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The use of public participation GIS (PPGIS) for park visitor management: A case study of mountain biking

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HIGHLIGHTS

- We evaluated the utility of public participation GIS (PPGIS) in park tourism planning.
- Our method was effective for engaging mountain bikers in complex spatial planning.
- Insights were gained on rider distributions, underlying reasons and management actions.
- We used GPS tracking to validate and surveys to complement PPGIS mapping data.
- We discuss the benefits of mixed PPGIS delivery modes (field vs. online data).

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ABSTRACT

Spatially-explicit participatory planning is a relatively new approach for managing visitors to protected areas. In this study we used public participation geographic information systems (PPGIS) mapping and global positioning system (GPS) tracking to monitor mountain bikers frequenting national parks for tourism and recreation in Northern Sydney, Australia. PPGIS was implemented using both an internet application and with hardcopy maps in the field. Our research addressed two fundamental questions for park planning: (1) What is the spatial distribution of visitor activities and location-specific reasons for riding; and (2) What location-specific actions are needed to improve riding experiences? The spatial distributions of riding activities generated in PPGIS showed strong correlation with the GPS tracking results, with riding locations being related to the reasons for track selection. Riders proposed a broad range of management actions to improve riding experiences. PPGIS mapping provides a cost-effective approach to facilitate spatial decision making, allowing park agencies to prioritise future visitor management actions. We discuss the strengths and limitations of these research methods.

1. Introduction

Providing quality tourism and recreation experiences is essential for national parks and other public lands to cultivate social support for their protection. Developing national park experiences that promote short and long-term benefits for visitors (Driver, 2008; Wolf, Stricker, & Hagenloh, 2015) may assist in conserving the natural and cultural values of parks (Weiler, Moore, & Moyle, 2013). To create a diverse and high-quality range of experiences, park managers need to understand the potentially conflicting demands of different visitor groups.

Visitors typically favour specific park locations and times along with supporting facilities that best provide for their preferred activity. These choices are reflected in visitors' spatio-temporal usage patterns of tourism and recreation areas (Wolf, Stricker, & Hagenloh, 2013; Wolf & Wohlfart, 2014). Parks need to supply experiences and facilities consistent with demand to satisfy visitor expectations and to protect natural resources from oversupply (Buhalis, 2000). Popular activity groups in parks around urban centres, such as mountain bikers, require tracks with distinct properties to achieve a desired experience for different styles of

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riding and trip motivations (Newsome & Davies, 2009; Symmonds, Hammitt, & Quisenberry, 2000). Hence, park tourism and recreation management requires critical information on the frequencies and spatial patterns of park use as a predictor of demand (Eagles, 2014), and the underlying visitor motivations that inform management actions to improve visitor experiences. Spatially-explicit information is also needed to better manage crowded areas and conflicts, and to foresee the partitioning of resources between visitor groups (Ostermann, 2009). However, for most parks there is very little information available on the spatio-temporal distributions of visitors and their location-specific needs (van Schaick, 2010).

While the use of detailed spatial data on the ecology, infrastructure, and other attributes of the landscape is common, social data at a similar spatial scale are much rarer, limiting visitor activity management and planning in parks. This issue is aggravated where the activity extends beyond park boundaries across land tenures managed by multiple agencies with variable approaches to visitor data collection and sharing. Mountain biking, for example, occurs on a range of public land tenures as well as on private lands such as commercial mountain bike parks. This demonstrates the need to increase the spatial extent of visitor monitoring efforts beyond park boundaries.

Spatially explicit social data on management processes of public lands can be collected from stakeholders through participatory planning processes. Growing attention has been given to the importance of engaging people for tourism and recreation planning across single and multiple land tenures. Public participation can enhance the quality and acceptance of decisions with spatial implications and alleviate concerns of the community when altering their environment (Raymond et al., 2009). Public participation geographic information systems (PPGIS) use geospatial technology to inform planning processes with public knowledge by inviting participants to provide geospatial information about perceived attributes of place (Sieber, 2006). This has relevance for tourism and recreation areas where visitors have particular needs regarding specific precincts and facilities such as tracks used for mountain biking. Brown and Weber (2011) described PPGIS as " … *the practice of GIS and mapping at local levels to produce knowledge of place*". This methodology finds application in many research areas such as socio-ecological hotspot mapping (Alessa, Kliskey, & Brown, 2008), identification of ecosystem services (Brown, Montag, & Lyon, 2012; Brown & Raymond, 2014; Raymond et al., 2009), land use conflicts (Brown & Raymond, 2014), forest planning (Brown & Donovan, 2013; Brown & Reed, 2012), tourism management (Brown, 2006; Marzuki, Hay, & James, 2012), public land management (Brown, Weber, & de Bie, 2014), and a growing list of other applications (see Brown & Kyttä, 2014 for a recent review). Further, Brown and Weber (2011) consider PPGIS to have great potential to advance national park planning of visitor experiences while there is a growing trend in the use of spatial information in park and protected areas management (Beeco & Brown, 2013). In PPGIS mapping, information is solicited by requesting participants to identify and mark locations on a map about perceived place attributes. PPGIS mapping may be administered in the field (e.g., private homes, park visitor centres) through mail surveys (Brown, 2004), stakeholder workshops (Donovan et al., 2009) or personal interviews and surveys (Donovan et al., 2009; Raymond et al., 2009) that typically use a hardcopy form of data collection. In contrast, internet-based implementations of PPGIS mapping, as advertised through mass media, email lists or online panels have numerous advantages (as reviewed by Pocewicz, Nielsen-Pincus, Brown, & Schnitzer, 2012) especially in the reduction of costs and the increased efficiency of data collection and entry (Couper & Miller, 2008). It is useful to compare the results achieved with both field- and internet-based PPGIS mapping to determine the representativeness of the recruited sample population and to identify other potential biases resulting from the data collection (Olsen, 2009). Outcomes that may vary with the mode of the PPGIS application include the participation rate, and the number and spatial distribution of mapped attributes of place. For example, Pocewicz et al. (2012) found that field-based PPGIS resulted in higher participation rates and greater numbers of mapped attributes.

PPGIS mapping provides insights into spatial distributions of attributes such as the locations people report to visit, and possibly the frequency of visitation, but not the exact time spent at specific facilities and attractions. In contrast, GPS tracking data presents actual (vs. reported) spatio-temporal distributions of visitors and captures entire travel routes (vs. singular locations) of visitors (Orellana, Bregt, Ligtenberg, & Wachowicz, 2012; Wolf, Hagenloh, & Croft, 2012). Typically this information is collected from visitors equipped with personal GPS receivers such as smartphones using tracking applications, or those supplied by a researcher. GPS receivers are easy to use with comparatively little effort required from participants apart from carrying and returning the equipment. More effort is involved in PPGIS mapping where participants need to accurately recall, locate, and mark specific places on a map to assign spatial attributes. In this study, we will evaluate the benefits and disadvantages of GPS tracking and PPGIS mapping to address different park management questions.

National parks and other public green spaces are frequented for a range of activities including mountain biking (Heer, Rusterholz, & Baur, 2003; Newsome & Davies, 2009). In recent decades the popularity of mountain biking has increased significantly in Australia, New Zealand (Mason & Leberman, 2000; Newsome & Davies, 2009; Ryan, 2005), North America (Attarian, 2001; Cordell, 2008) and Europe (Christie et al., 2006; Heer et al., 2003). A study by Christie et al. (2006) for instance revealed that technical single-track mountain biking and cross-country mountain biking, enjoyed by 20.0% and 10.5% of all visitors, respectively, were some of the most common visitor activities in seven forest areas in Great Britain. The Australian Cycling Participation survey 2013 (Australian Bicycle Council, 2013) showed that 37.4% of people in Australia participated in cycling over the last year with an increasing trend compared to previous years. The survey, however, did not segment by type of cycling.

Our study focused on mountain biking in the semi-rural, Northern Sydney area where demand for this activity is rapidly growing in national parks and surrounding land tenures. Increasing demand has resulted in the development of formal strategies to promote and sustain high-quality mountain biking experiences in national parks in Sydney and other parts of New South Wales (NSW). In 2011, the Office of Environment and Heritage NSW (2011) published a strategy that outlines the provision of high quality, sustainable mountain biking experiences that (1) improve and maintain existing tracks, (2) identify suitable links between tracks, and (3) where appropriate, develop new mountain biking experiences consistent with standards for design, construction, and maintenance proposed by the International Mountain Bicycling Association. The strategy targets all skill levels, as well as families and other travel groups to provide diverse riding experiences. In the strategy, high importance is placed on communication and consultation to build a strong partnership between management agencies and public stakeholders of mountain biking activities. Mountain biking currently co-exists with other tourism and recreation activities on certain multi-use trails in the region where potential conflicts need to be monitored closely, especially if demand for this activity continues to grow.

The aim of this study was to evaluate the utility of PPGIS in park visitor activity planning, exemplified in the context of mountain biking in Northern Sydney. The methods used and the findings of our study are relevant to the full spectrum of travel experiences on a continuum ranging from recreational activity to tourism experiences (McKercher, 1996). Our specific research questions include: (1) What are the spatial distributions and location-based reasons for mountain biking in the region; and (2) What location-specific management actions are required to improve existing experiences. We analyse our study results at different spatial scales: the Northern Sydney region, inside vs. outside national parks, and for individual tracks. To our knowledge, this is the first study to use PPGIS methods to evaluate mountain biking activities. Participant characteristics, collected from survey questions, are integrated with the spatial data to address more complex questions such as how rider preferences vary with skills and motivations. Finally, we examine PPGIS mapping results, conducted in the field or on-line, with GPS tracking results to validate the accuracy of the PPGIS methods.

2. Methods

2.1. Study area

This study was conducted approximately 5 km north of the Sydney central business district and the Sydney Harbour, covering an area of 561 km^2 (Fig. 1). The study area encompasses several local government councils, the Municipality of Lane Cove and the City of Ryde. A variety of national parks are accessible to riders including Ku-ring-gai Chase National Park (14,882 ha), Garigal National Park (2150 ha), Berowra Valley National Park (3884 ha), Lane Cove National Park (635 ha) and parts of Sydney Harbour National Park (392 ha). In the study area, there is demand to increase the number of authorized trails for mountain bikers in both national parks and adjacent tenures (Office of Environment Heritage NSW, 2011; Warringah Council, 2012) where numerous tracks traverse lands managed by different authorities. Thus, an important aspect of the study was to differentiate between riding within and outside of national parks as a cross-tenure approach is essential to planning quality mountain biking experiences with appropriate track lengths and linkages.

In NSW national parks and reserves, mountain biking is allowed on all public access roads managed by the NSW National Parks and Wildlife Service (NPWS) and on most management trails that are shared with other park visitors. Mountain biking and horse riding co-exist on some NSW national park trails and in other tenures, especially in the Terrey Hills area of Ku-ring-gai Chase National Park. Some of the most popular, legitimate mountain bike tracks are located outside of parks such as the purpose-built tracks at Manly Dam (Manly Dam Mountain Bike Circuit, administered by Warringah Council) and Old Mans Valley (Old Mans Valley Hornsby Mountain Bike Trail, administered by Hornsby Shire Council). Illegal mountain biking in prohibited areas and along unauthorised tracks also occurs in some NPWS parks in Northern Sydney and elsewhere in NSW, particularly in those parks located near urban centres. In recognition of the increasing demand for mountain biking experiences from both domestic tourists and recreationists in legitimate areas and to address illegal track creation, NPWS is planning to create sustainable experiences for riders of different skill levels. Several mountain biking parks and clubs are located in the area, including Jube Mountain Bike Park at Golden Jubilee Fields (Ku-ring-gai Council) and The Grove Bike Park (Manly Council).

2.2. PPGIS mapping and questionnaire

We administered PPGIS mapping and questionnaire-based surveys to mountain bikers, in the field and online, from January 2013 to July 2013. Participants were recruited by advertising the research via mountain bike riding clubs and associations in Northern Sydney. Additionally, advertisements were distributed in bike riding supply outlets. Invitations to participate provided a link to the mapping website and questionnaire along with information regarding the study purpose and methodology. Shopping vouchers were used as recruitment incentives and reminder invitations were disseminated throughout the sampling period.

Concurrently, participants were intercepted at track heads at multiple popular riding locations inside and outside national parks in Northern Sydney from Fridays to Sundays, on public holidays, and throughout the week during school holidays. People were randomly intercepted but needed to confirm that they in fact ride in the study area to qualify for participation. In addition, we distributed hardcopy invitations to riders who preferred to participate online.

Based on consultation with NPWS staff and following a literature review, three PPGIS marker groups were identified for the website to address the following questions: (1) On which tracks in Northern Sydney do participants ride and how often? ('location'); (2) What are the reasons to ride there? ('reasons'); (3) Which actions are required along these tracks to improve the experience of riders? ('actions', which also included markers to identify locations of conflicts with other visitor groups). Each marker group was represented by 8–14 individual markers that could be dragged onto a Google map (Fig. 2a–c; Table 1). The markers were pre-tested and revised in accordance with comments from NPWS staff. An operational definition of each marker was displayed if participants clicked on a particular marker (Fig. 2d). In January 2013, an interactive web-based PPGIS platform was launched (http://www.landscapemap2.org/nswmtnbike/). Upon accessing this website, a welcome page introduced the purpose of the research, the focus on the Northern Sydney area, study components (mapping, questionnaire) and approximate time needed for completion. Participants received a dynamic access code to enter the PPGIS website. After reading this background information and consenting to participate, participants were able to map locations, reasons, and actions by dragging different markers onto relevant map locations.

The map displayed 204 tracks known to be frequented by mountain bikers in Northern Sydney. Tracks were collated from NPWS GIS databases, a literature review, and online sources such as mountain biker clubs and track-share services (e.g., Strava). The initial track list was revised based on comments from mountain bikers. As there are many unofficial and lesser known tracks, the list was not exhaustive and so participants were instructed to place markers anywhere in the study area where they ride, even if a track was not displayed. In addition, we omitted to show several tracks known to be frequented by mountain bikers to discern whether participants would place markers along them. Instructions stressed to place markers exclusively within the study area which was clearly demarcated on the map. Participants were further instructed to place markers as close as possible to relevant tracks or specific locations along tracks (e.g., to indicate maintenance actions), or alternatively, to other non-track locations (e.g., to indicate where track linkages should be established; or along tracks not displayed on the map).

Participants were allowed to place markers once they had selected a minimum zoom level for the map (approximate scale 1:4500), which was chosen based on trials by NPWS staff. An option existed for participants to annotate markers, for example, to comment on why a track required a 'better track design'.

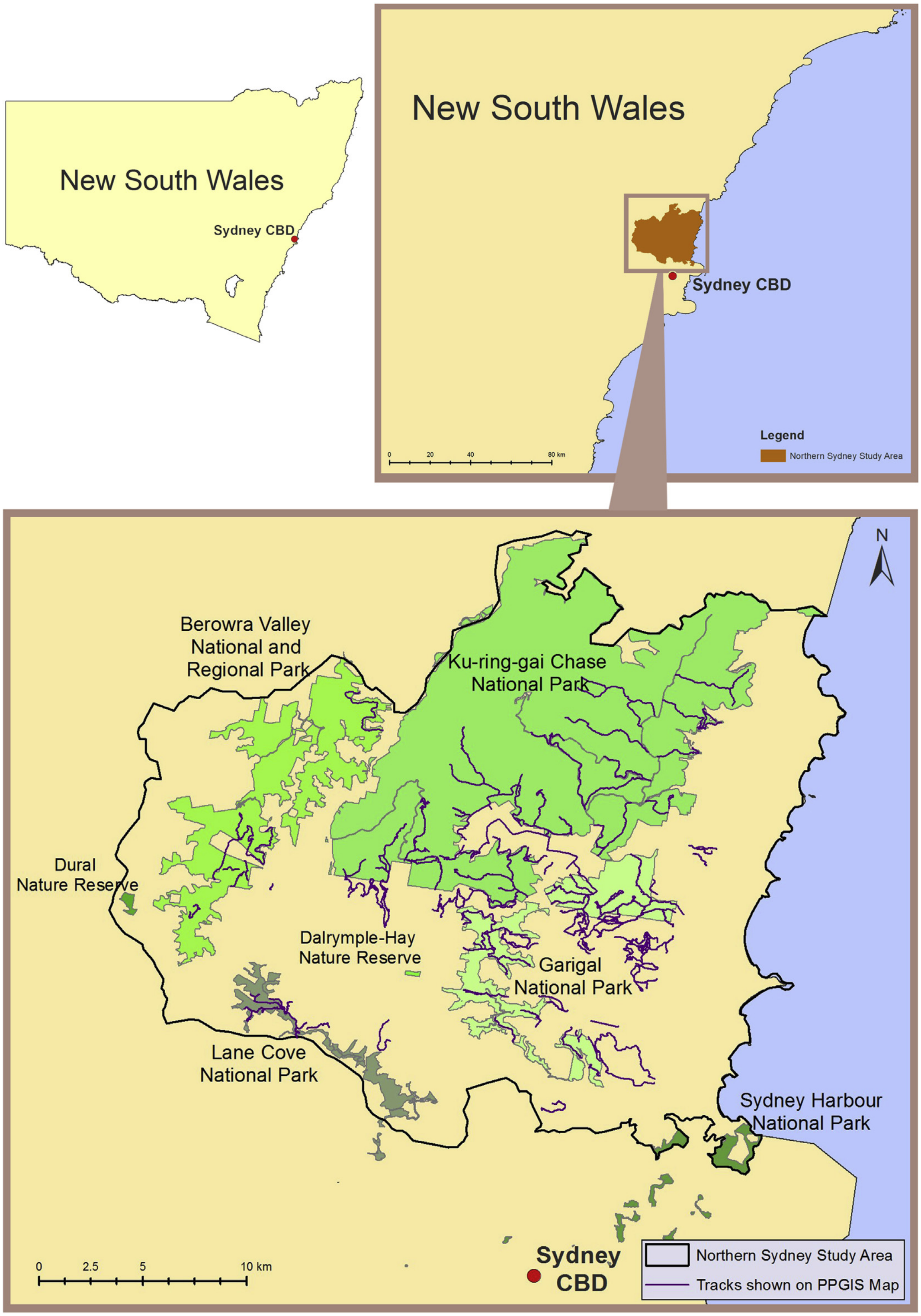

Fig. 1. Study area in Northern Sydney, New South Wales, Australia.

Participants could place as few or as many markers as they considered necessary.

The process was similar in the field, however, the researcher provided the instructions in person and markers were placed on an A0-hardcopy map. With this approach, annotations for individual markers were recorded separately and linked to specific markers by numbers. In both the online and field survey, participants needed to place at least one marker to be able to proceed to the accompanying questionnaire.

The questionnaire consisted of 29 questions and captured information on participants' socio-demographics, association with rider clubs, peak riding times and areas, riding skills, styles, preferences, importance of specific track properties and other facilities, track design, maintenance issues, and track experiences inside

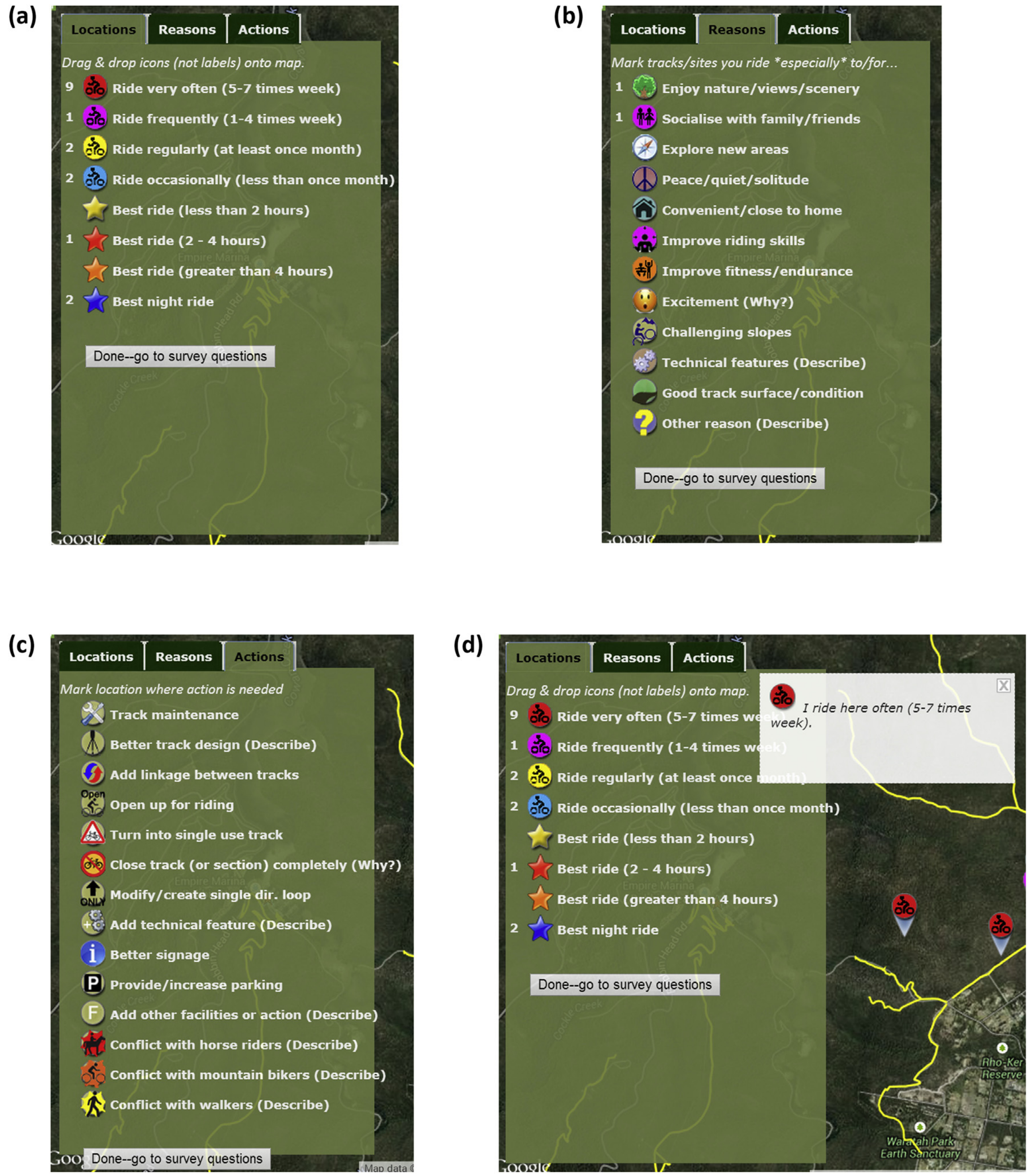

Fig. 2. PPGIS markers presented to mountain bikers to indicate (a) locations, (b) reasons for riding, and (c) actions to improve riding in Northern Sydney. (d) shows an example of annotations to explain marker symbols.

national parks compared to outside national parks. We also asked about conflicts with other visitor groups and solutions. All rating-scale questions were presented on a 5-point scale ranging from ‘Not at all important’ to ‘Extremely important’.

2.3. GPS tracking and questionnaire

For the GPS tracking component, mountain bikers were randomly selected from participants in the PPGIS mapping component who had expressed interest in this component of the study ($n = 329$; 49.3% of the mapping participants). If no response had been received after one week, a personal reminder was emailed. If another week lapsed without response, another reminder was sent. Non-respondents were excluded from further contact.

Participants were asked to record their rides in the study area using a smartphone tracking application or a GPS tracking device during a specified 4-weekly period between January 2013 and October 2013. Personal invitations were followed by detailed instructions for consenting participants. We aimed to collect rides from a similar number of participants per month but there was a bias towards spring when weather conditions were more favourable. We stressed the importance to record the same rides multiple times to indicate their popularity. Instructions further clarified which smartphone tracking applications to use, preferred settings to record tracks, and how to achieve the best possible satellite

Table 1
Marker categories and operational descriptions.

Locations	Description	Reasons	Description	Actions	Description
Riding frequencies		**Enjoyment**		**Track**	
Ride very often	I ride here often (5–7 times week).	Enjoy nature/ views/scenery	This track/site offers nature, good views or vistas, or scenery.	Track maintenance	This track/site needs maintenance.
Ride frequently	I ride here frequently (1–4 times week).	Socialise with family/friend	This track/site is good to socialise with family and/or friends.	Better track design (Describe)	This track/site would benefit from improved design.
Ride regularly	I ride here regularly (at least once a month).	Explore new areas	This track/site offers exploration of new areas.	Add linkage between tracks	Add a linkage between tracks here.
Ride occasionally	I ride here infrequently (less than once a month).	Peace/quiet/ solitude	This track/site offers quiet, solitude, or a peaceful ride.	Open up for riding	This area should be opened for mountain bike riding.
Best rides		**Improvement**		Turn into single use track	This track should be changed into a single use track.
Best ride less than 2 h	Mark the best less than 2 h ride	Improve riding skills	This is a good track/site to improve my riding skills.	Close track or section completely (Why?)	This section of track should be closed to all use. Explain why.
Best ride 2–4 h	Mark the best 2–4 h ride.	Improve fitness/ endurance	This is a good track/site to improve my fitness/ endurance.	Modify/create single dir. loop	This track should be modified to create a single directional loop.
Best ride greater than 4 h	Mark the best ride greater than 4 h.	Excitement (Why?)	This track/site offers great excitement in riding. Please describe why it is exciting.	Add technical feature (Describe)	A technical mountain bike feature should be added here. Please describe.
Best night ride	Mark the best track to do a night ride.	**Facilities**		**Facilities**	
		Convenient/close to home	This track/site is convenient or close to home.	Better signage	Improve the signage here.
		Challenging slopes	I like this track/site because of the challenging slopes.	Provide/increase parking	Provide increased parking here.
		Technical features (Describe)	I like this track/site because of the technical riding that is available here. Please describe the technical aspects.	Add other facilities or action (Describe)	Please add other facilities here (describe the facilities) or take other management action (describe the action).
		Good track surface/ condition	This track/site has a good track surface.	**Conflicts**	
		Other		Conflict with horse riders (Describe)	I experienced conflict with horse riders here. Please describe the conflict.
		Other reason (Describe)	Please describe the reason you like this track/site.	Conflict with mountain bikers (Describe)	I experienced conflict with mountain bikers here. Please describe the conflict.
				Conflict with walkers (Describe)	I experienced conflict with walkers here. Please describe the conflict.

reception. At the end of the tracking period, the track files were sent to the researchers in gpx-format.

The GPS tracking component was completed by answering a brief questionnaire in which participants were queried about their favourite tracks visited during the study period. We also enquired about any rides undertaken outside of the study area.

2.4. Analysis

Results from the questionnaire were analysed with IBM SPSS Statistics for Windows 21.0. Prior to analysis, the 5 skill levels (1 = complete beginner; 2 = advanced beginner; 3 = moderately experienced; 4 = very experienced; 5 = experts) for mountain bikers were re-classified by merging category 1 ('complete beginner') and category 2 ('advanced beginner') into one category ('beginner') to account for their smaller sample size.

To compare frequency data, such as the socio-demographics and rider characteristics (i.e., skill level and field vs. online), Pearson's chi-square tests were applied. The rating-scale data were analysed with analysis of variance (ANOVA) including skill level and sampling mode (field vs. online). ANOVA was also applied to continuous variables measuring self-estimated average distances travelled to tracks in the Northern Sydney area. Open-ended questions were analysed qualitatively by identifying the major categories/themes emerging from participants' comments.

We used several spatial scales ('planning areas') in our analysis to demonstrate the versatility of PPGIS mapping and associated GIS analysis including inside vs. outside national parks. Tracks were assigned to either being located 'in park' or 'outside' if most (>90%) of the track length was located in either category, otherwise, a track was considered located in 'both'.

Markers collected in the field were transferred by a researcher onto Google map and then exported together with the online mapping data for import into a geographical information system (ArcGIS 10.1). An attribute field was added to the database that coded whether data had been collected in the field or online. Prior to the data analysis, we excluded any markers placed outside the study area (6.8%). A few mountain bikers (5%) were excluded entirely from the analysis (both the survey and PPGIS mapping) because they indicated in the survey they never ride in the

Northern Sydney area and they placed marker(s) exclusively outside the study area.

Descriptive tables and maps were produced to showcase the range of possible data presentation modes. To create maps showing the varying numbers of markers placed along the 204 individual tracks, most markers were spatially joined in ArcGIS to the nearest track (Fig. 3a–b). We also observed that some clusters of markers demarcated the outlines of tracks not displayed on the map and have provided an example in Fig. 3c.

The 'location' and 'reason' markers were typically placed at the beginning/end of a track rather than somewhere along the track, and we considered the attribute to apply to the entire track. In contrast, we performed raster analysis on 'action' markers to identify specific sites within 150 m × 150 m raster cells along tracks for the actions. Raster analysis can identify specific 'hotspots' in the study area (e.g., for linkages) that require management attention (Fig. 4).

To relate the total number of mapped attributes to rider skill levels, we used one-way factor ANOVA. The relative frequency of different types of markers by skill level and planning area was examined with Chi-square statistics and standardized residuals (difference between observed and expected cell counts). Standardized residuals indicate which attributes were mapped more or less often than expected (sresid. > ±1.96) by skill level and planning area categories. Chi-square tests were also applied to examine differences in mapping results by sampling mode (field vs. online). To examine the underlying reasons for selecting specific locations for riding, we calculated Generalised Linear Model effects of reasons to ride on the popularity of specific tracks, measured as the number of reason and location markers, respectively, mapped inside or outside of national parks in Northern Sydney.

GPS tracking data were aggregated to calculate the average number of rides, distance covered, duration of rides, velocity, weekly/daily activity patterns, and location of rides during the

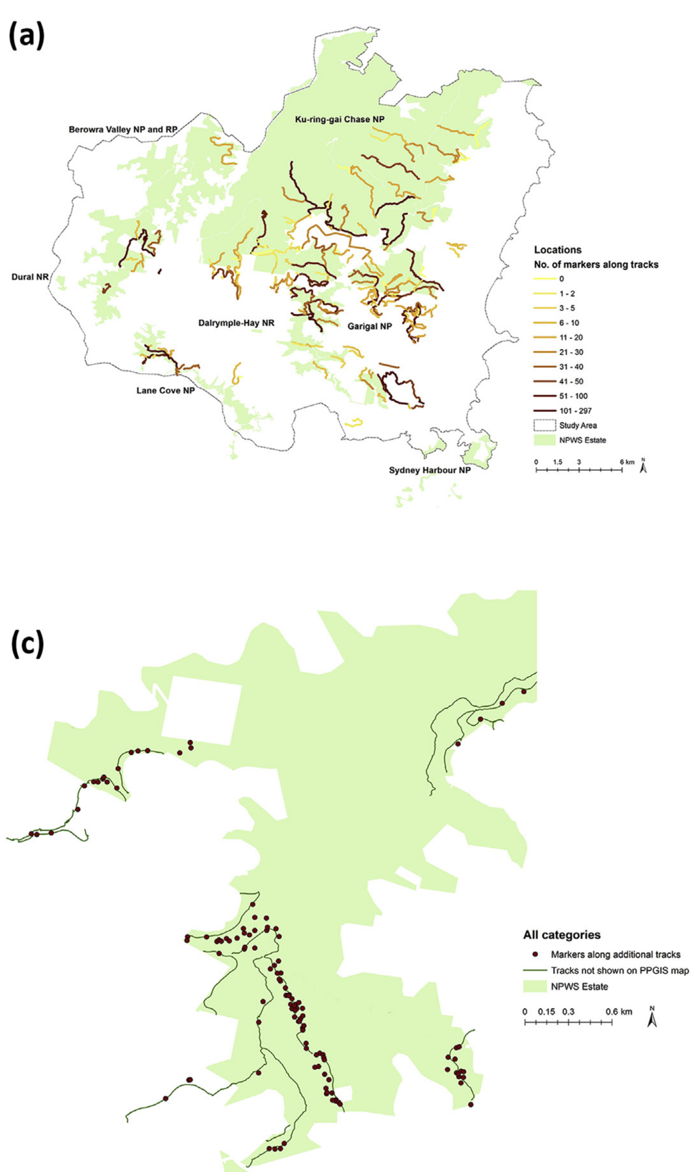

Fig. 3. (a) Popularity of tracks, as indicated by location markers, frequented by mountain bikers in Northern Sydney, and (b) an example for the distribution of an individual marker category (track maintenance), and (c) markers placed along tracks not shown on the map during the sampling. In (c) known tracks were superimposed on markers to demonstrate the close alignment.

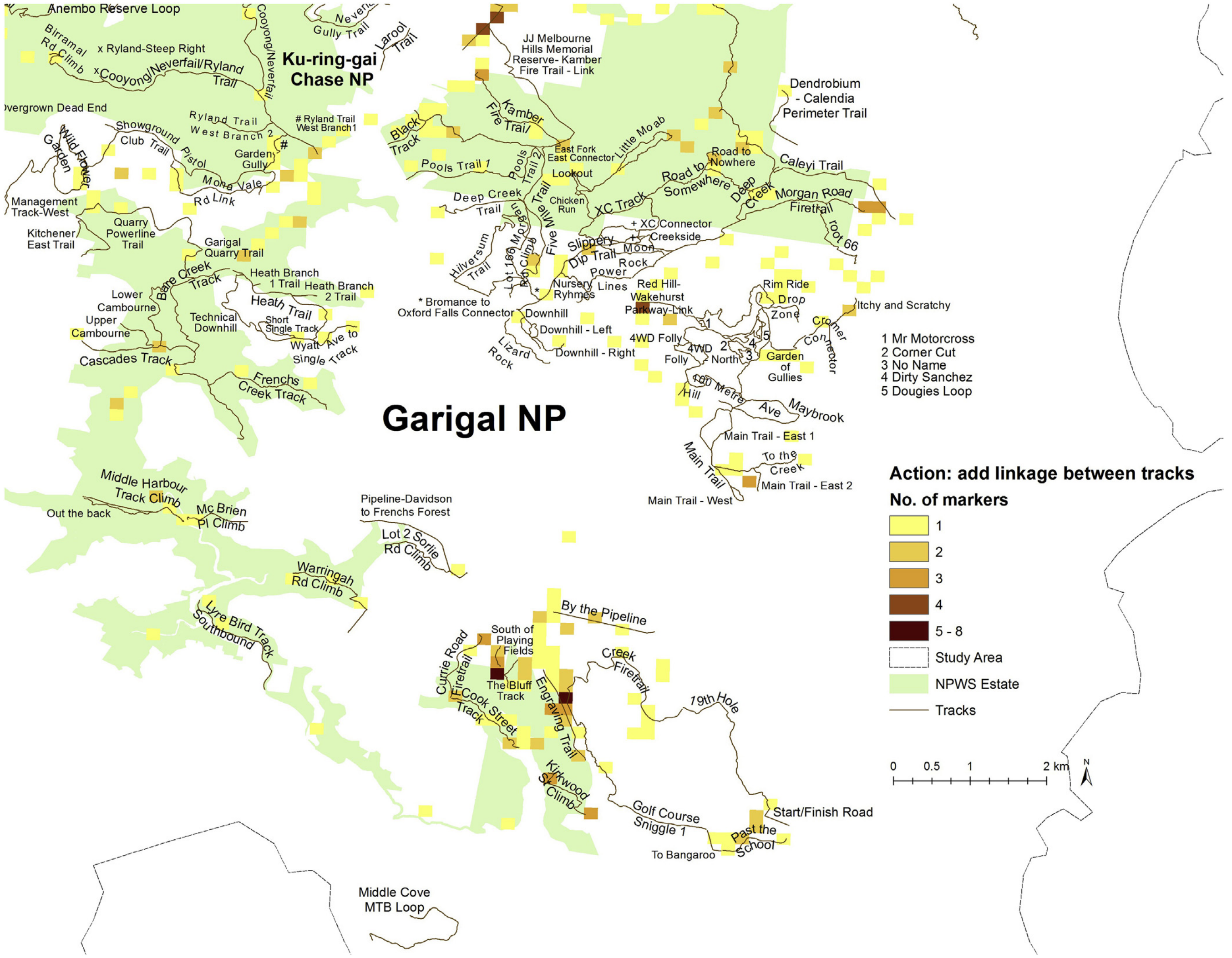

Fig. 4. Raster ('hotspot') maps of track linkages proposed by mountain bikers in the South-East of Northern Sydney.

4-weekly sampling periods. We examined how some of these trip variables varied by rider skill level.

We compared the popularity of the 204 tracks displayed on the PPGIS map with the results from the GPS tracking by spatially joining the tracked rides with the displayed tracks. We then ranked the tracks by popularity, measured by the number of markers (for mapping) or number of tracked rides (for tracking) joined with the displayed tracks, and calculated Pearson correlation coefficients to determine how closely reported track usage (mapping) related to actual track usage (tracking).

We refer to the GPS tracked routes as "rides" in contrast to PPGIS tracks. Some of the individual rides collected by tracking were exclusively located along the 204 PPGIS tracks. However, some rides also contained segments that connected with starting points at home, creating whole networks of rides.

3. Results

3.1. Participant characteristics and rider profiles

In total, 516 mountain bikers completed the questionnaire and placed PPGIS markers inside the study area. The majority of mountain bikers (81%) completed the study online. Most participants intercepted in the field were sampled on weekends during sunny weather conditions and temperatures ranging between 15° and 30 °C. Participation rates in the field were greater than 80%. Altogether, we sampled 19 beginner, 99 intermediate, 247 advanced, and 151 expert mountain bikers.

Mountain bikers comprised predominantly male riders between 25 and 54 years of age (Table 2). Expert mountain bikers were more likely to be younger with an overrepresentation of 25–34 year olds compared to other skill levels. The mountain bikers showed a fairly equal distribution of age categories across skill levels. Skill levels were significantly related to years of mountain biking (Table 2). 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.

About a third of mountain bikers (31%) were members of biking clubs and associations with increased membership associated with higher skill level (experts: 46.9%). Many mountain bikers ride regularly (at least once a month) to frequently (1–4 times a week) in the Northern Sydney area with almost half of beginners riding there only occasionally (less than once a month). The greater the skill level, the more often mountain bikers also ride outside the study area in other parts of NSW. The majority of non-beginner

Table 2
Characteristics of beginner ($n = 19$), intermediate ($n = 99$), advanced ($n = 247$), and expert ($n = 151$) mountain bikers in Northern Sydney.

	Beginner*	Intermediate*	Advanced*	Expert*	df	χ^2	*P*
	%	%	%	%			
Age					18	28.9	**0.049**
14–17	5.3	2.0	0.8	3.3			
18–24	5.3	6.1	2.8	4.0			
25–34	10.5	27.3	19.8	31.1			
35–44	42.1	37.4	42.1	41.1			
45–54	31.6	17.2	23.5	19.2			
55–64	5.3	9.1	8.9	1.3			
65 and plus	0.0	1.0	2.0	0.0			
Gender					3	5.8	0.12
Male	83.3	94.8	94.1	96.6			
Female	16.7	5.2	5.9	3.4			
Mountain Bike Club Member	11.1	12.4	29.4	46.9	3	37	**<0.001**
Years of riding					12	162.8	**<0.001**
Less than 1 year	36.8	8.1	0.4	0.0			
1–3 years	47.4	40.4	21.5	9.3			
3–5 years	10.5	8.1	3.2	1.3			
5–10 years	5.3	15.2	24.7	21.9			
More than 10 years	0.0	28.3	50.2	67.5			
Riding in northern Sydney area					9	28.1	**<0.001**
Never	0	0	0	0			
Ocassionally	47.4	23.2	22.7	11.9			
Regularly	26.3	26.3	17.4	21.2			
Frequently	26.3	48.5	56.3	58.3			
Very often	0.0	2.0	3.6	8.6			
Riding in other parts of NSW					81.2	12	**<0.001**
Never	31.6	17.5	3.3	0			
Ocassionally	47.4	51.5	49.8	34.4			
Regularly	10.5	22.7	27.2	35.8			
Frequently	10.5	8.2	18.1	26.5			
Very often	0	0	1.6	3.3			

Note: Significant differences in the Pearson's chisquare tests 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' = '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).

mountain bikers travel by vehicle to reach tracks, while a majority of beginners travel by bike (Table 3). Public transport was rarely used, and if so mostly by beginners (10%) to reach tracks outside the study area.

Mountain bikers participated in a range of disciplines (Table 3). Most popular amongst all skill levels was cross-country riding on a mix of fire trails ('management trails') and single tracks, and with a clear exception of beginners, riding on single tracks. Advanced and expert riders also commonly engaged in all-mountain and free-riding. Downhill riding was mainly popular amongst experts. Beginners and intermediate riders were the most likely groups to ride on fire trails. Preferred velocity for mountain biking increased with skill level (Table 3).

3.2. PPGIS mapping marker frequencies

In our analysis, we included a total of 11,256 valid markers (Table 4) from 667 mountain bikers who mapped at least one marker. Comments were annotated for 12.7% of markers.

The number of markers placed per participant was significantly related to one's mountain biking skill ($F_{(3,495)} = 8.1$, $P < 0.001$). The greater the skill level, the greater the number of markers. 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). The mean number of markers placed per participant was similar to other reported PPGIS studies (e.g., Beverly, Uto, Wilkes, & Bothwell, 2008).

Markers identifying location frequencies were most mapped (46.2%), followed by reasons for riding (35.1%), and actions (18.7%). The most common riding frequencies included riding less than once per month (16.9%), riding once per month (13.6%) and riding 1–4 times per week (8.9%). Most mountain bikers rode to improve their fitness/endurance (7.5%), to enjoy nature/views/scenery (4.0%) and to experience technical features (3.9%). Mountain bikers identified multiple key management actions to be addressed in Northern Sydney including opening up tracks/areas for riding (5.5%), adding linkages between tracks (5.3%), and track maintenance (2.5%). Conflicts with other activity groups were mapped in 0.5% of cases.

The relative frequency of individual types of markers also varied by the skill level of mountain bikers ($\chi^2_{(6)} = 65.2$, $P = 0.001$). Beginner and intermediate riders provided significantly more reasons to ride than advanced and expert riders. Expert riders, in contrast, suggested significantly more actions. The individual reasons for riding also varied by skill levels ($\chi^2_{(33)} = 97.8$, $P = 0.001$). Beginners and intermediate riders more frequently mapped tracks to explore new areas, for convenience, and good track/surface conditions while excitement and challenging slopes were less frequently marked. For action markers, facilities were more frequently identified by beginner and intermediate riders who expressed a particular interest in improved signage ($\chi^2_{(30)} = 91.5$, $P = 0.001$). Expert riders suggested the closure of tracks or sections more frequently while intermediate riders recommended opening up tracks for riding, or adding technical features.

3.3. Field vs. online PPGIS mapping

We observed few statistically significant differences between mountain bikers sampled in the field vs. online, and notably, there

Table 3
Riding preferences of beginner ($n = 19$), intermediate ($n = 99$), advanced ($n = 247$), and expert ($n = 151$) mountain bikers in Northern Sydney.

	Beginner*	Intermediate*	Advanced*	Expert*	df	χ^2	*P*
	%	%	%	%			
Riding season:							
Spring (September to November)	73.7	91.9	91.9	90.7	3	7.2	0.065
Summer (December to February)	57.9	74.7	80.6	81.5	3	7	0.07
Fall (March to May)	68.4	87.9	92.3	92.1	3	12.9	**0.005**
Winter (June to August)	63.2	73.7	71.7	79.5	3	4.2	0.239
Riding days:							
Weekdays	21.1	48.5	43.7	51.0	3	7.1	0.07
Saturdays	84.2	65.7	65.6	76.8	3	8.2	**0.04**
Sundays	73.7	66.7	82.2	78.8	3	10.1	**0.02**
Riding peak time in Spring/Fall:							
Before 9	36.8	30.3	44.9	41.1	3	6.4	0.09
9 am to 2pm	42.1	46.5	32.4	28.5	3	9.7	**0.021**
After 2 pm	31.6	28.3	15.0	23.8	3	10.7	**0.014**
After sunset	0.0	5.1	9.3	10.6	3	4.3	0.228
Any time	10.5	23.2	31.2	40.4	3	12.5	**0.006**
Not at all	5.3	0.0	0.0	0.0	3	26.2	**<0.001**
Riding peak time in Winter:							
Before 9	31.6	22.1	33.5	31.1	3	4.2	0.24
9 am to 2pm	42.1	50.5	40.8	37.1	3	4.5	0.217
After 2 pm	21.1	21.1	16.3	20.5	3	1.7	0.646
After sunset	5.3	6.3	9.8	15.2	3	6	0.111
Any time	15.8	22.1	24.1	33.1	3	6.2	0.102
Not at all	10.5	1.1	1.2	0.0	3	16.1	**<0.001**
Riding peak time in Summer:							
Before 9	47.4	51.6	60.2	57.0	3	2.9	0.407
9 am to 2pm	31.6	28.4	21.3	23.2	3	2.6	0.454
After 2 pm	15.8	25.3	18.9	26.5	3	4.1	0.245
After sunset	5.3	9.5	13.1	17.9	3	4.9	0.178
Any time	10.5	20.0	21.7	27.8	3	4.4	0.224
Not at all	15.8	2.1	1.2	0.0	3	27.6	**<0.001**
Reach the track by:							
Northern Sydney Area							
Bike	63.2	48.5	49.2	51.0	3	1.5	0.676
Car	47.4	72.7	73.2	66.2	3	7.2	0.066
Public transport	0.0	7.1	4.1	1.3	3	6.4	0.094
Other parts of NSW							
Bike	5.3	8.2	8.9	10.6	3	0.8	0.837
Car	63.2	76.5	91.1	90.1	3	23.8	**<0.001**
Public transport	10.5	6.1	10.2	4.0	3	5.7	0.129
Group Type 1					18	59.3	**0.001**
Alone	42.1	36.4	26.5	24.5			
Partner	10.5	12.1	4.9	5.3			
Family	21.1	39.4	57.1	53.6			
Friends	21.1	8.1	1.6	1.3			
Organised group	0.0	2.0	4.9	10.6			
Work colleagues	5.3	2.0	4.9	4.6			
Group Type 2					3	6.4	0.094
Alone	42.1	36.4	26.5	24.5			
Group	57.9	63.6	73.5	75.5			
Group Size					12	34.7	**0.001**
1	47.4	35.4	22.0	20.5			
2	31.6	36.4	32.7	21.2			
3	21.1	27.3	40.0	53.6			
4	0.0	1.0	4.5	2.6			
5	0.0	0.0	0.8	2.0			
Riding velocity					6	60.3	**<0.001**
Slow	10.5	3.0	0.4	0.0			
Moderate	73.7	64.6	50.6	30.5			
Fast	15.8	32.3	49.0	69.5			
Riding disciplines							
Cross Country (combination of single track and fire trail)	68.4	84.8	83.0	75.5	3	6.4	0.095
Cross Country (primarily single track)	26.3	66.7	80.2	86.1	3	42.4	**<0.001**
Primarily fire trails	42.1	39.4	32.4	23.8	3	8	**0.045**
All Mountain	21.1	37.4	63.2	74.8	3	48	**<0.001**
Free Riding	26.3	31.3	42.1	51.7	3	12.3	**0.006**
Downhill	15.8	19.2	25.9	43.7	3	22.9	**<0.001**
Dirt Jumping	10.5	8.1	4.9	13.2	3	8.9	**0.03**
BMX	5.3	2.0	1.6	2.6	3	1.4	0.705
Other	5.3	1.0	1.2	6.6	3	8.9	**0.03**

Note: Significant differences in the Pearson's chisquare tests 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’ = ‘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).

Table 4
Frequency of markers placed by mountain bikers in Northern Sydney.

Mountain bikers	Marker frequencies	
	n	%
Locations		
Riding less than once per month	1902	16.9
Riding once per month	1531	13.6
Riding 1–4 times per week	1004	8.9
Best ride for less than 2 h	276	2.5
Best ride for 2–4 h	175	1.6
Riding 5–7 times per week	133	1.2
Best for night ride	122	1.1
Best ride for more than 4 h	55	0.5
Reasons		
Improve fitness/endurance	840	7.5
Enjoy nature/views/scenery	450	4.0
Technical Features	435	3.9
Improve riding skills	418	3.7
Convenient/close to home	402	3.6
Challenging slopes	331	2.9
Socialise with family/friends	284	2.5
Excitement	211	1.9
Good track surface/condition	205	1.8
Peace/quiet/solitude	153	1.4
Explore new areas	127	1.1
Other	94	0.8
Actions		
Open up for riding	614	5.5
Add linkage between tracks	602	5.3
Track maintenance	281	2.5
Better signage	163	1.4
Better track design	150	1.3
Turn into single use track	78	0.7
Add technical feature	54	0.5
Modify/create single dir. loop	45	0.4
Add other facilities or action	35	0.3
Close track (or section) completely	18	0.2
Provide/increase parking	15	0.1
Conflict with walkers	23	0.2
Conflict with horse riders	18	0.2
Conflict with mountain bikers	12	0.1
Total	11256	100.0

were no differences in rider demographics. We had expected to observe a greater number of advanced and expert riders online and more beginners in the field because the online surveys were disseminated via dedicated mountain biker forums. However, only mountain bikers of intermediate skill level were slightly overrepresented in the field ($\chi^2_{(3)} = 11.06$, $P = 0.009$). We speculate that beginners may have a greater incentive to source mountain biking information online than intermediate riders who might be also less actively involved in the online rider community. As expected, less mountain bike club members were sampled in the field than online.

We found no significant differences in the overall number of markers placed per field or online participant, but there were some differences by marker category. In the field, mountain bikers placed more markers identifying reasons to ride and less location markers ($\chi^2_{(2)} = 84.3$, $P < 0.001$). Convenience, improvement of riding skills, and excitement were disproportionately more mapped in the field than online ($\chi^2_{(11)} = 424$, $P < 0.001$). People intercepted in the field were particularly keen to discuss their reasons to ride (vs. locations) with the interviewer while placing the markers. This verbal interaction likely encouraged participants to place a greater number of this type of marker as well as 'other reasons to ride'. Similarly, some action markers were overrepresented in the field ($\chi^2_{(10)} = 105.2$, $P < 0.001$), including those suggesting better track design, the addition of linkages between tracks, the addition of technical features, and the provision of increased parking.

3.4. Distributions and reasons for mountain biking

3.4.1. Questionnaire

Mountain biking occurs year-round in Northern Sydney with a preference for spring and fall when ambient temperatures in Sydney are most conducive to outdoor activities (Table 3). Advanced and expert mountain bikers were more likely to ride 'any time' during the day compared to other skill levels. Few participants undertake rides after sunset.

Track features were related to specific reasons (motivations) to ride and can partially explain rider distributions (Table 5). More skilled mountain bikers ascribed a greater importance to most track features. Beginners rated circuits, curves, up- and downhill sections, and a variety of tracks as the most important track features while more skilled riders rated highest, single tracks, tight and technical tracks, a variety of tracks, curves, and logs and rocks. Tracks between 10 and 20 km in length were preferred by all skill levels.

3.4.2. PPGIS mapping

Mountain bikers mapped similar percentages of location frequencies of rides and best-rides outside (45.6%) and inside (43.7%) national parks. However, a majority of all location marker types was placed outside of parks (45.4–67.4%), including those indicating best rides for less than 2 h and for rides 2–4 h (Table 6). In contrast, best rides for more than 4 h were more commonly mapped inside parks (56.4%) along with riding less than once per month (48.4%). This indicates that mountain bikers ride in parks to enjoy longer rides but do so less regularly.

Somewhat higher percentages of reasons to ride were mapped outside (52.5%) than inside (39.3%). There were significant differences in the frequency of reason markers placed inside vs. outside of parks (Table 7). The top three overrepresented reasons for riding inside parks included to improve fitness/endurance (27.2%), enjoy nature/views/scenery (16.4%), and experience tracks that are convenient/close to home (11.2%). In contrast, people riding outside parks did so primarily to experience technical features (15.7%), improve riding skills (15.4%), and improve fitness/endurance (15.5%).

Several motivations explained where mountain bikers ride (Table 8). Both inside and outside of parks opportunities to improve fitness/endurance, and excitement influenced where people ride. Outside of parks tracks with challenging slopes and technical features attracted mountain bikers, while inside of parks opportunities to improve riding skills and good track surface/conditions influenced track selection. Other reasons to ride, as annotated frequently on reason markers, included tracks linking well with other tracks, thereby creating loops/circuits, and well-designed, purpose-built tracks with a good 'flow'.

The PPGIS mapping approach provides for analyses and assessment of individual tracks located in Northern Sydney, a process that is difficult with traditional text-based surveys that attempt to match descriptions with locations, especially when tracks are known by multiple names. For example, less experienced mountain bikers were more adept at locating tracks on a map than identifying the correct aliases for a track.

In Fig. 3a, we show the distribution of all location markers placed by mountain bikers along tracks. The map is colour-coded to indicate the popularity of tracks based on the number of location markers. These results can also be displayed in table form to show, for example, the top-twenty tracks. Each individual marker category can be presented in additional maps (Fig. 3b) providing visual

Table 5
Preferences for facilities in national parks used by beginner (n = 19), intermediate (n = 99), advanced (n = 247), and expert (n = 151) mountain bikers in Northern Sydney.

	Beginner*		Intermediate*		Advanced*		Expert*		df	χ^2 or F	*P*
	Mean	SE	Mean	SE	Mean	SE	Mean	SE			
Track/feature preferences:											
Tracks less than 10 km	2.63	0.27	2.72	0.11	2.75	0.08	2.90	0.10	3, 499	0.7	0.52
Tracks between 10 and 20 km	2.89	0.25	3.39	0.10	3.67	0.06	3.84	0.09	3, 507	7.6	**<0.001**
Tracks greater than 20 km	2.63	0.31	2.95	0.11	3.36	0.07	3.68	0.10	3, 506	10.9	**<0.001**
Circuit	3.32	0.32	3.18	0.11	3.46	0.07	3.52	0.09	3, 504	2.1	0.093
Variety of tracks	3.05	0.30	3.75	0.10	4.05	0.05	4.36	0.06	3, 505	20.5	**<0.001**
Single-track	2.95	0.27	3.87	0.10	4.45	0.05	4.60	0.05	3, 508	38.4	**<0.001**
Up- and downhill	3.00	0.30	3.30	0.10	3.71	0.06	4.07	0.07	3, 506	17.2	**<0.001**
Flat track sections	2.84	0.28	2.90	0.10	2.80	0.07	2.85	0.09	3, 505	0.2	0.91
Short, steep, challenging slopes	2.42	0.23	3.15	0.11	3.49	0.06	4.03	0.08	3, 505	27.1	**<0.001**
Long, gentle, moderate slopes	2.74	0.23	3.14	0.10	3.01	0.06	3.17	0.09	3, 504	1.5	0.194
Open and clear	2.26	0.27	2.59	0.11	2.32	0.07	2.08	0.08	3, 504	4.7	**0.003**
Tight and technical	2.95	0.31	3.25	0.11	3.71	0.06	4.23	0.07	3, 506	25.5	**<0.001**
River, stream, creek crossing	2.63	0.30	2.54	0.11	2.50	0.07	2.45	0.10	3, 506	0.2	0.887
Logs, rocks	2.63	0.32	2.67	0.11	3.06	0.07	3.80	0.09	3, 506	25.1	**<0.001**
Jumps	2.53	0.33	2.45	0.12	2.74	0.08	3.35	0.11	3, 506	12.8	**<0.001**
Curves	3.16	0.33	3.52	0.10	3.91	0.06	4.26	0.07	3, 506	16.5	**<0.001**
Additional information and facilities:											
Information on track conditions	3.37	0.30	3.47	0.10	3.67	0.06	3.60	0.09	3, 502	1.2	0.304
Safety instructions for the tracks	3.37	0.27	2.72	0.12	2.55	0.07	2.37	0.09	3, 502	5.1	**0.002**
Signs with maps, distances, difficulties, directions, etc.	3.79	0.28	3.48	0.11	3.32	0.07	3.39	0.09	3, 502	1.5	0.219
Topographic maps	3.21	0.26	2.82	0.11	2.68	0.07	2.69	0.09	3, 502	1.9	0.138
Information on wildlife, plants and cultural heritage	3.00	0.32	2.71	0.11	2.71	0.07	2.75	0.09	3, 501	0.5	0.718
Scenic views, lookouts, water features	3.42	0.28	3.06	0.10	3.00	0.07	3.17	0.08	3, 501	1.7	0.161
Car parks close to track head	3.32	0.24	3.38	0.11	3.19	0.06	3.02	0.09	3, 502	2.6	0.054
Mobile phone reception or emergency phones	2.89	0.26	3.09	0.12	2.81	0.08	2.81	0.10	3, 502	1.5	0.221
Access by public transport	1.74	0.26	2.25	0.13	1.94	0.07	1.86	0.08	3, 501	3.1	**0.024**
Wheel-washing stations	2.11	0.24	2.09	0.12	1.94	0.07	1.98	0.08	3, 502	0.5	0.642
Toilets	2.53	0.22	2.54	0.12	2.36	0.07	2.30	0.09	3, 502	1.1	0.375
Drinking water	2.84	0.28	3.11	0.13	2.80	0.08	2.93	0.10	3, 502	1.4	0.233
Rubish bins	2.47	0.27	2.79	0.12	2.68	0.08	2.91	0.11	3, 502	1.4	0.232
Shelters	1.95	0.24	2.25	0.11	2.02	0.07	2.09	0.09	3, 501	1.3	0.282
National Park experiences:											
Mountain biking events	3.32	0.36	3.58	0.14	4.07	0.08	4.31	0.10	3, 501	8.9	**<0.001**
Long-distance rides	3.00	0.34	3.28	0.14	3.98	0.08	4.03	0.11	3, 501	9.9	**<0.001**
Multi-day trips	2.74	0.36	2.57	0.14	2.97	0.09	3.18	0.12	3, 501	3.6	**0.013**
Night riding	2.47	0.37	2.81	0.15	3.40	0.10	3.78	0.12	3, 499	10.8	**<0.001**
Guided tours/training	3.00	0.36	2.39	0.14	2.49	0.09	2.17	0.10	3, 501	3.1	**0.025**

Note: 5-point scales (1 = not at all important; 5 = extremely important) were averaged to calculate means and SE. Significant differences in the Pearson's chisquare tests 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' = '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).

Table 6
Row-percentages of location-frequencies and best mountain bike rides compared between inside and outside national parks in Northern Sydney. 'Both' indicates markers placed along tracks that are partially located inside and outside of parks.

	All	Both	Outside	Park
	n	%	%	%
Locations				
Riding 5–7 times per week	133	6.8	**54.9**	38.3
Riding 1–4 times per week	1005	8.1	**50.1**	41.8
Riding once per month	1532	11.7	**45.4**	42.9
Riding less than once per month	1902	12.5	39.1	**48.4**
Best ride for less than 2 h	276	4.7	**67.4**	27.9
Best ride for 2–4 h	175	8.0	**56.0**	36.0
Best ride for more than 4 h	55	18.2	25.5	**56.4**
Best for night ride	122	10.7	**45.9**	43.4

Note: Cells containing the greatest row percentage are presented in bold fonts.

tools for park managers. Only 12 of the 204 PPGIS-displayed tracks received no markers indicating that mountain bikers use a great variety of tracks although there are obvious hot spots.

In the PPGIS instructions, we explained that participants could map anywhere without being restricted to the tracks shown on the

Table 7
Column-percentages of reasons for mountain biking within and outside national parks in Northern Sydney. 'Both' indicates markers placed along tracks that are partially located inside and outside of parks.

	Both		Outside		Park	
	n	%	*n*	%	*n*	%
Reasons						
Enjoy nature/views/scenery	35	**10.9**	*161*	7.8	**254**	**16.4**
Socialise with family/friends	20	6.2	156	7.5	108	7.0
Explore new areas	12	3.7	57	2.7	58	3.7
Peace/quiet/solitude	13	4.0	*43*	2.1	**97**	6.2
Convenient/close to home	26	8.1	202	9.7	174	**11.2**
Improve riding skills	30	9.3	**319**	**15.4**	*69*	4.4
Improve fitness/endurance	**95**	**29.5**	*322*	**15.5**	**423**	**27.2**
Excitement	12	3.7	**157**	7.6	*42*	2.7
Challenging slopes	**45**	**14.0**	161	7.8	125	8.0
Technical Features	*21*	6.5	**326**	**15.7**	*88*	5.7
Good track surface/condition	*7*	2.2	116	5.6	82	5.3
Other	6	1.9	55	2.7	33	2.1

Note: Cells with underlined fonts indicate significantly larger and cells with italic fonts significantly smaller than expected contributions to the overall chi-square (standardized residuals >1.96 or < −1.96). Cells containing the top three most frequently marked actions for each planning area are presented in bold fonts. $\chi^2_{(22)} = 424.0$, $P < 0.001$.

Table 8
Generalised Linear Model effects of reasons to ride on the popularity of specific tracks mapped by mountain bikers inside or outside of national parks in Northern Sydney.

	Tracks to ride	
	Outside	Park
	p	*p*
Reasons		
Enjoy nature/views/scenery	0.322	0.381
Socialise with family/friends	0.323	0.167
Explore new areas	0.616	0.617
Peace/quiet/solitude	0.965	0.744
Convenient/close to home	0.517	0.245
Improve riding skills	0.492	**0.038**
Improve fitness/endurance	**0.015**	**0.028**
Excitement	**0.040**	**0.049**
Challenging slopes	**0.042**	0.463
Technical Features	**0.044**	0.060
Good track surface/condition	0.131	**0.039**
Other	0.434	0.090

Note: $p < 0.05$ is marked in bold.

map. This opportunity was seized by mountain bikers who identified less formal and lesser known tracks in the mapping activity. As an internal test of the online PPGIS method, we excluded a number of tracks from the map that are known to be frequented by mountain bikers to determine if these would be identified anyway. Participants did, indeed, place markers on these track locations (Fig. 3c).

3.4.3. GPS tracking

We invited a sample of 200 mountain bikers, of which 94 agreed to participate, with 77 included in our analysis for completing both the tracking activity and associated survey. We collected 507 rides of which 48 rides were excluded from analysis for being outside the study area or study period. Our final sample consisted of 2.6% beginner, 9.1% intermediate, 54.5% advanced and 33.8% expert riders which approximates the proportion of skill levels in the PPGIS mapping sample.

On average, participants submitted 6 (±0.46) GPS rides in the Northern Sydney study area during the 4-weekly trials. Participants undertook an additional 2.4 (±0.27) rides outside of the study area during the sampling period. Rides averaged 22.2 (±1.5) km in length, required 113 (±7.2) minutes for completion at an average velocity of 15.5 (±0.3) kmh^{-1}. For comparison, the survey results indicated a preference for rides of 10–20 km in length. The results indicated that mountain bikers covered a greater distance (25.2 ± 2.3 km) and spent more time (132.1 ± 7.8 min) on rides they had marked as their favourite. On average, 1–2 rides per sampling period were repeat rides. All riding statistics increased with skill level as follows: number of rides sent (beginner: 4.5 ± 1.5; intermediate 10 ± 5; advanced: 14 ± 6.1; expert: 17 ± 6.3), average length in km (beginner: 13.6 ± 4.1; intermediate: 16 ± 2.7; advanced: 22.6 ± 2; expert: 23.83 ± 2.8), and time spent in minutes (beginner: 99 ± 1; intermediate 78 ± 8.8; advanced: 119.3 ± 13.1; expert: 116.5 ± 9.6).

The majority of rides (65%) commenced prior to 2 pm, which is consistent with the survey results, and took place on the weekend (62%). Sixty-eight percent of rides were undertaken at least partially in NSW national parks, where also 77% of the favourite rides were located, with 82% of these located in Garigal National Park or Ku-ring-gai Chase National Park in equal proportions. The popularity of these two parks is consistent with the PPGIS-mapped results.

When we compared the popularity of the 204 tracks on the PPGIS map with the GPS tracking results (Fig. 5a), the correlation between the ranked tracks from the mapping and tracking was strong ($r = 0.6$; $P < 0.001$) indicating that the reported popularity of tracks (PPGIS mapping) was reasonably consistent with the actual popularity of tracks (GPS tracking). In addition, we used the tracking results to display favourite rides (Fig. 5b).

3.5. Actions to improve mountain biking experiences

We asked what additional information and facilities could contribute to the enjoyment of mountain biking (Table 5). Needs were universal across skill levels.

Mountain bikers mapped similar percentages of action markers outside (44.2%) and inside parks (46.6%). Although the overall number of actions was similar, the variety of actions requested outside of parks was greater, and categories such as the provision of better signage, better track design and adding other facilities or actions were disproportionally larger, as indicated by the standardised residuals (Table 9). The top three actions requested both outside and inside parks included adding linkages between tracks, opening up tracks/areas for riding, and track maintenance (Table 9). Two further categories that were important for mountain bikers included providing better signage, better track design and turning tracks into single use tracks, predominantly outside of parks (Table 9).

We produced an exemplary raster map to show action requests for specific locations in Northern Sydney and along specific tracks (Fig. 4). Raster maps consist of grid cells representing the density of points in a particular cell to indicate priority areas for managerial attention. Fig. 4 shows a raster map of track linkages proposed by mountain bikers where one can identify some of the routes and proposed connections between existing tracks in the South-East of Northern Sydney.

4. Discussion

4.1. Management questions for tourism and recreation planning in parks

We used different modes of PPGIS data collection to identify the spatial distributions and associated reasons for park visitor activity (mountain biking) in Northern Sydney, and to determine location-specific actions that could improve existing experiences. This information provides management direction at different spatial planning scales to prioritize resource allocation, monitor impacts, identify areas that require cross-tenure planning, promote qualities of particular areas to less informed visitors, and identify areas that need partitioning between visitor groups.

The PPGIS methodology was effective in addressing the first question about the distributions of rides. A large number of location-frequency and best-ride markers were identified by participants providing not only the location of rides, but the frequency of use, an important planning dimension (Brown & Weber, 2011). The PPGIS distributions showed strong correlation with the GPS tracking results suggesting the validity of the PPGIS method for future use. Cross-validation is an important step to increase confidence in the accuracy of visitor distribution data accrued from mapping procedures (Brown & Weber, 2011). GPS tracking proved an effective tool for this validation purpose and has been commended by others to gather reliable data on actual visitor movements (Hallo et al., 2012; Wolf et al., 2012).

Detailed knowledge on visitor distributions is important to monitor potential impacts on the environment or other visitor groups in a sustainable approach to visitor activity management

(Leung, 2012) with usage intensity a key parameter for predicting the intensity of impacts (Hammitt & Cole, 1998). To establish proactive management plans, Hadwen, Hill, and Pickering (2007) suggest four basic characteristics of visitor distributions: number of visitors, time of visitation, places of visitation, and activities undertaken. The PPGIS methods described herein generated information about time, place, and activities, including the relative popularity of different areas. Although it has not been done, one can imagine the possibility of using PPGIS data that is calibrated with field observations such as through traffic counters to derive estimates of actual track use. PPGIS mapping also enables the overlay of distributions of different visitor groups, where such information is

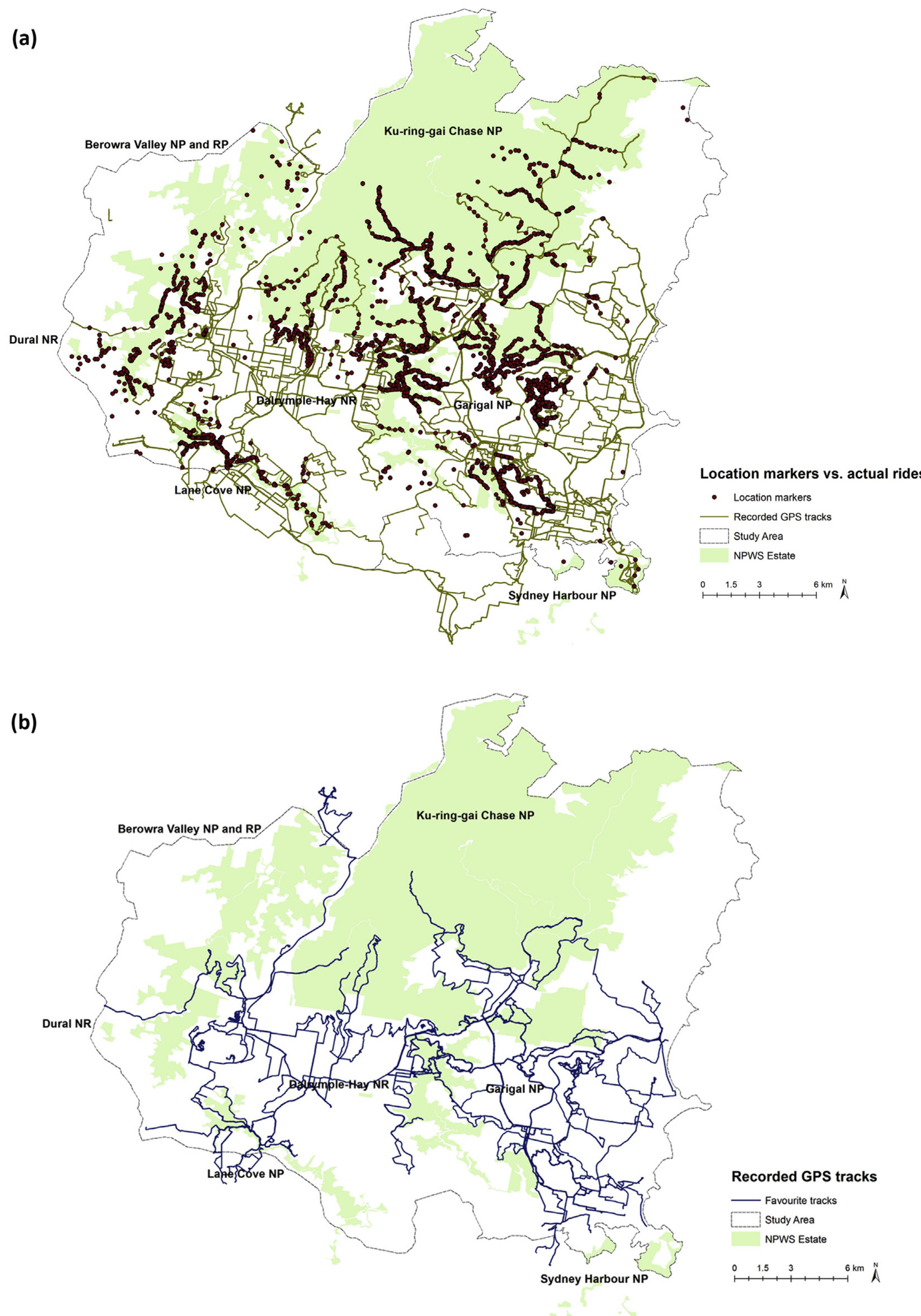

Fig. 5. (a) PPGIS mapping location markers vs. GPS tracking networks (actual rides) and (b) tracked favourite rides of mountain bikers in Northern Sydney.

Table 9
Column-percentages of actions to be addressed for mountain biking within and outside national parks in Northern Sydney. 'Both' indicates markers placed along tracks that are partially located inside and outside of parks.

	Both		Outside		Park	
	n	%	*n*	%	*n*	%
Action*						
Track maintenance	23	**12.0**	**185**	**20.4**	*73*	**7.6**
Better track design	19	9.9	**85**	9.4	*46*	4.8
Add linkage between tracks	54	**28.3**	*205*	**22.7**	**343**	**35.8**
Open up for riding	57	**29.8**	*197*	**21.8**	**360**	**37.5**
Turn into single use track	**14**	7.3	39	4.3	25	2.6
Close track (or section) completely	0	0.0	11	1.2	7	0.7
Modify/create single dir. loop	*0*	0.0	23	2.5	22	2.3
Add technical feature	8	4.2	31	3.4	*15*	1.6
Better signage	13	6.8	**96**	10.6	*54*	5.6
Provide/increase parking	1	0.5	10	1.1	4	0.4
Add other facilities or action	2	1.0	**23**	2.5	10	1.0

Note : Cells with underlined fonts indicate significantly larger and cells with italic fonts significantly smaller than expected contributions to the overall chi-square (standardized residuals >1.96 or <-1.96). Cells containing the top three most frequently marked actions for each planning area are presented in bold fonts. *χ^2 (20) = 189.2, P < 0.001.

available. For example, the same PPGIS approach was used with horse riders in the study area (see http://www.landscapemap2.org/nswhorse).

The spatially-explicit reasons for riding specific tracks provided insight into locational features that attract mountain bikers which was influenced by whether the location was inside or outside of parks. Our findings have implications for managing the visitor experience by identifying spatially explicit opportunities that are related to primary motivations for visiting a particular area. When the reasons to ride were considered independent of location, we found that enjoying nature/views/scenery, peace/quiet/solitude, and improving fitness/endurance were considerably more frequently mapped inside parks compared to outside parks. But reasons to ride in a particular location did not necessarily translate into actual rides which may be because of barriers such as limited (legal) access to tracks (suggesting latent demand) or simple convenience in reaching the tracks. Addressing latent demand and diversifying park visitor experiences is important as parks compete with other tourism and recreation service providers such as theme parks, wildlife parks or zoos (Taplin, 2012). However, such management decisions need to account for the demands and values held by different visitor groups and the legal mandate to conserve natural and cultural heritage in parks.

PPGIS mapping may also be used to develop marketing strategies that focus on the appropriate qualities of a destination as reflected in the reasons that attract visitors. Marketing strategies require in-depth knowledge of customers' expectations and research can provide the necessary insights to reposition marketing strategies for successful promotion of tourism and recreation areas (Beh & Bruyere, 2007). PPGIS mapping also enables public land managers to harness local expert knowledge to inform visitors, especially first-time visitors, where they can enjoy certain experiences such as the best tracks to view nature or technical rides. Importantly, this information enables public land managers to make informed decisions on where to allocate resources (Beeco & Brown, 2013; Beh & Bruyere, 2007), in this case, to specific tracks or other planning areas.

Our second research question sought to identify location-specific actions required to improve mountain biking experiences. A broad range of actions was suggested by mountain bikers. The most common requests were to open up tracks for riding and to add more linkages between tracks, indicating the need to expand riding options by adopting a network-approach to track development. Improving networks through proper linkages to create attractive loops and more riding options was a key insight of this research and offers many advantages over the establishment of new tracks. The PPGIS mapping approach provides multi-scale and cross-tenure analysis which is important to track network planning. Visitor activity planning is best addressed across geographic space, including different land tenures where issues in relation to tracks are interrelated (Brunckhorst, 2008; Fitzsimons & Wescott, 2005).

Such planning is particularly important for 'epic rides' that are at least 32 km in length and more than 80% single track (International Mountain Bicycling Association, 2014). These were popular amongst our participants. Most examples of epic rides are found in North America but planning is underway to establish an epic mountain bike ride in the Australian Alps (Australian Department of Resources Energy and Tourism, 2013), to be recognised by the International Mountain Bicycling Association (International Mountain Bicycling Association, 2014), with potential to boost local economies and attract more visitors, both domestic and international.

Acquiring spatial information on mountain biking in Northern Sydney, rather than exclusively for parks, did not require additional data collection effort. However, the time required to manage and analyse the data increased. Hence, a PPGIS study covering a larger region would benefit from collaboration among land management agencies. Sharing insights on visitor preferences and needs enables land managers to combine their resources to manage visitors with less (or shared) resources. This efficiency also extends to the promotion of visitor experiences through collaborative marketing, as highlighted by Fyall (2008).

4.2. Evaluation of the methodology

As a relatively recent field of participation and research methods, PPGIS would benefit from increased research effort (Brown, 2012; Brown & Kyttä, 2014). For example, the implications of different modes of PPGIS data collection are not well understood. This study provided a modest contribution to this knowledge gap by implementing a mixed-methods approach wherein PPGIS mapping was conducted both online and in the field, and included a partial validation of the spatial data using GPS tracking. We found general consistency between the online and field PPGIS data and the GPS tracking data confirmed the PPGIS-mapped popularity of tracks in the region. We have summarised the advantages and disadvantages of the different modes of PPGIS data collection in Table 10 which we will discuss in the following.

Increasing the rate of participation in PPGIS processes is a key research need (Brown & Kyttä, 2014). In this study, the PPGIS participation rates recorded in the field were high and volunteer participation from the mobilised online mountain biking community was sufficient to generate enough spatial information for meaningful analyses. In addition, we observed a strong word-of-mouth recommendation for the study via social media platforms and there was considerable positive feedback in the open-ended comments of the survey. These positive results for agency-sponsored research are consistent with those reported in a recent study of public lands in Victoria, Australia, that also involved recruitment through social media and the mobilisation of park user groups (Brown, Schebella, & Weber, 2014; Brown, Weber, et al., 2014). The extent of participation in this study was encouraging given the general trend for decreasing survey participation rates (Pocewicz et al., 2012). We speculate that the significant interest and participation in our study reflected the high relevance of this topic for participants, but participation rates will be lower for general populations where the topic is less salient. For example, Brown, Schebella, et al. (2014), Brown, Weber, et al. (2014) cautioned that " … digital mapping in internet-based PPGIS is insufficient to overcome declining survey response rates across all

Table 10
Advantages and disadvantages of GPS tracking and different modes of PPGIS data collection.

	GPS tracking	PPGIS mapping - online	PPGIS mapping - field
Sampling efficiency	Intermediate Considerably fewer people agreed to participate given the time commitment, hardware requirements, technical knowledge. Sampling needs to be undertaken over an extended time period.	Great We achieved high sample sizes, higher than typical for traditional questionnaire-based surveys. The innovative form of data collection appealed to participants and word-of mouth recommendation was strong.	Low Field-data collection was very time-consuming for the researchers. However participation rates were high as participants appreciated interaction with the researchers.
Time commitment	High Requires participants to commit for an extended time period, on-going communication with researcher, equipment and data handling.	Intermediate Requires a one-off commitment. Online mapping can be time-consuming.	Low Requires a one-off commitment Field mapping is less time-consuming for participants.
Hardware	Personal GPS tracking application or device, computer/internet. Considerably more investment and effort is required if the researcher needs to supply/collect the GPS tracking equipment.	Computer/internet	None
Technical knowledge	Some For data import and sharing.	Little For using the internet.	None
Audience	Those with technical knowledge/access to hardware.	Those with technical knowledge/access to hardware.	Everybody - consequently field samples might be more representative. However in the present study there were virtually no differences between online and field participant characteristics.
Representativeness of data	Captures actual rides. Can be used to validate PPGIS mapping results.	Captures stated rides. Potential for sampling artefacts (e.g., more mapping near the beginning of tracks).	Captures stated rides. Potential for sampling artefacts although less so than with PPGIS mapping - online as participants can query the researcher.
Spatio-temporal data coverage	Collection of in-depth spatio-temporal data of complete rides (networks). However data are restricted to rides undertaken during sampling period. In-depth information on trip parameters (distance, duration, velocity, breaks).	Collection of point data that need to be 'linked manually' to whole tracks. No information on whole networks. No information on temporal distribution of rides or trip statistics except frequency of rides. Markers could however be created to for instance determine during what time of the day/week people ride along specific tracks. An advantage compared to GPS tracking is that data are independent of the sampling period so the overall coverage ('where do people ride in general') is more extensive.	Same as for PPGIS mapping - online. However the interaction with the researcher and viewing of a hardcopy map of the entire study area can facilitate correct placement of markers.
Data processing	High to very high. Time-consuming data management and preparation due to very large datasets. Effort depends on the depth of the analysis, which can be very complex.	Same as for GPS tracking. However much less data are collected as they consist of singular points rather than point sequences.	Same as for PPGIS mapping — online. However data also need to be digitalised which is time-consuming and introduces potential for errors.
Marker quantity and quality	N/A	In the present study there were no significant differences in the number of markers placed. However other studies found less markers were placed online compared to field sampling.	Certain marker categories (reasons, actions vs. locations) were more commonly mapped in the field likely because participants were interested to discuss these markers with the researchers.

modes of delivery. Incentives will be needed to increase PPGIS participation rates to obtain quality data". We found this to be true for the GPS tracking component of the study because this was a more time-consuming and demanding task for participants.

We examined the results for potential bias associated with mixed PPGIS data collection methods (field vs. online) similar to Olsen (2009) cited in Pocewicz et al. (2012), but found no notable differences in demographics or rider skill levels. This instils confidence that the online communities solicited represented the mountain biker population well. The great majority of Australians use the internet and have access to broadband internet, with rapidly growing uptake (Ewing & Thomas, 2012). In other countries or for specific groups (e.g., older demographics) where internet use is lower, mixed or paper-based methods might capture a more representative sample. A negative age-bias towards adoption of an online survey mode that has been reported elsewhere (Klovning, Sandvik, & Hunskaar, 2009) was unlikely to be an issue for mountain bikers whose demographics tend to be younger. The fact that beginners and advanced and expert riders were represented in similar proportions online and in the field suggests that promoting the survey via dedicated mountain biker forums did not introduce a bias towards the more advanced riders. Although beginners are less likely to be members, they source information on rides from specialist forums.

There was also no significant difference in the overall number of markers placed per participant between online and field participants. Field sampling appealed to a number of participants who considered themselves to be less computer-literate or those who found it easier to view a hardcopy map of the entire study area. Some participants in the field acknowledged that this was their first time viewing a full map of Northern Sydney which allowed them to recognise specific locations and connections (or lack thereof) between tracks. The field researchers were able to provide an overview of the study area and assist in locating particular tracks if prompted. This more interactive approach can assist with orientation on the map and may result in more reliable spatial data. We believe the interactivity of field sampling likely encouraged people to place more markers that they could discuss with the researchers, although the overall number of markers placed by field participants was similar to online participants. Other PPGIS studies found differences in the number of markers, namely, lower marker numbers being placed online than in the field (Brown, Weber, Zanon, & de Bie, 2012; Pocewicz et al., 2012). One major disadvantage of field sampling was the time-consuming process of data collection and entry as markers and survey responses had to be digitalised.

There were research benefits with the GPS tracking study component beyond validation of the PPGIS-mapped data. The GPS data (1) identified networks that mountain bikers use to access tracks and connect between tracks, and (2) provided trip parameters including the covered track distance, trip duration, and velocity. The tracking data can be further examined to identify locations of rides that were not captured in the mapping, for example, along tracks that were unknown to the researchers. We also identified a potential artefact of the PPGIS mapping method: tracks comprising the farther segments of a loop were mapped less frequently than tracks at the beginning of the loop, even though the tracking data showed that most participants completed a full loop. Participants placed markers in the beginning sections of loop rides without repeating them for more distant segments. To mitigate this issue in future studies, loops could be presented in the PPGIS interface as one continuous track without individual sections.

In this research, participants used their own tracking devices rather than devices supplied by the researcher (e.g., as in Wolf et al., 2013). This reduced costs and potential loss of equipment, and eliminated the need to deliver the devices or instruct participants on how to use them, apart from general instructions on GPS settings and export options for data files. Thus, tracking is made accessible to anyone owning a tracking device such as a smartphone which are becoming more common. However, a limitation of tracking was the large effort required to sustain participant communication and engagement over an extended period of several weeks. Further, the time needed to collate and analyse the database was extensive. GPS tracking does not directly provide for relating ride locations with reasons, although one can envision a participatory mapping method in the future that provides participants with their own tracks online to allow annotation in a PPGIS system.

An alternative to GPS tracking would be to exploit volunteered geographic information (VGI) through online sharing platforms such as Strava or RunKeeper. Social networks used to share movements of various activities are becoming a comprehensive source of data readily available to be exploited in the future (Goodchild, 2007). The distinction between PPGIS and VGI is not well-defined, but one potential distinction is the more purposive sampling and structured data collection process in PPGIS compared to VGI which is more focused on the sharing of spatial information of activities (Beeco & Brown, 2013). For example, VGI could potentially provide insight into the riding habits of different activity groups (Elwood, Goodchild, & Sui, 2012; Kessler, 2011). However, with VGI methods, more investigation is needed on spatial data quality, recording methods, and legal and ethical concerns before this method can be fully integrated into scientific research (Elwood et al., 2012).

This study did not fully exploit the potential of the combined PPGIS spatial data and survey data. In the future, the data could be queried to examine how rider skill levels and preferences influence the spatial distributions as a type of market segmentation for mountain bikers. And yet, the basic integrative analysis performed in this study revealed track features preferred by different skill levels, providing results that are especially important for track management.

5. Conclusions and implications for future research

Our public participation GIS approach was effective for engaging park visitors in a complex and spatially explicit park planning process involving multi-scale and cross-tenure analysis. Valuable insights were gained in our study on visitor distributions and needs from spatial data covering a large geographic area with relatively low sampling effort. Participant information from the survey questions complemented the spatial data. Mapping data gathered both online and in the field, combined with tracking data, highlighted the potential benefits of mixed PPGIS delivery modes. In the future, the methods could be extended from mountain bikers to other stakeholder groups such as hikers and conservationists as they are likely to have different expectations of park management, hold different values, and contribute different knowledge and expertise (Brown, Kelly, & Whitall, 2013).

The PPGIS process can be modified to address a wider range of park management priorities with mapping markers adapted to different response categories and audiences (Brown et al., 2013). If additional stakeholder groups are involved, further comparisons can be made between their spatial evaluations, for example, between tourists and recreationists, as suggested by Brown and Weber (2011), or to assess the level of stakeholder agreement in place-based management options (Brown, de Bie, & Weber, 2015). In our study, a key focus was on identifying motivations for riding on specific tracks in the region. Another valuable research approach, for example, would be to examine the general values associated with specific land areas or public land categories (e.g., Brown & Brabyn, 2012; Brown, Schebella, et al., 2014; Brown, Weber, et al., 2014) that influence visitation. This study suggests there are landscape values associated with different national parks that influence the riding experience, but these values were not directly measured.

Variations in the spatial scale of the mapping process and in the spatial analysis of the data need to be explored further. This research encompassed a relatively large geographic area. Some of the maintenance icons, for example, were mapped near track heads which can be interpreted as a need for maintenance on the track, but not necessarily near the track head. Some track planning aspects may require a smaller spatial scale, for example, to determine specific track locations where maintenance is needed, where technical features would be beneficial, and where to plan detailed track networks. Brown, Schebella, et al. (2014), Brown, Weber, et al. (2014) found that people experience response fatigue if too many PPGIS mapping options are available. A smaller spatial scale or more specific focus on particular marker types may generate more in-depth data and elicit more annotations on specific markers. However, in many cases, a study with a larger spatial scale is all that land management agencies can afford to undertake. Even with the spatial limitations, our study was able to provide valuable information on place-based visitor experiences and areas in need of management action.

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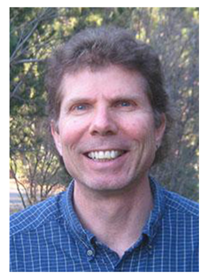

Assoc. Prof. Greg Brown has published in the areas of land use planning, natural resource policy, the human dimensions of ecosystem management, parks and protected areas management, and socio-economic assessment of rural communities. His current research involves developing methods to expand and enhance public involvement in environmental planning by having individuals map spatial measures of landscape values, management preferences, and special places in both terrestrial and marine environments.

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