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# Managing Tourism and Environment—Trail Erosion, Thresholds of Potential Concern and Limits of Acceptable Change

**Deirdre Dragovich * and Sunil Bajpai**

School of Geosciences, University of Sydney, Sydney 2006, Australia; sunil.bajpai@sydney.edu.au
* Correspondence: deirdre.dragovich@sydney.edu.au

**Abstract:** Natural area tourism may contribute to deterioration in biophysical environments important for sustainable conservation of biodiversity and/or historically significant sites. Levels of protection within the IUCN guidelines provide general descriptors of desirable outcomes, and the Limits of Acceptable Change (LAC) management tool has often been implicitly applied. This article presents an initial attempt to assess the value of Thresholds of Potential Concern (TPC) relative to LAC as management frameworks for protected areas, using the example of trail width as an indicator of visitor impacts on vegetation, soil, water and, potentially, visitor safety. Visitor preferences relating to trail width were incorporated when applying the TPC and LAC principles. Sections of three walking trails in a high-visitation national park near Sydney, Australia, were measured at ~10.7 m intervals: the mean trail widths were 1.6 m, 1.8 m and 2.14 m. Of the 115 recreationists surveyed, 16% of those having the greatest tolerance towards management interventions ('Non-purist' wilderness category) viewed a trail $\geq$ 2 m wide as acceptable, but 96% of 'Purists' nominated a maximum of $\leq$1.5 m. The TPC was found to provide a broad strategy for identification, assessment and grading of multiple biophysical thresholds within an ecological framework. Combined with stakeholder information, the TPC allows for timely, proactive and calibrated management responses to maintaining biophysical and social sustainability.

**Keywords:** protected areas; trail width; national park management; visitor preferences

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## 1. Introduction

A key challenge in protected area management is balancing tourism with conservation objectives [1–3]. Sustainable tourism is defined as 'tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities' [4], a definition that includes an ambitious array of interested parties. Protected areas present special challenges when used as destinations for nature tourism. Potential conflict may emerge between tourist demands (visitor satisfaction), tourist expenditure (financial benefits), management (visitor numbers and behaviours) and overall social/political objectives (biodiversity, national tourism targets), a set of incompatibilities which are ably highlighted by [5]. Sustainable tourism management attempts to ensure that visitors continue to enjoy a destination while not causing serious deterioration to biophysical/human environments or the living conditions of local people. While laudatory, such intentions may encounter practical realities in the form of policies designed to maintain or increase tourist numbers, and thus the financial returns they generate (e.g., [6]), without clearly addressing potential damage to the biophysical environment. Such a tourism/environment imbalance may be unintentional, a result of neglect or a deliberate choice between political, social or economic priorities. Regardless of the process, protected areas become less protected and potentially less sustainable.

Protected areas are generally designated in legislation and are clearly defined spaces that may include national parks, reserve areas, nature reserves and wilderness, within which the 'long-term conservation of nature with associated ecosystem services and cultural values' is recognized [7]. Although all protected areas contain biological, physical or human features worthy of conservation, different levels of protection are afforded to specific areas following the broad categories outlined by [8]. Areas in the highest category have the greatest protection (nature reserves and wilderness areas), with national parks in the second category, followed by natural monuments/features and habitat/species management areas in the third and fourth categories, respectively. Lower categories of protected areas incorporate a dominance of the combined interaction of people and nature which together create special values. Within these six major categories, the implementation of protection varies within and between countries, as management practices are influenced by cultural values, management attitudes and training, national and local policies, financial constraints and the nature of environments and visitors being managed. Each of these interacting biophysical and human/social systems provide further complexity by changing over time.

Diversity characterizes the nature of protected areas and thus the management approaches adopted. Visitor movements interact with the biophysical environment through trails which provide essential access routes for walkers (and bike- and horse-riders and recreational and park vehicles [9,10], where these are permitted) in national parks and other protected areas. Some walking trails are formally constructed while others are informal lines of movement where people create a direct route to a desired destination or seek to avoid uncomfortable or dangerous surfaces such as ponded water or eroded or stony ground [11–13]. Both formal and informal trails can have undesirable biophysical outcomes, including the direct effects of habitat-fragmenting 'corridor' creation, compaction of loamy soils, churning of sandy soils, wind and water erosion and trampling of vegetation in addition to the indirect effects of littering and its accompanying negative aesthetics and chemical pollutants, as well as visitor noise causing disturbance to birds and animals [14–20]. The overall effect of visitation may endanger the ecological functioning of the protected area; thus, considerable attention has been given to trail management, especially trail erosion in protected areas having high visitor numbers and minimal interventions in terms of constructed walkways or conservation measures (e.g., [21–26]).

Addressing these issues, 'carrying capacity' was a visitor management tool recommended in the 1960s [27,28] and more recently [29]. Numerous management frameworks have since been proposed and applied [30], including the Limits of Acceptable Change (LAC) and, less commonly, the Thresholds of Potential Concern (TPC). For national parks in particular, these approaches have not been compared when both biophysical and social inputs have been explicitly incorporated. In this initial attempt to investigate TPC principles in relation to trail management in a high-visitation, near-metropolitan national park, a physical attribute—trail width—was considered in conjunction with a social variable, namely, visitor preferences relating to this attribute, in the Royal National Park (RNP) near Sydney, New South Wales (NSW), Australia. Using this example, the aim was to evaluate whether the ecologically based TPC would provide a more effective management tool for sustainable tourism in national parks than LAC, a commonly used framework.

*Management Frameworks for Protected Areas—LAC and TPC*

'Carrying capacity' links undesirable impacts to excessive visitor numbers, and a reduction in visitation was the expected management response. Although this approach translates to different tourist numbers at different times in different environments, carrying capacity remains a useful concept for facilities provision (e.g., car parks) and in visitation to fragile cultural and physical environments such as limestone caves (e.g., [31–33]). In other more physically resilient environments, a systems perspective to managing visitor numbers can be adopted, and tourists' perceptions of crowding limits can also be incorporated [34].

Although the carrying capacity framework has limitations, its focus on adverse visitor impacts provides a foundation which has been incorporated and extended to identify (LAC and TPC) and predict (TPC) unacceptable levels of change.

The widely applied LAC management framework includes a nine-step process intended to minimize detrimental environmental impacts and was initially devised for application in wilderness areas [35]. Subsequently, it has been used in other settings such as wetland management [36,37] and marine farming [38]. The framework involves stakeholders' cooperation in the setting of acceptable limits, a key step involving challenges in both identifying and agreeing on a baseline condition from which often difficult-to-determine thresholds are measured. Where circumstances change or increased knowledge allows the setting of new thresholds, modified limits can be adopted and incorporated. This flexibility and adaptive management approach is emphasized by the circular nature of the original LAC planning system diagram [39], in which the final step relates to implementation and monitoring. Such monitoring may prompt a re-evaluation of issues and a recommencement (step 1) within the circular management framework. Cole and McCool [35] noted that four conditions need to be met for the framework to be appropriate, namely, conflicting management goals, compromise between issues, a hierarchy of goals and the identification of minimally acceptable change for each issue or goal. If any of these conditions cannot be met then LAC is not a suitable management framework. In general, LAC is often applied in response to existing problems but, once implemented, may subsequently act as a 'benchmarking' tool for managing protected areas. Although absolute limits could theoretically be supplemented by sub-limits warning of an approaching absolute value, in practice, resource constraints are often insufficiently flexible for such a 'predictive' process to be relevant.

The TPC framework involves four main components, commencing with setting the desirable ecological condition taking into account social, technological, economic, environmental and political values and goals. This first step incorporates a group of thresholds for key indicators which together provide a graded response to changed conditions. Originally proposed for assessing ecological condition and therefore addressing complex systems involving multiple attributes with differing responses to a given disturbance [40,41]. This gradation of threat or risk before the ultimate threshold is reached is a useful mechanism for protecting natural systems from serious or irreversible damage. If carefully designed, these thresholds provide a signal of deteriorating conditions which can be responded to before a critical point is reached, thereby ensuring sustainability. Flexibility is provided within the potential change framework by the ability to incorporate multiple thresholds relating to specific components of the ecological system. As with LAC, it is necessary to identify each disturbance threshold but, in addition, to view these thresholds as non-linear and interacting. This initial step in TPC is followed by the three components of management options, operationalization and evaluation and learning, each of which provides feedback to other components within the framework. As scientific or community knowledge increases, the thresholds of concern may be reset in a process of strategic adaptive management (e.g., [42,43]), and conservation policies are now likely to incorporate the social and economic benefits gained for improvements to the health and well-being of visitors to protected areas [44]. Conallin et al. [45] emphasized that the TPC framework requires ongoing participatory decision making to be effective in managing ecological issues.

Pre-requisites for the effective application of both LAC and TPC in relation to trails are the availability of relevant environmental and visitor data and experienced analysts to interpret thresholds. For both frameworks, a 'threshold rating' system is required to determine at what point management intervention is not only desirable (TPC) but essential (TPC and LAC). TPC, as an environmental framework, has been applied in the management of wetlands [37] and grazing in rangelands [46], so its structure is flexible and relevant in diverse ecological situations. Its adoption either separately or in conjunction with LAC would encourage greater attention being given to incorporating biophysical parameters in protected area management. Both TPC and LAC involve the consideration of the policy context within which management operates and the ways in which these structures interact with visitor impacts and perceptions. Although no official management framework is specified for national parks in NSW, the policy ideals relating to sustainable tourism and protected areas follow international guidelines (e.g., [47–49]). The aim of this paper is to investigate the potential for applying TPC principles to enhancing conservation through trail management using trail and visitor data in RNP near Sydney, Australia.

## 2. Materials and Methods

### *2.1. Study Area*

RNP borders metropolitan Sydney and was established in 1879; it has since expanded to cover an area of about 15,000 ha. As well as containing more than 1000 plant species including some which are nationally rare or threatened, the Park provides protection for native animals, birds and other fauna [50]. National parks in NSW are popular destinations with domestic visits increasing from nearly 34 million in 2010 to 60 million in 2018, of which about 6 million visits were to RNP [49]. Within RNP, walking trails of varying lengths and degrees of difficulty attract recreationists with diverse interests including hiking, swimming, fishing, sight-seeing, canoeing, photography, bird-watching, picnicking and bike riding.

### *2.2. Trail Measurements*

#### 2.2.1. Trail Width

Trail width is used here as an indicator of mainly trampling-generated erosion accompanying visitation. To ensure compatibility between visitation and trail information, investigated trail sections included only those which were used by walkers, had not been sealed and did not form part of a fire trail network. Measurements of trail width were recorded at 20-step intervals (approximately 10.7 m intervals) along parts of three access trails in areas where visitor surveys were also conducted. This distance-based measurement technique has been used elsewhere on long walking trails using 20 m recording intervals (e.g., [51]). Trail width was measured with a tape stretched taut and pinned between the edges of bare ('core' path) or nearly bare (trampled ground on either side of the trail). Trail 1 is used by both visitors and local communities, as is Trail 2, which additionally is popular with mountain bike riders. Less well-known and less visited is Trail 3, located within a State Conservation Area within the Park. Due to minimal use and substantial plant litter cover, definition of this trail was poor in some sections and a notional width (between beside-trail undergrowth) of 1 m was recorded. All assessed trail sections were less than about 600 m in length.

#### 2.2.2. Trail Erosion

Eroded sections of trails were of varying lengths and were defined as those having an incised depth exceeding 5 cm when measured vertically below a width-measuring pole placed beside the pinned tape at each 20-step interval. Where visually identifiable eroded sections were noted between the 20-step interval, they were also recorded. In contrast, not every non-eroded segment was measured as similar conditions were observed on these segments: Instead, 4 non-eroded sections of ~10.7 m (20 steps) in length were measured for each trail. Erosion at each site was calculated using the Cross-Sectional Area (CSA) method [52–54], in which depth to the ground below taut strings at the upper, middle and lower ends of each eroded section was measured at 20 cm intervals (using a measuring pole) across the width of the trail. For each site, these three sets of width/depth measurements were averaged to obtain the cross-sectional area. This value was then multiplied by the site length, and soil loss was recorded as $m^3$ per $m^2$. Data were obtained for a total of 24 sites (12 non-eroded sites and 12 eroded sites).

### 2.3. Visitor Survey

Visitors using walking trails are unlikely to hold uniform views about desirable trail widths, as their perception of an acceptable width is partly dependent on their past experience as well as their expectation of conditions and facilities within national parks. A total of 115 visitors provided responses to a survey which included the following question:

*When people walk along trails in a Park they sometimes step sideways and trample adjacent vegetation making the trail wider. As a result, vegetation loss and widening of trails is an inevitable use impact. How much trail widening do you think is reasonable and acceptable as a recreational impact?* Response choices: *On average a walking trail should not exceed: 1 m in width; 1.5 m width; 2 m width; 4 m width; doesn't matter.*

Survey information allowed respondents to be grouped according to a wilderness perception measure [55–57]. Although wilderness is a concept that has eluded precise definition [58], and visitors' views may diverge from those of management [59], it is possible to delineate a natural area as wilderness by focusing on attributes such as remoteness, lack of artifactualism, naturalness and solitude, which are translated into managerial and social settings that are deemed by 'Purist' visitors as essential qualities of a wilderness ([57], Figure 1). In our study, the Purism quantification process involved allocating points (using the Likert 1 to 5 scale model) for each response with the final Purism score of each respondent being the sum of points scored for all the wilderness-related questions. The maximum score achievable was 95 and the minimum, 19 (representing 19 Likert-scored questions—Figure 1). This followed the graded scoring system used by [55,57,60,61], in which the relatively least sensitive response was assigned a score of 1 and the most sensitive response, representing the more 'pure' and discriminating, was assigned a score of 5. All questions were assigned equal importance within the Purism determination process. Refs. [57,62] segregated Purism scores into four categories of wilderness perception: Purist, Moderate Purist, Neutralist and Non-purist. In the present study, Kliskey's [57,62] original four-category purism scoring based on a sample size of 233 could not be used due to our smaller sample of 115 and the distribution of scores in which very few respondents could be classified as Non-purist. Purism scores were thus sorted in a descending order, and individuals with responses in the top 20% were assumed to represent the 'Pure' group of surveyed visitors; individuals with the next highest 30% of scores were classified as Semi-pure; and the remaining 50% of respondents constituted the Non-purist visitor group.

As application of TPC to trail management would require the consideration of more than a single biophysical variable such as trail width, results of Likert-scaled visitor attitudes to solitude, human litter and non-native vegetation have also been summarized (Results: 3.3) to provide a more realistic context for management responses.

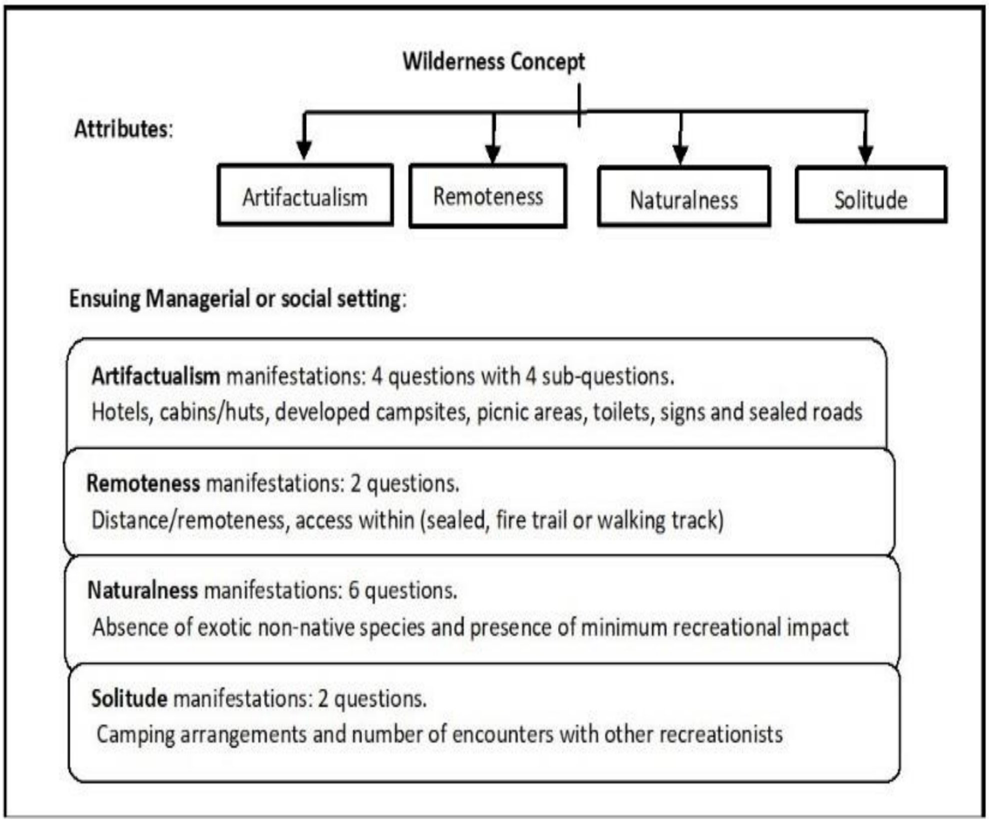


**Figure 1.** Wilderness concept and attributes translated into managerial and social settings (n = 18 questions and an additional question on 'definition of wilderness') in RNP. Listing of specific wilderness attributes is provided in [63], Table 1, p.86. Source: Based on [55,57].

**Table 1.** Maximum trail width (% of width measurements, rounded to nearest whole number).

| Trail Name | Max. ≤ 1 m | Max. 1.5 m (>1 ≤1.5 m) | Max. 2 m (>1.5–≤2 m) | Max. 4 m (>2–≤4 m) | No Max. (>4 m) | All Measurements > 1.5 m |
|---|---|---|---|---|---|---|
| Trail 1 | 0 | 12 | 48 | 34 | 6 | 88 |
| Trail 2 | 12 | 20 | 37 | 32 | 0 | 69 |
| Trail 3 | 53 | 33 | 13 | 0 | 0 | 13 |

## 3. Results

### *3.1. Measured Trail Width*

Widths varied both between and within measured trails (Figure 2), with average widths of 2.14 m, 1.8 m and 1.01 m recorded for trails 1, 2 and 3, respectively. Even though maximum and minimum width values differed widely between trails, the coefficient of variation for measurements was similar for each (37.4, 35.6 and 40.3%, respectively).

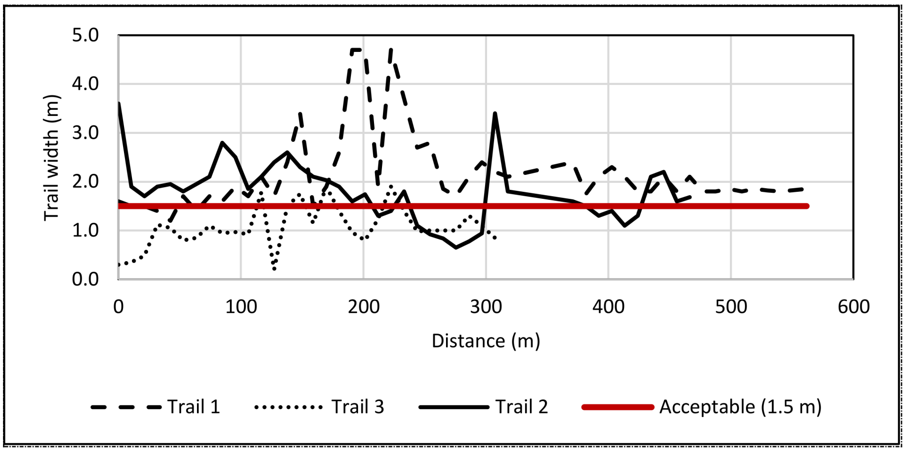


**Figure 2.** Width measurements of three studied trails in RNP. 'Acceptable' refers to the average visitor result.

When recorded measurements were grouped according to the maximum width categories used in the visitor survey question, the widest trail on average (Trail 1) had no measured sections of <1 m, with most widths (48%) being between 1.5 and 2 m and 6% exceeding 4 m (Table 1). Average widths of the other two trails were lower, with no values exceeding 4 m and between 12% (Trail 2) and 53% (Trail 3) of widths recording <1 m.

### 3.2. Trail Erosion

Trail width and soil loss were greater in sections visually identified as being eroded than on non-eroded sites for each of the studied trails (Table 2 and Figure 3). Within the eroded sites, soil losses varied considerably for any given trail width, while for non-eroded sites erosion losses remained consistently lower across a wide range of trail widths.

**Table 2.** Mean lengths, widths and soil loss of eroded and non-eroded sites on 3 trails, RNP.

| Trail | Eroded | | | Non-Eroded | | |
|---|---|---|---|---|---|---|
| | Site Length (m) | Site Width (m) | Soil Loss ($m^3/m^2$) | Site Length (m) | Site Width (m) | Soil Loss ($m^3/m^2$) |
| Trail 1 | 8.5 | 1.57 | 0.095 | 10.7 | 1.49 | 0.017 |
| Trail 2 | 14.7 | 2.08 | 0.130 | 10.7 | 1.40 | 0.023 |
| Trail 3 | 9.5 | 1.37 | 0.063 | 10.7 | 0.95 | 0.018 |

### 3.3. Trail Width and Visitor Survey

The average maximum acceptable trail width for the 115 respondents was 1.5 m (70%), with >90% nominating a maximum width of 2 m (Table 3). When the average maximum value of 1.5 m was applied to measured widths, the two trails with the highest average widths (Trail 1 and Trail 2) exceeded visitors' acceptable limits. Of the three studied trails, only Trail 3 met the accepted average suggested by the visitor survey (Figure 2). The proportion of measured widths meeting the 1.5 m maximum was 87% for Trail 3, but only 31% for Trail 2 and 12% for Trail 1.

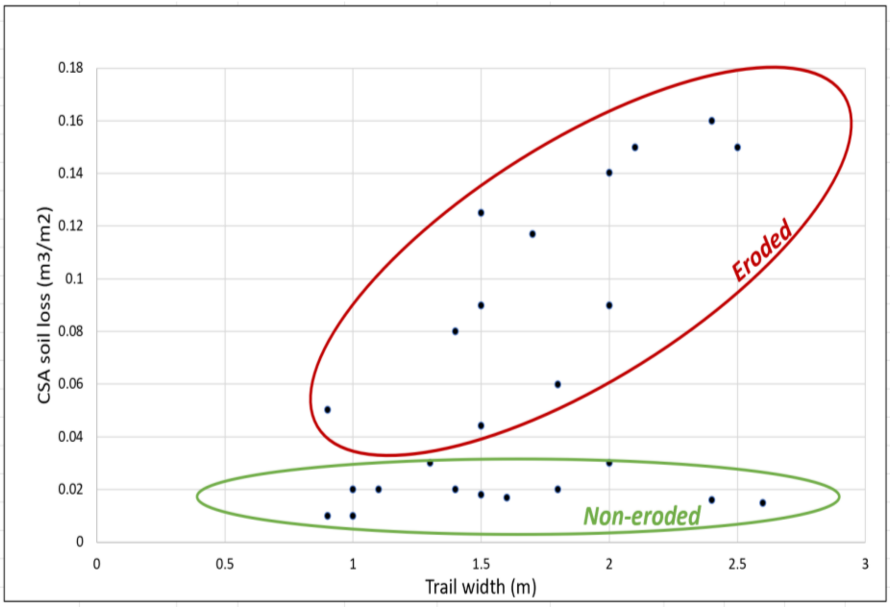


**Figure 3.** Width and cross-sectional area (CSA) soil loss on three studied trails, RNP.

**Table 3.** Maximum acceptable trail width: % survey respondents by wilderness perception category.

| Wilderness Perception Category | Max. Width = 1 m | Max. Width = 1.5 m | Max. Width = 2 m | Max. Width = 4 m | Does not Matter |
|---|---|---|---|---|---|
| Pure | 40 | 36 | 20 | 4 | 0 |
| Semi-pure | 33 | 52 | 15 | 0 | 0 |
| Non-purist | 18 | 40 | 26 | 5 | 11 |
| **All respondents** | **27** | **43** | **22** | **3** | **5** |

Differences in responses between the various wilderness perception groups were evident, with Non-purists being the most accepting of maximum widths exceeding 1.5 m (42%), compared with only 15% of the Semi-pure group (Table 3).

The pattern of average responses to wilderness attributes of trail width, solitude, litter and non-native flora showed that the variables of trail width and litter peaked closer to the Pure position (Likert scale 4) while the variables of solitude and non-native flora shifted towards the Semi-pure (Likert 3) (Figure 4). However, wide differences in attitudes between the Pure and Non-purist groups were evident, with 38% of Purists scoring solitude, for example, at Likert scale 4–5 compared with only 14% of Non-purists. In relation to litter, the Likert 4–5 comparison was 42% for the Pure group compared with 16% for the Non-purists.

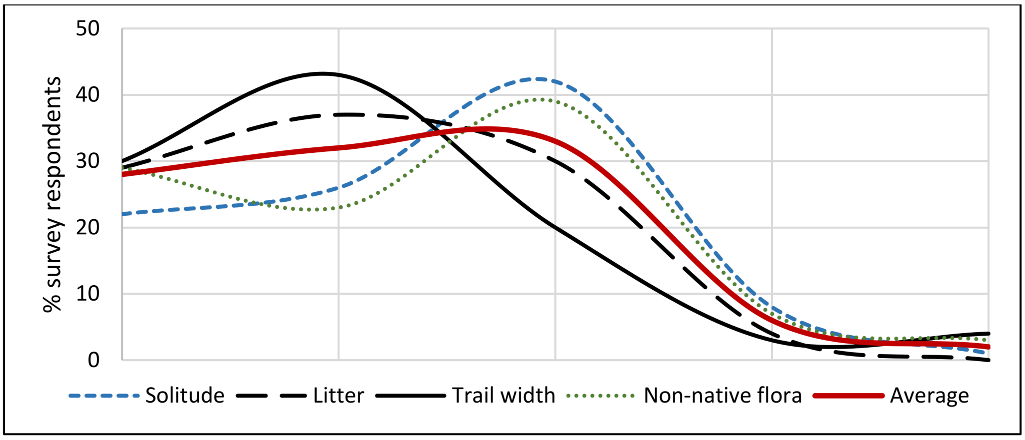


**Figure 4.** Response of all surveyed visitors to four wilderness attributes (averaged to Likert scale 5–1, from left to right).

## 4. Results

### *4.1. Trail Widths and LAC*

The assumption in this study is that soil erosion on trails is a biophysical and social problem and application of the LAC management framework is a potential response to these concerns. Used as an example, trail width information from RNP can be incorporated within the nine steps of the LAC model (Table 4). In Step 1, soil erosion on trails will be visible as bare ground and trampled near-path vegetation, some aspects of which may be deemed to adversely affect visitor safety and satisfaction. The use classes in Step 2 only partly relate to spatially defined areas for specific activities, as visitors to RNP have access to all areas, and uses are not mutually exclusive. For example, heritage items such as aboriginal rock drawings or engravings are reached by walking trails, and this activity could be labelled as either 'heritage' (the drawings or engravings themselves) or 'recreation' (walking to the drawing or engravings), or both. Regardless of precise definitional issues, the interaction between visitor activities and biophysical impacts in Steps 2 and 3 leads to Steps 4–6, which require management to engage in establishing an inventory and defining biophysical and social standards for acceptable change in each use. Step 7 involves reconciling current indicators for trail condition (Step 3) with specified standards (Step 5). Following confirmation of management actions to remediate existing conditions to standards, these actions will be implemented and monitored. The LAC model thus involves multiple physical, social, political and legal considerations and levels of decision making, with stakeholders including tourists, park managers, government departments and policy makers influencing the existing biophysical, ecological and heritage attributes of a protected area.

**Table 4.** LAC model, applied in a national park having trail erosion (case study of RNP).

| LAC Steps | Biophysical Aspects | Social Aspects |
|---|---|---|
| Step 1—identify concerns and issues | ■ Soil erosion on trails<br>■ Near-trail vegetation loss | ■ Visitor safety on trails<br>■ Visitor walking comfort<br>■ 'Unnatural' aesthetic |
| Step 2—describe use classes | ■ Conservation, heritage, recreation, education | ■ Visitor activities |
| Step 3—indicators for use classes | ■ Trail width/depth<br>■ Off-site sedimentation<br>■ Wildlife disturbance | ■ Visitor satisfaction |

**Table 4.** *Cont.*

| LAC Steps | Biophysical Aspects | Social Aspects |
|---|---|---|
| Step 4—inventory | ■ % trails acceptable width<br>■ Location of 'unacceptable width' sections | ■ Visitor/management definition of acceptable trail widths |
| Step 5—specify standards | ■ Trail width<br>■ Remediation needed? | ■ Visitor satisfaction<br>■ Assess walking surface |
| Step 6—identify all use classes (from Step 2) | ■ Conservation—soil, vegetation<br>■ Heritage—visitor numbers<br>■ Recreation—walking or multi-purpose?<br>■ Education—as for conservation, plus heritage | ■ Collect trail use information for all visitor types |
| Step 7—identify actions needed for use classes | Compare Step 3 (current) with Step 5 (standard) | Are current trail conditions acceptable? |
| Step 8—select management actions for use classes | ■ Install raised walkways?<br>■ Harden trail surface?<br>■ Re-locate/close trail sections?<br>■ Restrict visitor numbers/uses? | ■ Connectivity of access routes<br>■ Key activity and use destinations |
| **Implementation? = financial/resources barrier?** | | |
| Step 9—implement and monitor management actions | ■ Non-congruent international, national, State government policies (tourism, biodiversity, conservation)<br>■ Financial/human resource provision for management goals—volunteers?<br>■ Monitoring—biophysical and social (technical and financial) | |

### *4.2. Trail Widths and TPC*

In this example of trail widths, 27% of visitors nominated a maximum width of 1 m (Table 3), with 43% stating that 1.5 m should be the maximum. If these assessments accorded with those of managers, then the LAC and TPC points would coincide at 1.5 m, when the trail condition would be prioritized (LAC) and intervention would follow. As a substantial proportion of survey respondents selected 1 m as a maximum, TPC would provide warning of a threat before the ultimate limit or threshold of 1.5 m was reached (Figure 5).

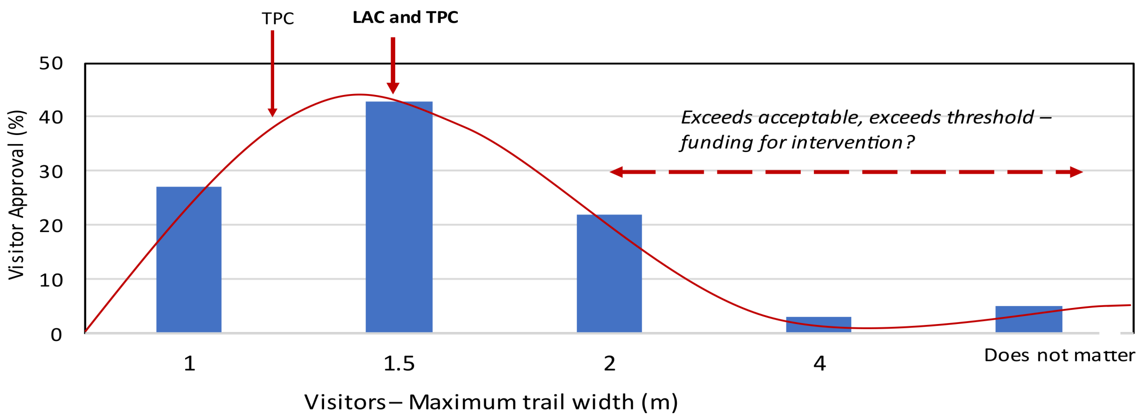


**Figure 5.** Visitor-preferred trail width and LAC and TPC response points, RNP.

When thresholds are considered in more detail, it becomes apparent that deciding on benchmarks even within a single stakeholder group, in this case visitors, is complex. Visitors' responses to preferred path widths varied depending on whether they were described as Purists, Semi-purists or Non-purists. A reasonably high proportion of Non-purists (42%) reported that trails exceeding 1.5 m in width were acceptable, compared with only 24% of Purists and 15% of Semi-purists (Figure 6 and Table 3). It is unclear to what extent the surveyed visitors' assessments may have been influenced by a relatively standard width of 1 m for constructed trails in many Australian national parks. Additionally, cultural attitudes may have contributed to results, as visitor nationality in Europe has been found to substantially affect purism results [58], and 30% of the culturally diverse Australian population was born overseas [64]. Further uncertainty over desirable trail widths may be introduced over time as visitor numbers and potential crowding increase [65].

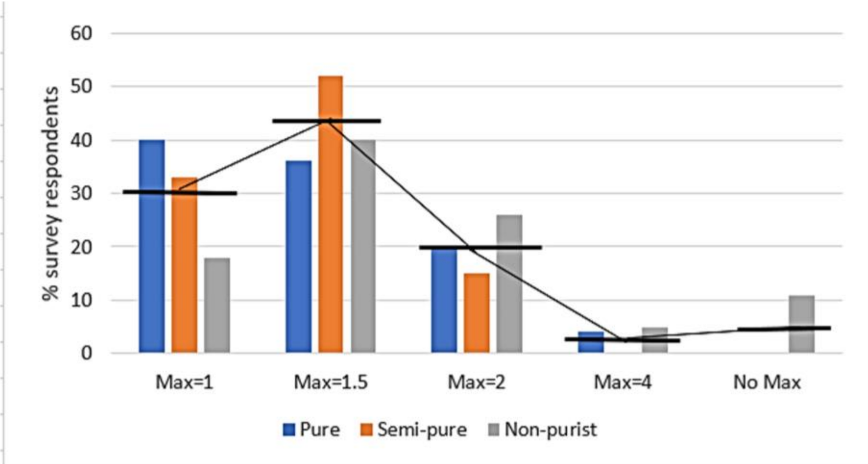


**Figure 6.** Visitor-preferred trail width (in m), by wilderness perception category, RNP. Horizontal bars represent the average value for all purism groups for each width category.

### 4.3. LAC, TPC and Managing Trails

The national and state governments in Australia require plans of management for all national parks, although management frameworks are not specified. Contributors to these planning documents include government departments, visitors, educationists, community groups and researchers whose perspectives are placed within the prevailing government's broader policy guidelines, which may change in response to changing political circumstances or parks personnel.

The complexities raised when investigating a single quality measure such as trail width relate to stakeholders' perceptions, biophysical parameters and park management policies of minimizing the importation of non-local materials to protected areas. Although trail width may be reduced by 'hardening' surfaces with materials such as polymer modified pervious concrete [66], elevated walkways and timber constructions are more commonly used in Australian national parks. In relation to non-constructed trail widths in RNP, nearly one-quarter (24%) of Purists, for example, found a maximum trail width of 2 m or more to be acceptable. This group would likely have also visited Trail 3 which has sections exceeding 1.5 m of poorly defined 'trail' having a dense leaf litter cover, often with no bare ground. Logically, a wider area of bare ground would generate greater amounts of soil loss, but using trail width as a surrogate for all physical variables is only a partial solution. When eroded sections are measured and soil loss estimated, no clear association emerges between low erosion and narrow (<1.5 m) trails (Figure 3). Factors other than the number and type of visitors creating trails of particular widths affect erosion, including the biophysical variables of soil type (clayey or sandy); steepness of slope; angle of trail across or up-and-down slope; the presence of gravel, rocks or ponded water; and the general layout of trails [24].

Multiple variables contribute to an overall ecological threshold of potential concern, as noted by [67], and trail width is only one indicator of environmental, and potentially social, concern. Wider trails may be associated with other attributes such as increased visitor-generated litter or noise, multiple (braided) trails or increased trail depth. Trends in each of these variables can be considered separately within the TPC framework, but a combination of the potential threats allows any individual variable to be a key indicator and/or contributor to a general threat level. For example, only about 30% of sampled points on a major walking trail exceeded a width of 1.5 m, but 40% exceeded a depth of 0.5 m [68], and relative erosion losses were closely related ($R^2$ = 0.87) to maximum trail depth [69]. Trails below the width threshold may thus require intervention based on depth as an indicator of erosion and/or walking comfort. However, width is a better indicator of direct vegetation impact than is trail depth. An important advantage of TPC is its capacity to identify trends pointing to deterioration in one or more biophysical or social conditions before critical points are reached, allowing for earlier intervention than is likely in the LAC framework. By incorporating TPC, the binary condition of reaching or not reaching a threshold (limit) instead becomes an assessment of the direction and intensity of change along a continuum of increasing concern, which can incorporate/categorise interim thresholds. This approach is analogous with the IUCN's guide to the status of biological diversity, in which flora and fauna are categorized (in ascending order of concern) as being of least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN), critically endangered (CR), extinct in the wild (EW) and extinct (EX) [70].

TPC, LAC and Government Policies and Funding

Sustainable tourism is defined in an Australian government document as 'tourism which can be sustained over the long term because it results in a net benefit for the social, economic, natural and cultural environments of the area in which it takes place' ([47], p.63). In NSW, increased tourism to national parks is encouraged ([49], p. 77–78, [71]). However, no management framework can be effective in the absence of availability of appropriate resources. In NSW, government funding of national parks has decreased substantially over the last decade, leading to a management system characterized by reduced staffing and increased reliance on volunteers, which has adversely impacted fire management [72,73], pest management [74], public safety [75] and trail maintenance [76] and has increased the recruitment of volunteers as tour guides for visitors [77]. In RNP, a key attraction is the 26 km-long Coast Walk; estimates of annual visitation to the Walk range from >80,000 [78] to 90,000 [79]. A high priority since the 2000 Plan of Management has been to 'Restore the Coast Walk' [50], but funding only commenced in 2016 [78] and included 17 km of work on signage, constructed vantage points, landscaping, parking areas and amenities in addition to the Walk (trail) itself [80]. The extent to which an aspirational symbiosis of parks and visitors [81] can compensate for inadequate resourcing for trail management is debatable [82].

## 5. Conclusions

Few would object to the generous policy intention of maintaining both human and biophysical sustainability, probably including those in the 'non-purist' wilderness category in this study, and most would likely agree that achieving this ideal is a complicated process. Different societies and individuals have diverse perspectives and priorities, and evaluations of what constitutes sustainable societies/activities and biophysical environments may evolve over time. In addition, the larger-scale repercussions of climate change are being superimposed on existing human-generated habitat loss and animal and plant extinctions. Decision-making for conservation has thus become increasingly complex [67,83]. These broader issues prompt rising concern about identifying the most effective management structures for sustaining biophysical environments in heavily utilised protected areas suffering from inadequate resourcing.

Trail width is only one of many variables contributing to the overall assessment of trail condition, which itself can provide an indicator of the sustainability or otherwise of tourist-impacted biophysical environments in protected areas. The notion of thresholds in TPC is important for balancing conservation and tourism in protected areas, although, ideally, biophysical thresholds would coincide with acceptable limits in LAC and suitably resourced management actions would address both the identified thresholds and limits. Both LAC and TPC have the functionality to incorporate diverse biophysical and human (stakeholder) variables, with TPC having the advantage of ensuring attention is given to biophysical issues for which it can operate as an early warning system. Recognition of thresholds/limits for environmental deterioration provides opportunities for pre-emptive management intervention. In real-world situations, thresholds and/or acceptable limits are frequently exceeded when management objectives encounter the 'hard' barrier of insufficient funding or resources resulting from political decisions, an impediment which can only rarely be offset by the 'soft' response of volunteer engagement. To be achievable, sustainable tourism in protected areas requires continuous awareness and effective management frameworks, such as TPC or an enhanced LAC, that incorporate both conservation and visitation.

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