Mounts Gnomon (124) and Dial (102), while

Mount Duncan had moderate values (31). Mounts Gnomon and Duncan ranked highest overall for scientific (3.4, 3.4), tourism (3.9, 3.9), and conservation (2.9 2.7) values. However, the subjectivity evaluation tool showed that the assessment of geodiversity and geoconservation was highly influenced by subjective factors, including the absence of recent and relevant scholarly literature, limited interdisciplinary engagement, and subjective personal judgment. Therefore, the framework showed that Category E management measures of interdisciplinary engagement of expert stakeholders using objective hierarchical methods, combined with remote sensing or GIS statistical validation were required to mitigate the high degree of subjectivity of the tool at DRRR. To achieve Category A in subsequent research, the framework recommended several steps such as engagement of experts from multiple interdisciplinary backgrounds for future assessments, as well as the adoption of methods which reduce the degree of individual judgment, such as remote sensing and GIS. The subjectivity evaluation tool and management framework developed has global implications, for improvement in subjectivity management in geoconservation assessment, to allow better alignment of comparisons between practitioners and sites.

Authors' contribution:

Jake Crisp (70%) - Conception of idea, research planning including fieldwork, figure production, and writing, and preparation of manuscript for submission in Geoconservation Research.

Joanna Ellison (30%) - Review the manuscript, addition of some references, and rewrite some areas of the manuscript ready for publication.

Conflict of interest statement

The authors declare that there are no conflicts of interest associated with this study.

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