Applying Public Participation GIS (PPGIS) to inform and manage visitor conflict along multi-use trails.

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Abstract

Managing visitor conflict is an important task in protected areas. This study used public participation GIS (PPGIS) mapping and a visitor survey to research conflicts between mountain bikers and horse riders, and other groups frequenting trails for tourism and recreation in national parks in northern Sydney (Australia). The goal was to evaluate the effectiveness of the PPGIS for determining conflict locations, and to integrate stated reasons and conflict resolution measures in a model. The survey showed that 42% of mountain bikers and 69% of horse riders had experienced conflicts, with each other, motorbike riders, walkers/hikers and dog walkers. PPGIS effectively mapped concurrent usage intensity to predict potential conflict locations over a reasonably large study area thereby identifying trails of the greatest concern. PPGIS also offered high-quality GIS visualisation options, and the novelty of the PPGIS increased participant engagement. We evaluated PPGIS compared to questionnaire-based surveying, direct visitor observations, GPS tracking, traffic counters and cameras. Because visitor conflict occurs within a spatial context, conflict management will require greater spatial knowledge of visitor activity, which can be obtained through the innovative PPGIS mapping. A conflict model is presented that integrates this study's empirical findings on conflict reasons and resolutions with existing conflict theory.

Key words: Public participation GIS; Recreational conflict; Spatial distributions; Protected areas; Mountain biking; Horse riding.

1 Introduction

1.1 Recreational conflict in protected areas

Protected areas service visitor groups with potentially conflicting needs and expectations due to differences in their recreational goals and social values (Newsome, Smith, & Moore, 2008; Wolf, Wohlfart, Brown, & Bartolomé Lasa, 2015). Visitor conflict is a complex and multidimensional construct that needs to be addressed early to avoid escalation and to enable widespread participation in park activities under the paradigm that tourism and recreation offer valuable opportunities for parks (Weaver & Lawton, 2017; Wolf, Ainsworth, & Crowley, 2017; Wolf & Croft, 2012; Wolf, Stricker, & Hagenloh, 2015).

Multi-use of trails is a source of potential visitor conflict in protected areas because different tourism and recreation activities spatially coincide. Much of the conflict research has focused on the personal and psychological sources of conflict with insufficient attention to the spatial dimension of conflict. However visitor conflict occurs within a spatial context and thus conflict management will also require greater spatial knowledge of visitor activities. Monitoring of conflicts through innovative spatial methods such as public participation GIS (PPGIS) mapping, which is the focus of this paper, will be essential to identify and manage conflicts along multi-use trails in the future. The aim of this research was to evaluate how effective PPGIS mapping is compared to other visitor-monitoring techniques for determining concurrent trail usage of mountain biking and horse riding as a predictor of potential conflict locations, and for mapping actual conflict locations.

To achieve a sustainable coexistence of different tourism and recreation activities along multi-use trails, park managers also need to understand reasons for conflicts and their resolution. Therefore findings attained through the PPGIS mapping coupled with visitor surveying were combined with elements of interpersonal conflict theory (Jacob & Schreyer, 1980) and social value conflict theory (Carothers, Vaske, & Donnelly, 2001; Vaske, Needham, & Cline Jr, 2007), which we introduce in the following, to create an integrated descriptive model of trail visitor conflicts and their management in tourism and recreation sites. A particular focus was on various visitor behaviour characteristics described by Jacob and Schreyer (1980) and reported issues with differing trail use leading to goal interference-related conflicts, reflecting direct personal contact or indirect observation of the conflicting activity, and differences in social values rooted in diverging beliefs and attitudes.

1.2 Literature review

Conflicts pose a significant issue for park management as they affect three predictors of visitor satisfaction (Stankey, 1971), namely perceived adverse environmental impacts; appropriateness of other visitor activities and efficacy of park management (Dorwart, Moore, & Leung, 2009; Lynn & Brown, 2003). Unmanaged conflicts may also impact on repeat visitation, word-of-mouth recommendation and hinder the development of a constituency for parks; in the worst case they lead to injury. Therefore, a better understanding of the methods used to monitor conflicts is required to enable an effective management.

Interpersonal conflict theory defines conflicts as goal interference attributed to another's behaviour (Jacob & Schreyer, 1980), which according to Owens (1985) involves negative social interaction resulting from competition for shared resources and preventing participants from accruing expected benefits. Competition intensifies with resource specificity, that is, the significance attached to using a specific tourism or recreation resource (Jacob & Schreyer, 1980). Trails, if multi-use, are a good example of a specific resource where conflicts arise because a range of fast- and slow-moving travellers depend on it for different activities (Arnberger & Eder, 2008; Moore, 1994) and unwanted behaviour of others may be encountered (Beeton, 2006).

In contrast, social value conflict theory posits that conflicts can accrue from perceived problems with other visitors and their activities, even when they are not directly experienced (Carothers et al., 2001; Vaske et al., 2007). For example, in the Australian Alpine National Park walkers expressed negative attitudes towards horse riders without having encountered them (Beeton, 1999). In fact, actual encounters with other visitor groups can improve previously held negative beliefs and attitudes, as was observed for mountain bikers and walkers in New Zealand (Cessford, 2003). Social value conflicts originate from the formation of shared normative beliefs and negative attitudes adopted from other members of a group to reinforce a sense of belonging to this group, resulting in firm beliefs about socially acceptable activities (Rossi, Byrne, Pickering, & Reser, 2015). Research suggests that values, fundamental principles that filter environmental information, shape beliefs and attitudes, which in turn mediate perceptions as sensors/processors of the environment, resulting in specific behaviour towards other trail visitors (Rossi et al., 2015).

Conflicts along multi-use trails have different origins. Competition for trails means competition for investment by park management into specific designs. Mountain bikers, for instance, may prefer narrow single tracks with features such as rocks and jumps while horse riders prefer wide and open tracks without obstacles (Taylor, 2010; Wolf, Wohlfart, et al., 2015). Perceived inequality in investment may lead to resentment of others. Historical users of trails may resent access by others if their use is perceived as incompatible, or if increases in visitation from new users cause trail congestion. Historical users may have been heavily involved in their activity over the years, even volunteered time for trail maintenance, and therefore have developed a sense of ownership of specific trails. Conflicts often occur between different activity groups in relation to their grade of gear and technology involved (Manning, 1999). For instance, conflicts may arise between motorised and unmotorised travellers (e.g. Adelman, Heberlein, & Bonnicksen, 1982; Rossi et al., 2015), or mountain bikers, horse riders and walkers (e.g. Arnberger & Eder, 2008; Heer, Rusterholz, & Baur, 2003). The inherent properties of an activity may offend others such as the noise and exhaust fumes of motorized vehicles, or horse manure left along trails (Cessford, 2003).

Conflicts where park visitors interfere with each other's goals or diverge from values they hold within their own groups occur both between and within the same activity. Interactivity conflicts are often asymmetric where one activity group may perceive another group as disruptive but not vice versa (Adelman et al., 1982; Watson, Williams, & Daigle, 1991). Ramthun (1995), for example, found that 32.3% of hikers on the Big Water trail system in Utah experienced conflicts with bikers while this was the case for only 5.6% of bikers. Even though some activities may share the same underlying mode of travel, for example ambulatory in the case of walking, running and bird watching, motivations and expectations for the experience vastly differ and conflicts may arise (Moore, 1994). Conflicts, however, emerge even within the same activity group (Vaske, Dyar, & Timmons, 2004) such as between fast- and slow-moving mountain bikers (Manning, 1999), and often relate to different motivations to visit (Stankey, 1971). Generally though, conflicts are more common between groups (Vaske et al., 2004).

To predict and manage conflicts along multi-use trails, park managers need to understand the spatio-temporal distributions of the involved activities, reasons for conflicts and their resolution. We focused on these aspects in the context of mountain biking and horse riding in Northern Sydney, New South Wales (NSW), Australia. As is the case in our study area, these are increasingly popular activities worldwide (Cordell, 2008; Heer et al., 2003). Our research applies to a full spectrum of activities on a continuum ranging from recreation to tourism. Multi-use trails in NSW National Parks and surroundings provide access to mountain bikers, horse riders, walkers/hikers and wildlife watchers who recreate frequently in their neighbourhood parks or travel longer distances to visit parks as tourists. Motorbike (motocross/trail bike) riders and dog walkers also gain access even though these activities are mostly prohibited. Although visitor conflicts relating to mountain biking (Carothers et al., 2001; Cessford, 2003; Chiu & Kriwoken, 2003; Mann & Absher, 2008; Pickering & Rossi, 2016; Ramthun, 1995; Rupf, Haider, & Pröbstl, 2014) and horse riding (Alleyne, 2008; Schneider, Earing, & Martinson, 2013; Stankey, 1971; Watson, Niccolucci, & Williams, 1994) have been studied, academic research about evaluating methods to predict conflict locations is almost non-existent, with a few relevant exceptions (Beeco, Hallo, & Brownlee, 2014; Miller, Vaske, Squires, Olson, & Roberts, 2016; Santos, Mendes, & Vasco, 2016), and so are studies that conceptualise visitor conflicts (Arlinghaus, 2005; Mann & Absher, 2008). Our research fills both of these gaps.

A survey approach was combined with PPGIS mapping. In PPGIS mapping, participants are recruited to provide geospatial information by identifying and marking locations on a map about perceived place attributes. This method was considered to have great potential to advance national park planning (Brown & Weber, 2011) and more generally in spatial planning of protected areas (Beeco & Brown, 2013). The PPGIS was used to map locations of riders providing detailed insights into their spatial distributions and overlap, and on actual conflicts. PPGIS has proved an effective tool on a range of land-use planning issues (as reviewed by Brown & Kyttä, 2014) including tourism management (Brown, 2006; Wolf, Wohlfart, et al., 2015), land-use conflicts (Brown, Kangas, Juutinen, & Tolvanen., 2017; Brown & Raymond, 2014), assessment of ecosystem services (Brown, Montag, & Lyon, 2012; Brown & Raymond, 2014; Raymond et al., 2009), forest planning and public land management (Brown, Weber, & de Bie, 2014). Public participation can enhance the acceptance of decisions with spatial implications and alleviate concerns of the community when administering measures of conflict resolution (Moore, 1994; Raymond et al., 2009).

The aim of this research was to evaluate how effective PPGIS was for determining concurrent trail usage as a predictor of potential conflict locations, and for mapping actual conflict locations. The authors evaluated the methodology in the context of a literature review and by drawing from their combined knowledge of over 30 years in people monitoring to identify advantages and disadvantages of PPGIS mapping compared to other techniques, including questionnaire-based surveying, direct visitor observations and indirect observations through PPGIS (GPS) tracking, traffic counters and cameras. The primary focus was on conflicts between mountain bikers and horse riders but conflicts with other visitor groups including motorbike riders, dog walkers, walkers/hikers and wildlife watchers were also considered. The study's empirical findings on conflict reasons and resolutions were integrated with existing conflict theory to present a comprehensive descriptive conflict model.

2 Methods

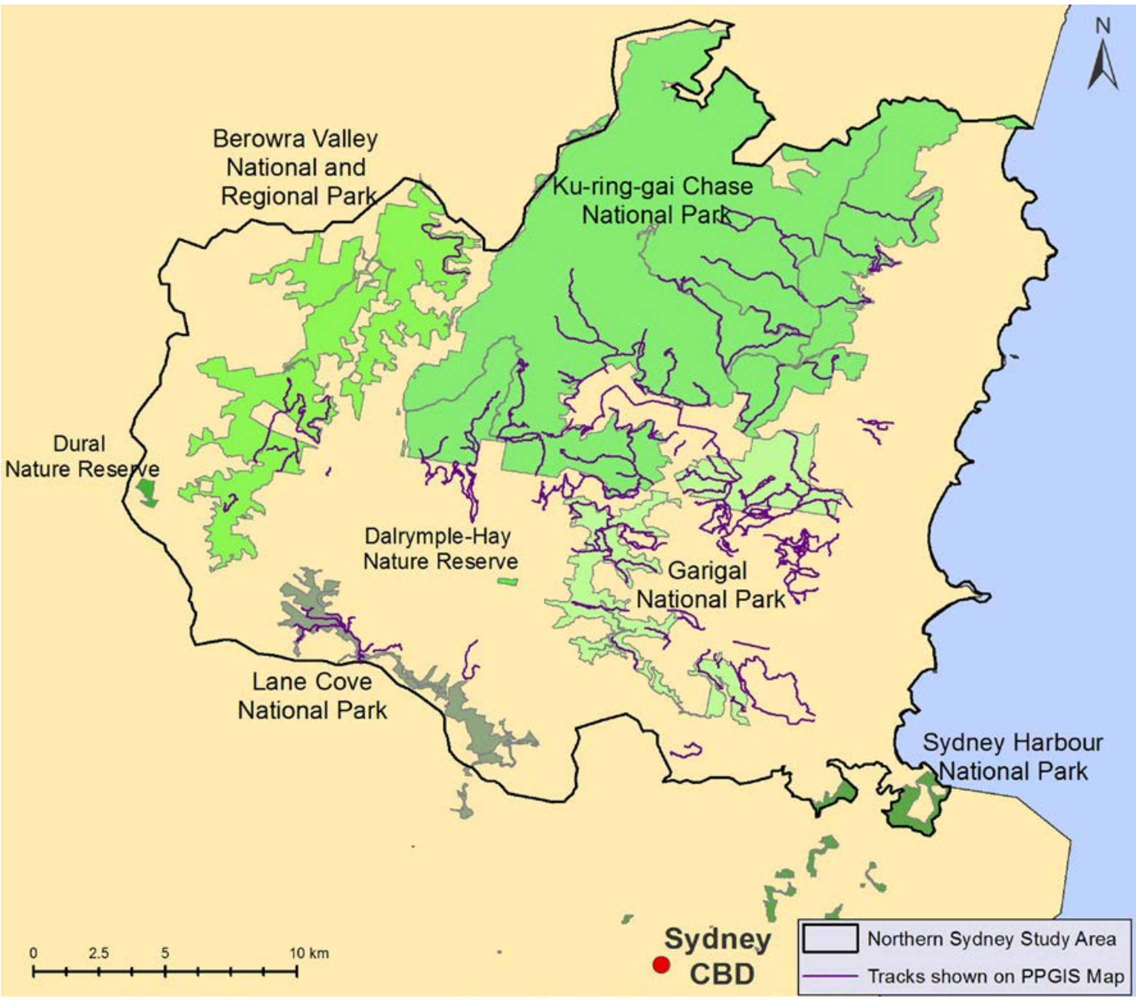
2.1 Study area

The study area in Northern Sydney covers a total of 561 km² with approximately 220 km² (21,943ha) of national parks that are managed by the NSW National Parks and Wildlife Service, and adjacent communal green spaces belonging to different councils (Figure 1). In recognition of an increasing demand for mountain biking and horse riding in legitimate areas and to address illegal trail creation, the NSW National Parks and Wildlife Service is planning on creating sustainable experiences for riders of different skill levels.

Many of the management trails within NSW National Parks such as fire trails are accessible to multiple activities. Mountain bikers can explore an established network of multi-use and single-use trails suitable for most types of mountain biking that attracts visitors residing in NSW and elsewhere in Australia. Single-use trails include jumps, logs and other trail features, and are adaptable to different skill levels. However, most trails are shared at least to some extent and therefore need to accommodate multiple activities. Mountain bikers also use purpose-built trails and mountain bike parks outside of NSW National Parks.

Horse riding has a history of more than 150 years in NSW National Parks. Currently, it is permitted on specific management trails in, for example, Ku-ring-gai Chase National Park and Garigal National Park. Outside NSW National Parks, there are purpose-built equestrian facilities (arenas). Most horses in the study area are boarded in two suburbs in the local government of Warringah Council with approximately 1200 horses in 2007 (Warringah Council, 2009). The study area caters for all skill levels and the grounds hold different club events which attract horse riders from outside the study area.

Figure 1. Study area with national parks located in Northern Sydney, Australia.



2.2 PPGIS mapping

Mountain bikers and horse riders were invited to participate in a PPGIS mapping survey. Participants were recruited in online forums, bike and equestrian shops and through clubs and associations. The invitation provided an online link to the survey (mapping interface and questionnaire) and explanations of the study purpose and methodology. Data were collected through July 2013 and included several reminder invitations.

In addition to recruitment for the online survey, riders of both groups were intercepted at popular trails, arenas and events inside the study area to broaden the sample. The field study was administered concurrently, and especially on weekends and public holidays. Most mountain bikers were intercepted at trail heads while horse riders were mainly recruited at arenas and events because interception along trails proved too difficult. Before consenting to participate, people had to confirm that they were riding at least occasionally in the study area to qualify for participation. In case people preferred to participate online rather than using a hardcopy map, they were given the internet URL and instructions for the online survey.

We collected data on riding locations (location frequencies and best rides) and locations of conflicts. A variety of other markers was collected as per Wolf, Wohlfart, Brown, and Bartolomé Lasa (2015). The markers were pretested and revised in accordance with comments from NSW National Parks staff. Location markers were classified into eight markers (Table 1). The three conflict markers distinguished conflicts with mountain bikers, horse riders and walkers, focusing on three common trail visitor groups with a large quantity of data for analyses. This information enabled identification of areas with a high density of concurrent usage by mountain bikers and horse riders, as a predictor for potential conflict trails, and actual intra- and inter-activity conflict locations.

The interactive web-based PPGIS platform (mountain bikers: http://www.landscapemap2.org/nswmtnbike/; horse riders: http://www.landscapemap2.org/nswhorse/) started with an introductory page with explanations of the purpose of the study, study area and how to proceed with the mapping and the questionnaire. After consenting to participate, people were requested to drag and drop specific markers representing frequency of trail use, reasons for riding, suggested management actions, and conflict areas onto a Google map of the study area. Participants could access an operational definition for each marker and add annotations. The same markers were used for mountain bikers and horse riders except the icons were adapted to fit the context.

Table 1. Row percentages of location markers (location frequencies and best rides) placed by mountain bikers and horse riders along trails inside and outside national parks in Northern Sydney, Australia. "Both" indicates markers placed along trails that are partially located inside and outside of parks. Bold numbers mark the greatest row percentages.

	Mountain biking				**Horse riding**			
	All	**Both**	**Outside**	**Park**	**All**	**Both**	**Outside**	**Park**
	n	**%**	**%**	**%**	*n*	**%**	**%**	**%**
Locations								
Riding 5-7 times per week	133	6.8	**54.9**	38.3	126	18.3	**48.4**	33.3
Riding 1-4 times per week	1005	8.1	**50.1**	41.8	430	18.1	39.3	**42.6**
Riding once per month	1532	11.7	**45.4**	42.9	237	17.7	31.6	**50.6**
Riding less than once per month	1902	12.5	39.1	**48.4**	171	20.5	28.1	**51.5**
Best ride for less than 2 hours	276	4.7	**67.4**	27.9	59	28.8	30.5	**40.7**
Best ride for 2-4 hours	175	8.0	**56.0**	36.0	56	7.1	25.0	**67.9**
Best ride for more than 4 hours	55	18.2	25.5	**56.4**	15	6.7	6.7	**86.7**
Best for night ride	122	10.7	**45.9**	43.4	4	0.0	**50.0**	**50.0**

For spatial guidance, 204 trails known to be frequented by mountain bikers and/or horse riders were shown on the map. However, people were instructed to place markers anywhere in the study area as PPGIS can achieve sensible results even without providing reference locations. A boundary line helped participants to discern the study area. We also asked to place markers as close as possible to trails/relevant areas such as potentially conflicting areas (e.g. curves, steep slopes). To be able to do that as accurately as possible online, the mapping function was only enabled after reaching a minimum Google map zoom level (Level 15 = approximate scale 36,000:1). Participants could only see their own markers but not those placed by others, and could place as few or as many markers as they considered necessary. In the field, markers were placed on a printed A0-map and annotations were noted by the researcher and linked to specific markers by numbers. To complete the non-spatial questionnaire, participants had to place at least one marker.

2.3 Survey

The results presented here are part of a larger survey which contained 29 questions on socio-demographics, riding times and areas and motivations, some of whose results were presented in Wolf et al. (2015). Rating-scale questions were asked on a five-point scale ranging from "Not at all important" to "Extremely important". This study presents results on questions focused on spatio-temporal usage of trails by mountain bikers and horse riders in Northern Sydney, and conflicts experienced with other visitor groups and their resolutions. We inquired whether respondents have been involved in any conflict with other mountain bikers, horse riders, walkers, dog walkers, wildlife watchers, motorbike ("motocross/trail bike") riders; and whether this involved a verbal conflict, physical (fight) conflict, collision/fall, or near collision (multiple responses allowed). Participants were also encouraged to comment on the conflicts/misunderstandings that they experienced with any of these groups, and to state the trail/area if this happened frequently at a specific location. Furthermore, we asked to rate to what extent the following strategies would help to avoid conflicts/misunderstandings between the different parties: multi-use trails fostering a greater understanding between users; separate user-specific single trails; single-directional loop trails that scatter different user groups; extended use of signage to inform about other user groups; distribution of information identifying needs, safety, issues and priorities for all trail users. Open-ended survey comments were prompted on strategies to resolve or mitigate conflicts/misunderstandings between trail users.

2.4 Analysis

Results from the questionnaire that accompanied the PPGIS mapping were analysed with IBM SPSS Statistics for Windows 21.0. Mountain biker and horse rider data were analysed separately. Prior to analysis, the five skill levels (complete beginner; advanced beginner; moderately experienced; very experienced; experts) of mountain bikers were re-classified by merging complete and advanced beginners into one category of beginners to account for their low sample sizes; similarly, advanced beginners and moderately experienced horse riders were merged into intermediate riders. Hence depending on the activity, intermediates were differently skilled; they should be comparable though given the low number of beginning horse riders ($n = 4$). None of the horse riders considered themselves to be complete beginners.

To determine whether skill level influenced the percentage of riders who experienced conflicts with other trail visitors Pearson's chi-square tests were applied. The rating-scale data were treated as ordinal (Norman, 2010), and thus analysed with ANOVAs to test for the effect of skill level on preference for conflict resolution measures. Open-ended questions about conflicts/misunderstandings with other visitor groups, and measures to resolve or mitigate conflicts/misunderstandings were analysed qualitatively by identifying the major categories/themes emerging from participants' comments by two independent coders.

We used several spatial scales in our analysis to demonstrate the versatility of PPGIS mapping and associated GIS analysis. This included the overall study area, inside versus outside national parks, individual parks and individual trails. To analyse trail usage inside and outside national parks, trails were assigned to either being located "in park", "outside" or in "both". Trails were assigned to parks or assigned to "outside" if most (>90%) of their length was located in either, otherwise they were considered as being located in "both".

Markers collected in the field were transferred by a researcher into Google maps and then exported together with the online data for import into a geographical information system (ArcGIS 10.1). A discussion of the effect of field versus online PPGIS mapping is presented in Wolf et al. (2015). To create maps showing the varying numbers of markers placed along the 204 individual trails that we had displayed in Google maps, location (location frequency and best rides) and conflict markers were spatially joined in ArcGIS with their nearest trail. From these location and frequency data, maps were produced to discuss rider distributions, concurrent trails use and areas of conflict.

3 Results

3.1 Sample characteristics and rider profiles

The questionnaire was completed by 516 mountain bikers (mb) and 115 horse riders (hr) who placed at least one PPGIS marker inside the study area. The sample included 19 beginner, 99 intermediate, 247 advanced and 151 expert mountain bikers; and 14 intermediate, 62 advanced, and 39 expert horse riders. The smaller sample size for horse riders reflects the smaller market share of this activity in Northern Sydney. The majority of beginners (84.2%) have been mountain biking for up to 3 years compared to advanced riders (50.2%), and experts (67%) who have been riding for more than 10 years. The majority of horse riders (intermediate hr: 57.1%; advanced hr: 85.5%; expert hr: 92.3%) have been riding for more than 10 years although 42.9% of intermediate riders had been riding for 1-3 years. Mountain bikers were mostly male (beginner: 84%; intermediate to expert: 95%–96%) while horse riders were mostly female (intermediate: 70%; advanced to expert: 92%), and both typically aged between 25 and 54 years.

Altogether, 667 mountain bikers and 123 horse riders placed 11256 and 2675 PPGIS markers, respectively, about locations where they ride, reasons to ride and actions to take (including conflicts) by park management. Participants (mb: 5%; hr: 2%) who did not place any markers within the study area or stated they do not ride in Northern Sydney were excluded from the analysis. Mountain bikers and horse riders added comments to approximately 13% of markers. Detailed results on all marker types were discussed in Wolf et al. (2015). This study focused on location markers (mb: 46.2%; hr: 41.1% of all markers) to determine concurrent use of trails by mountain bikers and horse riders, and markers about conflicts (mb: 1%; hr: 2.1% of all markers) with mountain bikers, horse riders and walkers. Expert (27.1 ± 2.0 markers) and advanced (21.7 ± 1.6 markers) mountain bikers placed significantly more markers than intermediate riders (13.3 ± 2.5 markers) and beginners (7.8 ± 5.5 markers). This pattern was not evident for horse riders, with all skill levels placing similar average numbers of markers (intermediate: 18.2 (± 5.5), advanced: 23.5 ± 2.7 ; experts: 23.3 ± 3.4 markers).

3.2 Concurrent trail use

Mountain biking and horse riding occur year-round in Northern Sydney with a preference for spring and fall when ambient temperatures are most conducive to outdoor activities. Mountain bikers of all skill levels rode throughout the day, but preferably prior to 9 am (>48%) in summer and up to 2 pm in spring to winter (>29%). Expert horse riders were equally active all day while intermediates (>57%) preferred afternoons (>2 pm), and advanced riders (>25%-35%) preferred mornings (9 am to

2 pm) and afternoons. In summer, riding activity increased prior to 9 am. More skilled mountain bikers and horse riders rode more often "any time" compared to less skilled riders. Riding after sunset was rare except for some expert mountain bikers and a few horse riders during the summer months.

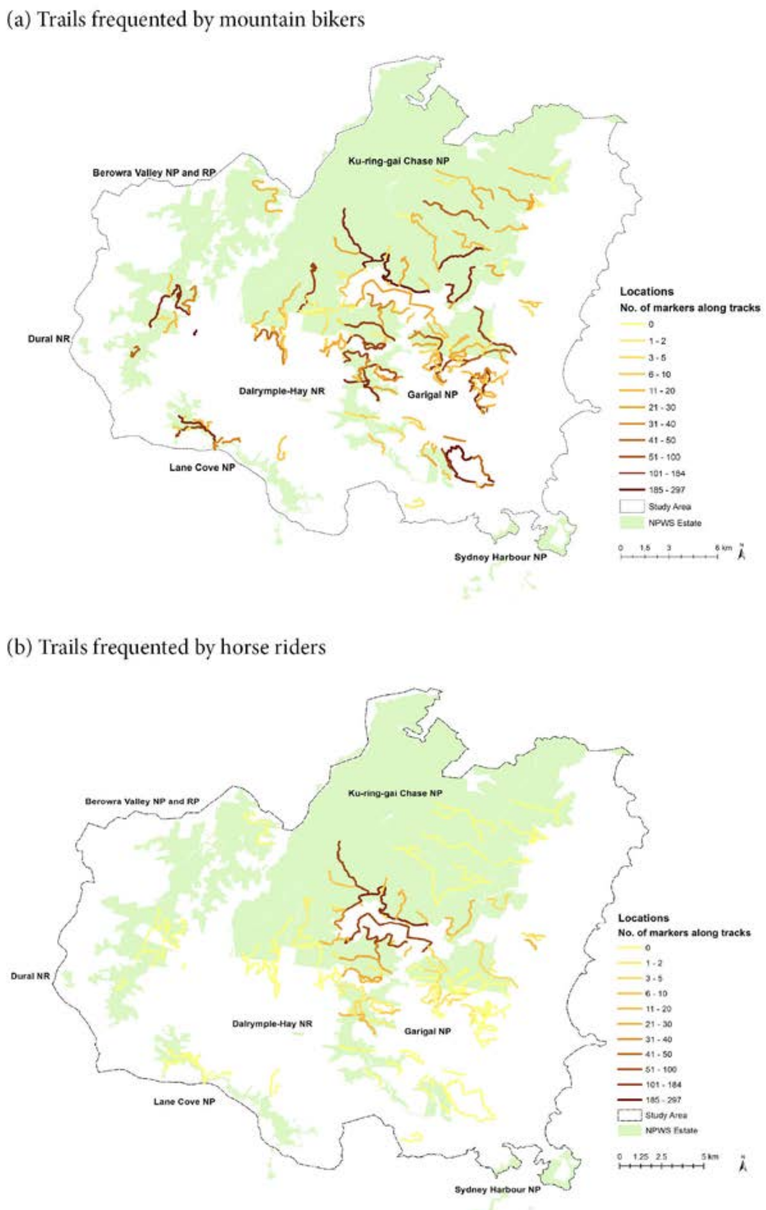
There were clear differences in preferred trail design between mountain bikers and horse riders. Mountain bikers, especially if more skilled, ascribed a high importance (average ratings of >4 on a five-point scale) to track features such as circuits, curves, up- and downhill sections, single tracks, tight and technical tracks, logs and rocks, and short steep and challenging slopes. All skill levels favoured tracks between 10 and 20 km in length. Many horse riders favoured (average ratings of >3.7) a variety of tracks and circuits, open and clear, long/gentle/moderate slopes, flat track sections and trails less than 5 km. Among expert horse riders, short/steep/challenging slopes, and trails with up and downhill sections, as well as the longer 5 to 10-km trails were more popular. Technical features such as logs and rocks were not important (average rating of 3.2).

Mountain bikers mapped similar percentages of location markers outside (45.6%) and inside (43.7%) Northern Sydney national parks (vs. both = trails traversing park boundaries: 10.7%). However, trails outside of parks were used for more frequent but shorter rides vs. less frequent ("riding less than once per month") but longer rides ("best ride for 2-4 hours") that were popular inside of parks (Table 1). Horse riders placed location markers somewhat more often inside (46.5%) compared to outside of parks (35.2%), but a considerable percentage of markers was also placed along trails traversing park boundaries (18.2%). This reflects that horse riders often access parks via trails from outside, commencing their rides from homes or stables to avoid using horse trailers. Similar to mountain bikers, the most frequent horse riding ("5–7 times per week") occurred outside of parks; however this marker type was placed less frequently compared to all other location-frequency markers which were placed more often inside parks (Table 1). Except for night rides, all best rides, especially the longer ones, were mapped considerably more often inside parks (Table 1).

Mountain bikers and horse riders aggregated in specific parks: most mountain bikers rode in Ku-ring-gai Chase National Park (39.9%) followed by Garigal National Park (20.6%). Garigal National Park was the preferred location though for best rides for 2–4 hours (37.7%). Ku-ring-gai Chase National Park and surrounds were also most popular among horse riders, followed by Garigal National Park.

Figure 2 shows how PPGIS mapping captured detailed distributions of mountain bikers (Figure 2(a)), and horse riders (Figure 2(b)) in Northern Sydney. Mountain bikers dispersed more widely using 192 of the 204 displayed trails while horse riders frequented 79 of the 204 trails. However, only two trails received more than 100 markers by mountain bikers and horse riders, flagging them as the highest-use areas, followed by another five trails where either mountain bikers or horse riders had placed at least 100 markers and the respective other group had placed at least 50 markers. The mapping corroborates results from the survey in that horse riders tend to travel shorter distances to trails so their distribution is closer to their stables.

Figure 2. Public participation GIS location markers indicating trail usage by (a) mountain bikers, and (b) horse riders in Northern Sydney, Australia.



3.3 Conflict occurrence

Forty-two percent of mountain bikers stated that they had experienced conflicts with other trail users, especially motorbike riders, walkers/hikers and dog walkers (Table 2). Conflicts occurred considerably less often with other mountain bikers or horse riders, and rarely with wildlife watchers. The likelihood to experience conflicts increased with skill level, with 55.4% of expert riders having experienced some type of conflict (cf. beginners: 31.6%). Advanced and especially expert mountain bikers described mainly verbal conflicts and near collisions with motorbike riders, and dog walkers (Table 2). Mainly verbal conflicts were described with walkers/hikers. Physical conflicts were mentioned by a few beginners with other mountain bikers. Collisions/falls were not mentioned.

Table 2. Relationship of beginner (*n* = 19), intermediate (*n* = 99), advanced (*n* = 247), and expert (*n* = 151) mountain bikers with other trail users in Northern Sydney, Australia.

	All	Beginner*	Intermediate*	Advanced*	Expert*			
	%	%	%	%	%	df	χ^2 or F	*P*
Experienced any conflicts	42.3	31.6	34.7	46.3	55.4	3	11.9	**0.008**
Experienced conflicts with								
Motorbike rider	23.3	5.3	14.3	28.5	40.1			
Walker/hiker	17.9	10.5	15.3	19.6	20.4			
Dog or dog owner	17.4	15.8	15.3	18.3	27.2			
Another mountain biker	8.7	15.8	5.1	9.6	14.3			
Horse rider	7.3	10.5	7.2	7.1	8.8			
Wildlife watcher	2.5	10.5	2.0	2.1	2.0			
Types of conflicts experienced with								
Motorbike rider								
None	76.7	94.7	85.7	71.5	59.9			
Verbal	14.6	0.0	8.2	18.4	29.3			
Near collision	8.7	5.3	6.1	10.0	10.9			
Physical	0.0	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
Walker/hiker								
None	82.1	89.5	84.7	80.4	79.6			
Verbal	13.7	0.0	13.3	15.0	15.6			
Near collision	3.9	5.3	2.0	4.6	4.8			
Physical	0.3	5.3	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
Dog or dog owner								
None	82.6	84.2	84.7	81.7	72.8			
Near collision	8.7	10.5	7.1	9.2	9.5			
Verbal	8.1	0.0	8.2	8.8	17.7			
Physical	0.6	5.3	0.0	0.4	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
Another mountain biker								
None	91.3	84.2	94.9	90.4	85.7			
Near collision	4.5	0.0	2.0	5.8	5.4			
Verbal	3.9	10.5	3.1	3.8	8.8			
Physical	0.3	5.3	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
Horse rider								
None	92.7	89.5	92.8	92.9	91.2			
Verbal	5.3	5.3	6.2	5.0	7.5			
Near collision	2.0	5.3	1.0	2.1	1.4			
Physical	0.0	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
Wildlife watcher								
None	97.5	89.5	98.0	97.9	98.0			
Verbal	2.0	5.3	2.0	1.7	2.0			
Near collision	0.6	5.3	0.0	0.4	0.0			
Physical	0.0	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0	0.0			
	Mean	Mean	Mean	Mean	Mean			
Conflict resolution/mitigation								
Extended use of signage to inform about other user groups	3.83	3.61	3.86	4.01	4.18	3, 492	2.1	0.102
Separate user-specific single tracks	3.78	3.39	3.85	4.11	4.24	3, 492	3.6	**0.014**
Single directional loop trails that scatter different user groups	3.69	3.39	3.72	3.97	4.23	3, 492	4.9	**0.002**
Distribution of information identifying needs, safety issues and priorities for all park users	3.19	2.94	3.28	3.36	3.78	3, 492	4.7	**0.003**
Multi-use tracks fostering greater understanding between users	2.74	2.39	2.90	2.94	3.58	3, 488	9.1	**<0.001**
Other	2.09	2.13	2.08	2.07	3.08			

Note : Five-point scales (1 = not at all important; 5 = extremely important) were averaged to calculate means and SE. Significant differences in the Pearson's chisquare test or ANOVAS are marked in bold. *Responds to the following question and response categories: How would you describe your skill level? 'Beginner' was pooled across "Complete beginner" (almost never gone mountain biking) and "Advanced beginner" (done a little bit of mountain biking); "Intermediate" was pooled across "Moderately experienced" (am getting into mountain biking); "Advanced" = "Have a lot of experience (done lot's of mountain biking); "Expert" = "Very experienced expert rider" (do expert/difficult mountain biking).

Sixty-nine percent of horse riders stated that they had experienced conflicts with other trail users, especially with mountain bikers and motorbike riders, and to a lesser extent with dog walkers (Table 3). Conflicts with walkers/hikers and other horse riders were rare, and almost non-existent with wildlife watchers. Likelihood to experience conflicts increased with skill level (trend), with 78.9% of expert riders having experienced some type of conflict (cf. intermediate: 61.5%). Horse riders described mainly near collisions and verbal conflicts with mountain bikers and motorbike riders (Table 3). Dog walkers were also of concern, especially among intermediate riders with 23% stating verbal conflicts and 8% a near collision. Physical conflicts were mentioned by a few experts during encounters with dog walkers. Collisions/falls were not mentioned.

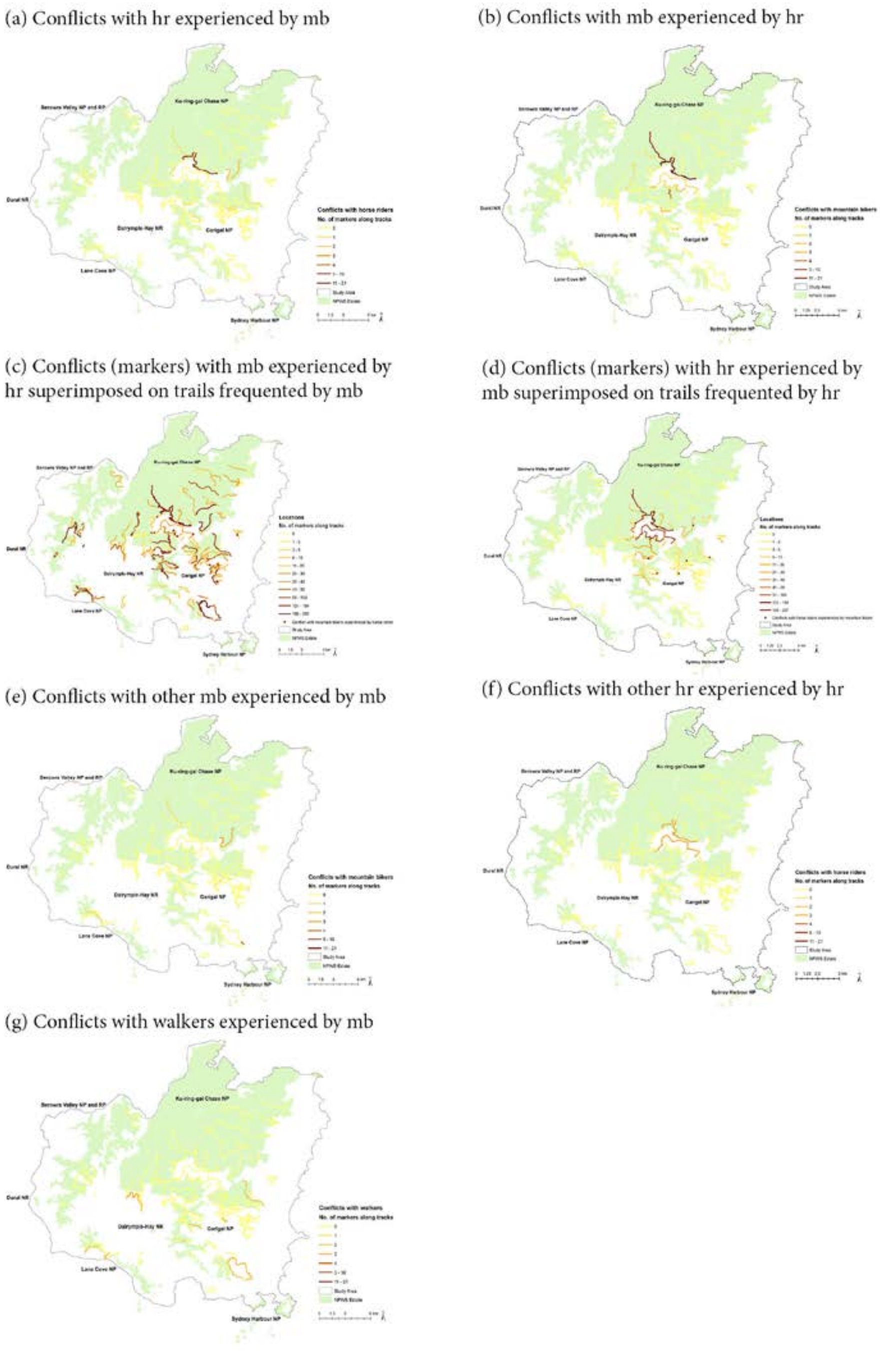
Table 3. Relationship of intermediate (n = 14), advanced (n = 62), and expert (n = 39) horse riders with other trail users in Northern Sydney, Australia.

	All	Intermediate*	Advanced*	Expert*			
	%	%	%	%	df	χ^2 or F	*P*
Experienced any conflicts	69.1	61.5	64.4	78.9	2	2.7	0.262
Experienced conflicts with							
Mountain biker	49.1	46.2	44.1	57.9			
Motorbike rider	46.4	38.5	42.4	55.3			
Dog or dog owner	22.7	30.8	25.4	15.8			
Walker/hiker	4.5	15.4	5.1	0.0			
Another horse rider	2.7	15.4	0.0	2.6			
Wildlife watcher	0.9	0.0	0.0	2.6			
Types of conflicts experienced with							
Mountain biker							
None	50.9	53.8	55.9	42.1			
Near collision	35.5	23.1	30.5	47.4			
Verbal	13.6	23.1	13.6	10.5			
Physical	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0			
Motorbike rider							
None	53.6	61.5	57.6	44.7			
Verbal	26.4	23.1	23.7	31.6			
Near collision	20.0	15.4	18.6	23.7			
Physical	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0			
Dog or dog owner							
None	77.3	69.2	74.6	84.2			
Verbal	17.3	23.1	20.3	10.5			
Near collision	4.5	7.7	5.1	2.6			
Physical	0.9	0.0	0.0	2.6			
Collision or fall	0.0	0.0	0.0	0.0			
Walker/hiker							
None	95.5	84.6	94.9	100.0			
Verbal	2.7	7.7	3.4	0.0			
Near collision	1.8	7.7	1.7	0.0			
Physical	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0			
Another horse rider							
None	97.3	84.6	100.0	97.4			
Verbal	1.8	7.7	0.0	2.6			
Near collision	0.9	7.7	0.0	0.0			
Physical	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0			
Wildlife watcher							
None	99.1	100.0	100.0	97.4			
Verbal	0.9	0.0	0.0	2.6			
Physical	0.0	0.0	0.0	0.0			
Collision or fall	0.0	0.0	0.0	0.0			
Near collision	0.0	0.0	0.0	0.0			
	Mean	Mean	Mean	Mean			
Conflict resolution/mitigation							
Extended use of signage to inform about other user groups	3.72	3.75	3.56	3.86	2, 105	0.7	0.498
Distribution of information identifying needs, safety issues and priorities for all park users	3.65	3.83	3.32	3.81	2, 103	2.5	0.086
Separate user-specific single tracks	3.40	3.82	2.86	3.51	2, 104	3.9	**0.023**
Multi-use tracks fostering greater understanding between users	3.29	3.67	3.12	3.08	2, 102	0.9	0.376
Single directional loop trails that scatter different user groups	3.10	3.42	2.81	3.08	2, 104	1.3	0.27
Other	2.51	2.33	2.50	2.69			

Note: Five-point scales (1 = not at all important; 5 = Extremely important) were averaged to calculate means and SE. Significant differences in the Pearson's chisquare test or ANOVAS are marked in bold. *Responds to the following question and response categories: How would you describe your skill level? "Intermediate" was pooled across "Advanced beginner" (done a little bit of horse riding) and "Moderately experienced" (am getting into horse riding); 'Advanced' = 'Have a lot of experience' (done lot's of horse riding); 'Expert' = 'Very experienced expert rider' (do expert/difficult horse riding). Nobody responded to be a "Complete beginner" (almost never gone horse riding).

Notably, relatively few mountain bikers mapped conflicts in the PPGIS mapping. Nonetheless Figures 3(a-d) show that conflicts indeed occur along trails where mountain bikers and horse riders meet most frequently based on their preferred riding locations (see 3.2), in particular in Ku-ring-gai Chase National Park. Horse riders especially mapped such conflicts. Conflicts were mapped along trails with the greatest concurrent usage intensity, and both parties independently mapped the majority of conflicts with each other along the same trails, which instils confidence in the validity of the results. Horse riders also experienced conflicts with mountain bikers in numerous other locations where the latter did not map any conflicts, indicating that conflicts can be asymmetrical. Conflicts within the same activity group were rarely mapped and affected only a few trails (Figure 3(e-f)). Mountain bikers also experienced conflicts with walkers and these concentrated outside of parks (Figure 3(g)).

Figure 3. Public participation GIS conflict markers indicating tourism and recreation conflicts experienced by mountain bikers and horse riders with other trail users in Northern Sydney, Australia.



3.4 Conflict reasons

In the survey and PPGIS mapping, 341 comments were received from 199 mountain bikers about conflicts with other trail-user groups and about specific locations where these happened frequently. Most comments were about conflicts with walkers, motorbike riders and dog walkers, followed by conflicts with other mountain bikers and horse riders, and rarely about conflicts with wildlife watchers. A total of 212 comments about conflicts were received from 78 horse riders. Most comments were about conflicts with mountain bikers, followed by motorbike riders and dog walkers. Few comments were about conflicts with walkers or other horse riders, and none about wildlife watchers.

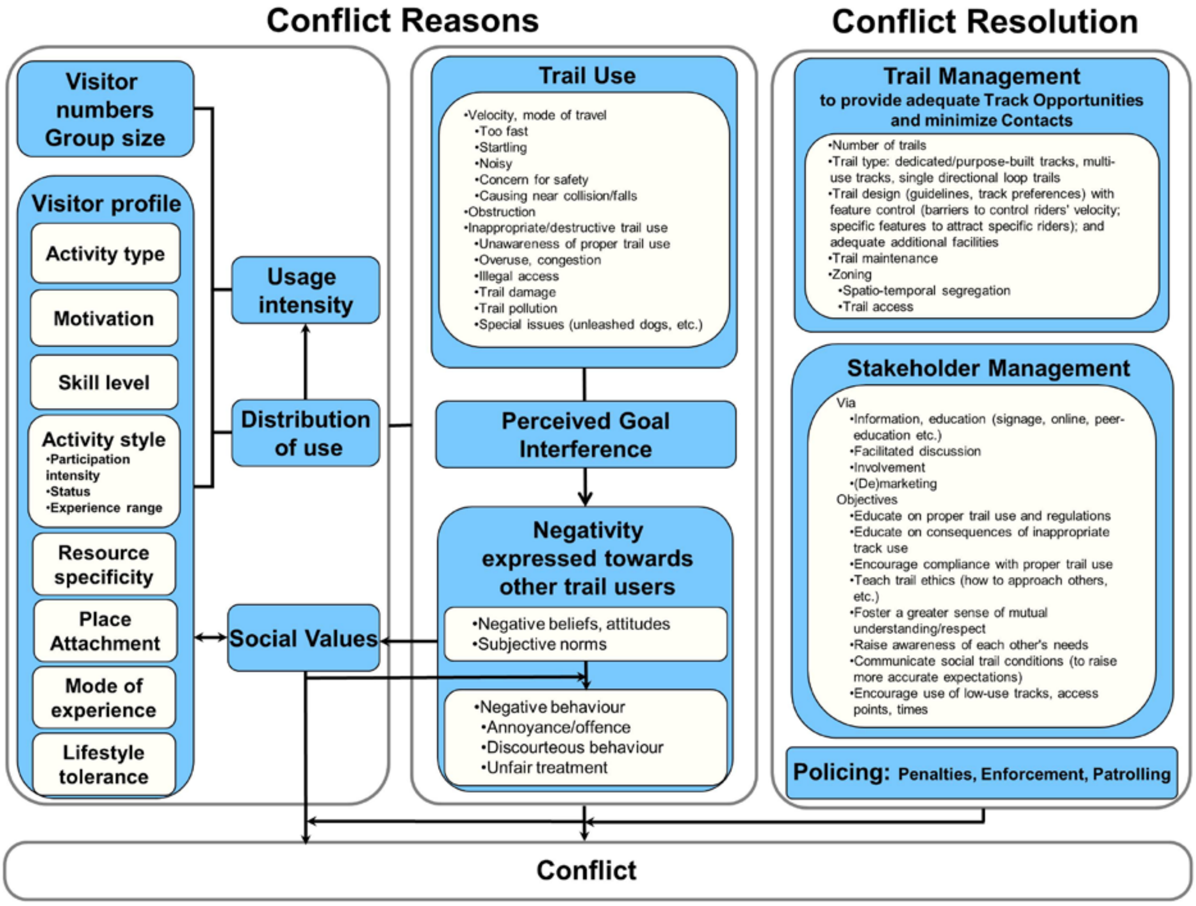
The most important reasons for conflicts are summarised in Table 4 and Figure 4. Inappropriate/destructive track use, followed by negative behaviour, and trail obstruction were the main reasons for conflicts of mountain bikers with other visitor groups while horse riders experienced conflicts mainly because of issues with the velocity and mode of travel of other visitor groups. Table 4 also shows who is commonly involved when particular reasons for conflict arise.

Table 4. Reasons for conflicts between mountain bikers (MB), horse riders (HR) and other trail user groups in Northern Sydney, Australia, with *n* = combined number of comments stated in the survey or appended to markers placed in the public participation GIS (PPGIS) mapping.

	All		**In general**		**Mountain bikers**		**Horse riders**		**Walkers/Hikers**		**Dog walkers**		**Motorbike riders**	
	MB	**HR**	**MB**	**HR**	**MB**	**HR**	**MB**	**HR**	**MB**	**HR**	**MB**	**HR**	**MB**	**HR**
Velocity, mode of travel														
Too fast	10	52	4			45			6					7
Startling	**22**	**54**				39	12		10	1		4		10
Noisy	0	7												7
Near collisions/falls	18	19			5	16					7	3	6	
Concern for safety	0	13				13								
Inappropriate/Destructive track use														
Unaware of proper trail use	27	9	6		6	8			15	1				
Overuse/congestion	8	**10**			5	10			3					
Illegal access	40	0	18						10		12			
Unleashed dogs, dog attacks	**66**	11									66	11		
Trail damage	38	0					6						32	
Trail pollution (dogs, horses)	10	0					3				7			
Obstruction	**31**	1			5				20	1	6			
Negativity expressed towards others														
Negative beliefs/attitudes	9	0							9					
Annoyance/offence	**22**	1							17	1	5			
Rudeness	21	15				6			7			3	14	6
Unfair treatment	6	0							6					
Sum	328	192			21	**137**	21	0	**103**	4	**103**	21	52	30

Velocity and mode of travel caused issues when trail users travelled/approached too fast, startled others, were too noisy, and caused near collisions/falls; and horse riders had particular concerns for the safety of their horses. Conflicts were also noted where trail users obstructed/dominated the trail. Inappropriate/destructive trail use incited conflicts when trails became overused/congested; or trail users caused damage to the trails and surroundings; trail users accessed trails illegally; trail users were unaware of the proper use of trails. Facility issues aggravated such conflicts where trails were narrow ($n = 3$); blind corners caused incidents ($n = 25$); and trails went downhill ($n = 5$). Finally conflicts arose specific to encounters with dog walkers and horse riders, most prominently when dogs were not kept on a leash, or dogs chased/attacked/injured others, and in a few cases because dogs or horses polluted the trails. Issues with trail use by other groups created negativity towards others, and caused further conflicts. This included trail users expressing negative attitudes, annoyance/offence, and trail users behaving in a discourteous manner, or treating others unfairly. Although many of the comments were presented in the context of actual personal experiences, we noted 62 and 34 comments made by mountain bikers and horse riders, respectively, that lacked any personal context and suggested a purely social value conflict without interpersonal conflict.

Figure 4. Integrated model of trail user conflicts showing the interrelationships between tourism and recreation conflict reasons and resolutions.



3.5 Conflict resolution

In the survey, we asked participants to rate several measures to resolve or mitigate conflicts (Table 2; Table 3). Both mountain bikers and horse riders thought signage to inform about other user groups to be the most effective measure. Horse riders rated the distribution of information identifying needs, safety issues and priorities for all park users as the second most important measure, followed by the provision of separate user-specific single trails. Mountain bikers also rated the provision of single-directional loop trails that disperse different visitor groups highly. Interestingly, expert mountain bikers thought that multi-use trails fostering a greater understanding between visitors were effective, and generally rated most measures more highly than other mountain bikers.

A total of 157 comments were received from 97 mountain bikers on strategies to resolve or mitigate conflicts. A further 69 comments were received from 38 horse riders relating to the most promising conflict management strategies including management of trail types, stakeholder management and to a lesser extent policing (summarised in Figure 4).

As for the management of trail types, riders specifically recommended offering more/improved dedicated/purpose-built trails (n_{mb} = 23; n_{hr} = 12); and more trails that are shared between different trail users (n_{mb} = 11; n_{hr} = 2); single-directional loop trails that disperse different visitor groups (n_{mb} = 6) were recommended less often; temporal segregation was rarely suggested where specific times/days of trail use are allocated to different visitor groups (n_{hr} = 2). Intelligent trail design in accordance with guidelines was another suggestion (n_{mb} = 16).

Stakeholder management should be achieved through education and facilitated interaction/dialogue, and various other means (n_{mb} = 14; n_{hr} = 9), to encourage different user groups to agree on/adhere to specific trail rules (n_{mb} = 14; n_{hr} = 3); educate on proper trail use (n_{mb} = 6) and on how to approach horses on the trail (n_{hr} = 12); develop a greater sense of mutual understanding/respect (n_{mb} = 17; n_{hr} = 4); raise awareness of each other's needs (n_{mb} = 2). This may require better signage on/near trails (n_{mb} = 15; n_{hr} = 12); and the provision of online information (n_{mb} = 5). Horse riders suggested that peers should advise others about conflict prevention/resolution (n_{hr} = 3).

Policing should reinforce that dog walkers keep their dogs on a leash (n_{mb} = 4; n_{hr} = 1); apply penalties to all trail users for illegal access of trails (n_{mb} = 4; n_{hr} = 1); and in particular apply penalties for illegal access of trails by motorbike riders (n_{mb} = 4); reinforce that trail visitors slow down for safety reasons (n_{mb} = *2;* n_{hr} = 8); and consider other means (n_{mb} = 14) such as to create barriers to slow riders down; increase patrolling through park rangers; reinforce limited access to riders to some trails.

4 Discussion

We structure our discussion by evaluating how PPGIS mapping performed in predicting the location of visitor conflict within the study area. We then compare and contrast PPGIS mapping methods with other visitor-monitoring techniques to assess the relative strengths and limitations of the PPGIS methods. Finally, we seek to advance understanding of trail-use conflict by combining the empirical findings of this study with current knowledge of trail-use conflict in an integrated descriptive model..

4.1 Predictions of conflict locations

This study used PPGIS mapping to determine potential and actual locations of conflict between trail visitors frequenting parks for tourism and recreation. PPGIS mapping was invaluable for identifying multiple visitor activities in concurrent-use locations as a spatial predictor for conflicts. Usage intensity is important when predicting tourism impacts (Wolf & Croft, 2014; Wolf, Hagenloh, & Croft, 2012, 2013), and specifically conflicts from concurrent use as conflicts most likely occur where different activity groups meet frequently (Santos et al., 2016). PPGIS mapping captured the number of trail visitors and frequency of usage based on marker counts associated with various trails. Actual conflict locations mapped by participants corroborated that conflicts occur along concurrent high-usage trails. The three trails where horse riders experienced the majority of conflicts with mountain bikers and vice versa included the three trails where high-usage horse riding coincided with high-usage mountain biking. Conflicts were rarely mapped in low-usage areas, and no conflicts were mapped without overlap in usage. Thus, concurrent high usage of trails was a good predictor for inter-activity conflicts.

Horse riders mapped more conflicts with mountain bikers indicating that conflicts were asymmetric. Horse riders had significant concerns for the safety of their horses while sharing trails with others which was noted elsewhere (e.g. Cessford, 2003). Encounters with walkers do not pose safety and noise concerns which explains why horse riders did not map any conflicts. In this study, mountain bikers and horse riders could place markers on conflicts with other mountain bikers, horse riders and walkers. In the future, other visitor groups could be considered by adding marker types to the PPGIS, especially if asymmetric conflicts are expected.

The greatest number of intra-activity conflicts was also mapped along high-usage horse and mountain bike trails, but intra-activity conflicts were localised and many of the high-usage trails were not flagged for such conflicts. Thus, high trail usage is not necessarily a good predictor of intra-activity trail conflict if they are rare and localised.

As Santos et al. (2016) highlighted, usage intensity plays an important role when predicting conflicts from concurrent use as conflicts most likely occur where different activity groups meet frequently. A benefit of the PPGIS method was the ability to narrow the focus of conflict management from many to only a few trails even without investigating frequency of usage through active field monitoring. PPGIS appears especially useful as an initial diagnostic to assess conflict potential in settings with an extensive and spatially-dispersed trail system where real-time monitoring would be difficult or not cost-effective. If the diagnostic results indicated a large number of high-usage trails (>50 location markers), the results would suggest partitioning the study area to provide greater spatial resolution for identifying visitor conflicts. Regarding the temporal component of potential conflict, the mapping of trail-use location information, in combination with general survey questions about seasonal and daily usage within a range of times, was adequate as a management diagnostic for the purposes of this study. A more specific time-of-day variable when people ride could be added to the PPGIS marking system to improve detection of overlap in use and crowding on specific trails. However, the benefit of collecting specific time information would need to be carefully weighed against the time and cognitive burden on study participants where participants already identify trail location and activity information.

The effectiveness of PPGIS methods is highly sensitive to sampling design and participant characteristics (Brown, 2017). The target population for participation influences PPGIS design parameters. Our sample comprised many visitors who have been active riding in NSW and therefore knew the study area well, which increases reliability of the PPGIS results. If the sample mainly comprised first-time or interstate visitors, maps would need to contain landmarks for orientation. To recruit a representative sample, varied sources were used including rider clubs/associations, equipment stores and field interception. Although we queried mountain bikers and horse riders in relation to conflicts with other trail visitor groups, these other groups need to be included in the future to gain a more comprehensive understanding of conflict relationships and benefit from the expertise of these different groups. Knowledge of other stakeholders such as tour operators facilitating mountain biking and horse riding in parks could be harnessed too. Maps can be generated to compare preferences between different stakeholder groups or the distributions of different visitor groups such as first-time versus repeat visitors, different age groups or visitors travelling for a specific purpose, where such information is available.

4.2 PPGIS mapping compared to other visitor-monitoring techniques

PPGIS mapping has been trialled for monitoring visitor experiences within a park or regional setting (Pietilä & Kangas, 2015), but the implementation of PPGIS for identifying potential conflict along linear features such as trails appears novel. A range of techniques are available to park management agencies to monitor visitor conflicts. In the following we outline the respective strengths and weaknesses of these techniques, as summarised in Table 5, based on our own knowledge and the following publications: Muhar, Arnberger, & Brandenburg (2002), De Bie & Wolf (2016), Cessford & Burns (2008), Cessford, Cockburn, & Douglas (2002), Cessford & Muhar (2003), Cope, Doxford, & Probert (2000), Griffin, Moore, Crilley, Darcy, & Schweinsberg (2010), Hornback & Eagles (1998), Kajala (2007), Veal (2006), Watson, Cole, Turner, & Reynolds (2000), Wolf, Hagenloh, & Croft (2012), Wolf, Stricker, & Hagenloh (2013), Wolf, Wohlfart, Brown, & Bartolomé Lasa (2015) and Wolf & Wohlfart (2014).

Much of the information that parks require regarding visitor conflicts is location specific, such as where does usage overlap and conflicts occur. The most effective way to capture and visualise location-specific information is through maps. These can be produced from PPGIS mapping which enables a sophisticated GIS analysis with great visualisation options. PPGIS mapping has the benefit of generating detailed spatial information on visitor use of individual trails over a reasonably large study area, data which are typically unavailable in parks and cannot be obtained from direct observations at the same scale. An advantage compared to GPS tracking is that data are independent of the sampling period so the overall coverage ("where do people experience conflicts in general") is more extensive. This applies to other techniques where data are derived from people's verbal accounts of their past activities such as surveys. Compared to surveys however, we noted that the novelty of the PPGIS increased attention span of participants and therefore PPGIS platforms coupled with surveys are likely to achieve considerably longer participation times (>20 minutes). This is critical as data quality and quantity depend on the amount of time people are willing to invest.

Table 5. A comparison of techniques to monitor visitor data needed for conflict management in parks.

	Verbal accounts		Direct observations	Indirect observations		
	PPGIS mapping (online vs. field/paper-based)	Surveys	Personal observation	(PPGIS) GPS tracking	Traffic counters	Cameras
Type of data	Con: Stated.	Con: Stated.	Pro: Greater control of representativeness of sample as sample does not depend on who chooses to participate. Directly observed and therefore data (e.g., visitor numbers per site) are 'actual' and accurate provided that visitor traffic is not too high. Con: Subjective interpretation of observations	Con: Indirectly observed. Privacy issues. However since participation is knowingly and voluntary these can be addressed during the briefing.	Pro: Greater control of representativeness of sample as sample does not depend on who chooses to participate. Con: Indirectly observed.	Con: Indirectly observed. Accurate only if visitor traffic is not too high. Privacy issues. Subjective interpretation of observations (especially behaviour).
Data coverage	Pro: Generates detailed information on visitor distributions (point locations) over a reasonably large study area. Not restricted to a sampling period so the overall coverage ('where do people visit in general') is more extensive. Could generate estimates of actual park use if coupled with methods that determine absolute visitor numbers. Con: No networks, no time data. Potential issues with recall.	Pro: Collects various visitor data useful for conflict management, apart from location data. Not restricted to a sampling period so the overall coverage ('where do people visit in general') is more extensive. Con: Location data may be coarse or unspecific. Potential issues with recall.	Pro: Can include detailed observations of, for example, visitor characteristics and behaviour. Observers can relatively easily change locations in different sampling periods. Con: Monitoring of only one site at any one time by one observer, therefore spatially restricted and prone to capture short-term fluctuations in visitor behaviour. Not useful for extended observation periods and therefore tends to be used unsystematically and opportunistically, especially in low-traffic areas (long periods without visitors). Data are restricted to a sampling period.	Pro: In-depth spatio-temporal data, whole networks, can be used for visitor tracking over an extended time period. Could generate estimates of actual park use at each point in the park if coupled with methods that determine absolute visitor numbers. Con: Data are restricted to a sampling period.	Pro: Generate accurate absolute visitation data, given a proper installation, calibration and correction for possible counting errors. Con: Usually used to monitor key locations due to cost and maintenance. Depending on counter type, effort to move locations can be great. Data are restricted to a sampling period.	Pro: Locations are more flexible compared to some type of traffic counters. Can generate detailed data of, for example, visitor characteristics and behaviour. Con: Nonetheless, generally better suited for permanent sites or key access ways. Can be difficult to distinguish passenger numbers when using vehicle counts (compared to direct observations). Data are restricted to a sampling period.
Analysis and data processing time	Pro: Sophisticated analysis with great visualisation options. Con: (Very) high effort, however data sets are smaller compared to GPS tracking. Additional time needed to digitise data if collected in the field. Requires expertise in GIS data management and analysis – analysis can be quite time-consuming.	Pro: Intermediate effort required. Con: Effort increases with number of open-ended comments, especially if location data with ambiguous names need to be matched to official names. Manual transfer of location data needed for mapping.	Pro: Effort varies depending on type of data collected.	Pro: Sophisticated analysis with great visualisation options. Con: (Very) high effort due to the continuous tracking and large datasets. Requires considerable expertise in GIS data management and analysis – analysis can be quite time-consuming.	Pro: Low effort required. Con: Retrieval of data (travel time) may be time-consuming if data loggers are not remotely accessible.	Con: Time-intensive to evaluate recordings.
Sampling efficiency	Pro: Great (online; if response rate is high). Can achieve high response rates, possibly higher than traditional questionnaire-based surveys if the innovative form of data collection appeals to participants resulting in word-of mouth recommendation and longer attention spans (willingness to participate for longer). Con: Low (field)	Pro: Great (online; if response rate is high). Con: Low (field).	Con: Low. Costly in staff time (travel time, on-site time).	Pro: Intermediate. Con: Response rates might be lower than for standard surveys as time commitment is greater and privacy concerns could arise.	Pro: High, if a sufficient number of counters has been installed.	Pro: High, if a sufficient number of cameras has been installed.
Time commitment by participants	Pro: Low to intermediate (field) Con: Intermediate to high (online)	Pro: Intermediate effort and can easily be varied with survey length.	Pro: None.	Con: High.	Pro: None.	Pro: None.
Hardware and equipment	Pro: None (field) Con: Requires internet (online).	Pro: None.	Con: Binoculars (optional).	Con: Requires GPS tracking devices. Potential loss of equipment if people fail to drop it off, although to our knowledge this has not been reported as a major issue.	Con: Requires traffic counters, power source, data logger. Equipment may be conspicuous. Non-target counts may be recorded. Cost to buy and install, proneness to vandalism/damage; varies with counter type. Power requirements pose issues for long-term monitoring at unattended sites.	Con: Equipment is costly and potentially vulnerable to damage. Power requirements pose issues for long-term monitoring at unattended sites.
Technical knowledge	Pro: Low (field: map literacy). Con: Intermediate (online: computer capabilities; map literacy).	Pro: None (field). Con: Intermediate (online: computer capabilities).	Pro: None.	Con: Intermediate, if participants have to supply the GPS tracking data.	Con: Requires sensitivity adjustment and calibration for different vehicle types and loadings. Depending on counter type can have issues with aggregation of visitors where more than one person passes counter at the same time, and with detection range (optical detectors).	

We used a combination of online and paper-based PPGIS mapping, with the main difference being that the sampling efficiency is much greater online compared to time-intensive field sampling. Irrespective of the sampling and data collection mode, map literacy is important to participation in a PPGIS mapping study. In sampling populations with lower map literacy, “facilitated” mapping in the presence of a research team member can be used to increase the quality of spatial information collected (Zolkafli, Brown, & Liu, 2017). For “self-administered” online PPGIS surveys, website design features can improve the capacity to place markers in the correct locations. For example, the online mapping function was only enabled after reaching the required zoom level. Study area boundaries, landmarks, and most trails were provided to orient the participant within the study area. In the field, the large size of the map and the standardised introduction to familiarise participants with the map were helpful.

The PPGIS generated information about time, place and activities, including the relative popularity of different areas but not data on absolute visitation. However, there is potential to use PPGIS data that are calibrated with field observations such as through traffic counters to derive estimates of actual track use to determine social carrying capacities and management thresholds required for conflict management.

Location-specific information on visitor conflicts can also be collected in traditional non-spatial surveys with questions asking about conflict locations, reasons and potential overlap with visitor activities. However, a major drawback with traditional surveys is that location-specific survey data need to be manually assigned to map locations which is time consuming and error prone (Muhar et al., 2002; Wolf et al., 2012). In our study, survey comments about conflicts were more extensive than the placement of conflict markers in the PPGIS. This may be due to response fatigue, as suggested in other PPGIS studies (Brown, Schebella, & Weber, 2014), given the conflict markers in this study were the last listed among 34 marker types. If the main focus of PPGIS mapping is on conflict, then conflict markers should be presented as an early option in the process. Participant recall may have also contributed to observing fewer conflict markers than comments. Many advanced and expert mountain bike riders have been riding for more than 10 years, where recall of conflicts experienced in particular locations may be limited compared to trail design or maintenance issues that occur consistently in the same location. A final explanation for the observed conflict marker counts is that some participants may have withheld from mapping, especially if they expected repercussions for pursuing their activities in parks. Despite the relatively low number of specific conflict markers, we nonetheless recommend that PPGIS mapping include them in addition to location markers, as conflict markers can validate predictions from investigations of concurrent use.

Direct observations by park staff or others are another method to record conflicts between visitors. Observers at strategic locations may record conflict behaviour, visitor numbers, characteristics and other behaviour, travel routes/spatial distributions, date and time entered/left, and vehicle type/pedestrian, passengers per vehicle/group size. Direct observations have the advantage that they can deliver accurate information of actual conflicts, provided that visitor traffic is not too high, and observation locations are flexible. Disadvantages are that observations are costly in staff time, not useful for extended periods (and therefore often opportunistic), sampling efficiency is low as only one site can be observed at a time, and there is potential for observer errors. Direct observations are therefore only recommended if specific insights are needed on visitor conflict behaviour rather than for conflict distribution mapping.

Traffic counters are one of the most commonly used methods for collecting information on visitor volumes and distributions in parks, and appeal because of the timesaving nature of data collection and lack of time commitment needed from participants. However, they can only be used to record visitor numbers, time and date, and in some cases speed, direction of travel and vehicle class, as opposed to the wide range of data attainable through a combined PPGIS and survey approach. Hotspots of activity overlap can be identified with traffic counting but only in the limited number of locations where the counters are based and where they are appropriately supported with maintenance, calibration studies and data retrieval protocols. Problems associated with traffic counting include, for example insufficient resources to service counters; equipment failures; vandalism or theft of counting units; insufficient durability and poor maintenanceand data being used without being supported by appropriate, recent and accurate calibration studies (Griffin et al., 2010).

Data for conflict management can also be collected with continuous video recording such as visitor numbers, date and time, travel direction, spatial distribution, group size, visitor characteristics and behaviour. However, this requires a time-consuming manual evaluation. Time-lapse video or photo recording is mainly useful to determine visitor numbers but can possibly be evaluated to collect the other variables mentioned above with the exception of spatial distributions. Arnberger and Eder (2008), for example, applied video monitoring to identify specific causes of visitor interactions and what they depended on at access points to shared trails in an urban forest in Vienna. Other disadvantages of video or photographic recordings include that the equipment is costly and vulnerable to damage, power requirements pose issues for long-term monitoring of unattended sites, and there could be privacy issues of recording people who did not consent.

GPS tracking, a form of PPGIS where participants are equipped with a GPS data logger that tracks their travels, delivers the most granular data on visitor movement including small-scale variations in visitor distributions and whole networks of travel. Same as for the PPGIS mapping, GPS tracking allows for sophisticated GIS analysis and visualisation. Participants can also be tracked over longer time periods (e.g.Wolf, Wohlfart, et al., 2015) and, same as with the PPGIS, GPS tracking could generate estimates of actual park use at each point in the park if coupled with methods that determine absolute visitor numbers. The major drawback is that datasets are typically much larger compared to PPGIS mapping which impacts data management and analysis; also the sampling efficiency is lower as more effort is required to collect data, e.g. to distribute and retrieve equipment, or participants who provide their own tracking equipment need to be instructed on settings to track themselves. Also response rates might be lower than for standard surveys as time commitment from participants is greater; potential loss of equipment if people fail to drop it off and privacy issues may be other concerns. GPS tracking can however be coupled with PPGIS mapping to validate its results (Wolf, Wohlfart, et al., 2015).

Santos et al. (2016) have presented results of a volunteered geographic information (VGI) system to predict conflicts through investigation of the concurrent usage intensity based on rides/runs shared by mountain bikers and runners online. This could be a useful alternative or addition to PPGIS mapping and GPS tracking.

5 Conclusions

Park trail use is a natural source of potential visitor conflict because different tourism and recreation activities spatially and/or temporally coincide. Figure 4 summarises the sources and potential resolutions of visitor conflict as described in the literature, in combination with our empirical findings from this case study: Conflicts occur where trail visitor activities coincide spatially and/or temporally and require innovative forms of monitoring such as PPGIS mapping. The type of activity may influence conflicts where encounters with more contested activities can trigger asymmetric conflicts. Various visitor behaviour characteristics described by Jacob and Schreyer (1980) were noted as a source for conflict in this study, including resource specificity, and the herewith added, related but more complex construct of place attachment, where one attaches value to a particular trail. Trail users with intense activity styles, assigning great personal meaning to an activity, are prone to conflict. Hierarchical status acquired through technical expertise can lead to conflicts between visitors of a different status. Finally the mode of the experience, ranging from unfocused to focused, and lifestyle tolerance, an individual's tendency to accept or reject a lifestyle different from their own, can cause conflicts. These visitor characteristics along with the reported issues with differing trail use lead to goal interference-related conflicts, reflecting direct personal contact or indirect observation of the conflicting activity. Differences in social values (Carothers et al., 2001; Vaske et al., 2007) deeply rooted in diverging beliefs and attitudes can also lead to conflict in the absence of (in)direct interaction. To achieve a sustainable coexistence of different tourism and recreation activities along multi-use trails, policing has its place although more indirect trail and stakeholder management measures may be preferred. Communication measures that achieve a shift in conflict behaviour such as persuasive communication interventions (e.g. Hughes, Ham, & Brown, 2009; Steckenreuter & Wolf, 2013) should be considered as part of a park agency's strategic conflict management plan in addition to demarketing attempts where trail usage is steered by "unselling" particular trails (Armstrong & Kern, 2011; Groff, 1998).

Visitor conflict occurs within a spatial context and thus conflict management will also require greater spatial knowledge of visitor activity. Monitoring of conflicts through innovative methods such as PPGIS mapping will be essential to identify and manage conflicts along multi-use trails in the future. To our knowledge, we presented the first comprehensive evaluation of a public participatory research approach (PPGIS mapping) to aid decision-making on selecting appropriate methods to monitor visitor conflicts in academic and park management studies. In-depth comparisons were made with other techniques including questionnaire-based surveying, direct visitor observations and indirect observations through PPGIS (GPS) tracking, traffic counters and cameras (Table 5). PPGIS mapping in this study was effective for identifying trails used by different visitor groups, and showed promise for predicting areas of conflict. A survey was used to validate findings from the PPGIS mapping, and to explain conflict reasons and identify measures for mitigation. From a high number of trails, a few trails were identified where conflicts are most likely. This information is most critical for tourism and recreation management in allocating limited park resources to the areas of greatest concern, and for academics to correctly identify potential hotspots of usage and conflict in order to link these to other variables. For example, the effect of specific trail visitor characteristics, distributions and intensities or conflict resolution measures can be tested on conflict occurrence to validate the model of the relationship between reasons and resolutions for visitor conflicts that we created (Figure 4) which will further our understanding of social use and effects in tourism and recreation systems.

We see PPGIS methods as offering an alternative set of recreation and visitor management tools that supplement and complement existing research methods. The older Recreation Opportunity

Spectrum (ROS) model (Clark & Stankey, 1979) and associated literature does not offer specific guidance for trail-use conflict and management because it does not scale well to specific linear features. ROS lacks the spatial precision required to adequately inform the management of multi-use tails. At the other end of the spatial scale, the more recent work of Manning and others (e.g. Manning & Freimund, 2004; Rathnayake & Gunawardena, 2014) on visual crowding and norms using photography and simulation in site-specific park settings is more closely related to this PPGIS research. However, this latter visual approach may be too site specific to be cost-effectively applied to larger trail systems such as those described in this study. The PPGIS approach occupies the spatial middle ground between ROS and site-specific visual studies. As a conflict diagnostic, PPGIS can identify trail segments that would benefit from more site-specific investigation and management.

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