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Research Article

Effect of the COVID-19 pandemic on the popularity of protected areas for mountain biking and hiking in Australia: Insights from volunteered geographic information

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ABSTRACT

Although the popularity of protected areas for recreation has been increasing, short term changes in visitation occurred during the COVID-19 pandemic. To examine how volunteer geographic information data can be used to monitor such often rapid changes in visitation across multiple locations, data from online fitness platforms for mountain biking (Trailforks) and remote area hiking (Wikiloc) were analysed before (2019) and during (2020–2021) the COVID-19 pandemic for 40 protected areas in Queensland, Australia. Mountain biking was popular with a total of 93,311 routes on Trailforks, with 26,936 routes in 2019, increasing to 37,406 in 2020, and then decreasing to 28,969 in 2021. Approximately 66% of all the routes were from just three urban protected areas out of the 12 with route data. There were 4367 routes for remote area hiking on Wikiloc across 36 protected areas, which increased slightly from 1081 in 2019, to 1421 in 2020 and to 1865 in 2021. Across 18 factors, distance from urban areas and networks of mountain biking trails best predicted popularity for mountain biking based on Generalised Linear Models. In contrast, average slope and large networks of hiking trails best predicted hiking, with similar results for each year. The two sources of online data were correlated with trail counter data, although not consistently. The results highlight how external factors affect visitation, but also how the same types of protected areas remained popular, and that the impacts of COVID-19 pandemic on visitation in South-East Queensland protected areas was less dramatic than for other regions. This study further highlights how volunteered geographic information can be used to assess the popularity of protected areas, including in rapidly changing conditions.

Management implications: Rapid changes in visitation can be challenging to monitor and manage, as occurred with the COVID-19 pandemic. The impacts of the COVID-19 pandemic on mountain biking and hiking and factors predicting protected area popularity were examined across different parks. Visitation increased at different stages of the pandemic, with mountain bikers’ preferring urban parks with networks of mountain bike trails while some hikers preferred more remote large parks. Managers can expand on traditional methods of visitor monitoring by using volunteered geographic information to monitor rapid and longer-term trends of visitation to protected areas.

1. Introduction

1.1. Hiking and mountain biking in protected areas

Protected areas are a major mechanism for the conservation of biodiversity and provide a wide range of ecosystem services including tourism and recreation (Gray et al., 2016; Monz et al., 2020; Sisneros-Kidd et al., 2021; Souza et al., 2021; Worboys et al., 2015). Approximately 15.8% of the world’s land surface is occupied by protected areas (Protected Planet, 2022) with billions of visits to these areas annually before the COVID-19 pandemic (Sisneros-Kidd et al., 2021). Common motivations for visiting protected areas include to exercise and...
experiencing the largest increases in use (Norman et al., 2019; Job et al., 2019; Tenkanen et al., 2017). Visitation to some protected areas has risen dramatically in recent years (Sisneros-Kidd et al., 2021; Svobodova et al., 2019), with those in or close to cities often experiencing the largest increases in use (Norman & Pickering, 2019; Sisneros-Kidd et al., 2021).

Two popular recreational activities in many urban protected areas are hiking (Harris et al., 2021; Huddart & Stott, 2019; Nordbo & Prebensen, 2015; Torn et al., 2009) and mountain biking (Newsome & Davies, 2009; Pickering & Rossi, 2016). Hiking is popular in many countries (Chamberlin, 2016; Nordbo & Prebensen, 2015) with over 45 million people hiking in 2018 (Harris et al., 2021). Hiking can occur in a range of settings, from urban green spaces to wilderness, is more inclusive than some other recreation activities and is popular with men and women for a range of ages (Huddart & Stott, 2019; Nordin & Jamal, 2021). People hiking in urban areas often do so for exercise and a sense of community, whereas remote area hikers may be more motivated by achievement and experiencing nature (Kil et al., 2014), but both can improve mental and physical health (Nordbo & Prebensen, 2015).

As with all recreational activities, hiking has environmental impacts including trampling vegetation, changes in plant species richness and composition, soil loss, erosion, and disturbance to wildlife (Evju et al., 2021; Martin et al., 2018; Pickering et al., 2011; Torn et al., 2009). These impacts are relatively well researched compared to other recreational activities such as environmental impacts of mountain biking (Pickering et al., 2010; Sumanapala & Wolf, 2019).

Mountain biking has increased in popularity over the last twenty years, in part due to advances in bikes, but also a greater focus on more active recreation (Monz & Kulmatiski, 2016; Newsome & Davies, 2009; Wolf et al., 2015). Millions of people mountain bike, with estimates of 8.6 million riders in the United States in 2016 (Huddart & Stott, 2019), 18.6 million riders Europe in 2015 (Pröbstl-Haider et al., 2017) and 342,000 riders in Australia in 2020 (Pelling & Jones, 2021). Mountain biking is often more popular with men and those 30–40 years of age (Hardiman & Burgin, 2013; Pelling & Jones, 2021). As with hiking, there are environmental impacts associated with mountain biking including soil erosion, changes to hydrology, introduction of invasive species and changes to vegetation composition and structure (Evju et al., 2021; Martin & Butler, 2021; Martin et al., 2018; Pickering et al., 2010; Weiss et al., 2016). There is less research on why and how mountain bikers use protected areas than for hiking (Norman & Pickering, 2019; Pickering et al., 2010), with few studies comparing the relative popularity of protected areas for the two activities (Norman & Pickering, 2019).

1.2. Monitoring visitation in protected areas

It is important for managers to understand why certain protected areas are popular and for which activities to enhance social benefits and reduce environmental impacts (Liu et al., 2021; Rota et al., 2019; Sisneros-Kidd et al., 2021; Wolf et al., 2015). Traditional methods to measure visitation to protected areas include registration data, road and trail counters and cameras, and online or in park surveys, among others (Eagles, 2014; Job et al., 2021; Liu et al., 2021; Norman & Pickering, 2019; Tenkanen et al., 2017). These methods can provide important information. They are, however, often time consuming, expensive, spatially limited, and prone to errors (Barros et al., 2019; Job et al., 2021; Norman & Pickering, 2017; Tenkanen et al., 2017). For example, with trail counters such as passive optical counters there can be gaps in data associated with technical issues (battery failure, and so on) and they vary in how well they register large group (Job et al., 2021) and faster activities such as mountain biking and running compared to slower activities such as hiking (Norman et al., 2019).

The use of online data sources, such as volunteered geographic information posted to fitness platforms are an emerging method to assess park usage (Campelo & Nogueira Mendes, 2016; Heikinheimo et al., 2017; Norman et al., 2019; Sisneros-Kidd et al., 2021). Volunteered geographic information is user-generated geographical data such as routes, reports and images that are shared online on a range of platforms (Cui et al., 2021; Rota et al., 2019). Previous studies using volunteered geographic information have found considerable variation in the availability, popularity, and access to different platforms including different fitness platforms such as Strava, GPSies, MapMyFitness and Wikiloc (Campelo & Nogueira Mendes, 2016; Cui et al., 2021; Farias-Torbidoni et al., 2022; Norman & Pickering, 2019). Furthermore, there can be biases associated with volunteered geographic information (Farias-Torbidoni et al., 2022; Norman & Pickering, 2019). For example, people posting volunteered geographic information on fitness platforms can be younger and favour fitness activities (running, mountain biking) compared to others using the same protected area (Farias-Torbidoni et al., 2022; Norman et al., 2019). Advantages of volunteered geographic information is it is available for many countries, can be obtained remotely, is often more time and cost effective than traditional sources (Campelo & Nogueira Mendes, 2016; Rota et al., 2019), and can be used to compare patterns of visitation across different spatial and temporal scales (Heikinheimo et al., 2017; Rota et al., 2019). For example, Norman & Pickering (2019) found that people using the fitness platforms Strava and MapMyFitness preferred protected areas close to cities whereas those using the adventure-based fitness platform Wikiloc preferred more remote areas.

1.3. Effect of COVID-19 pandemic on visitation to protected areas

Due to restricted travel and to maintain minimum distance for health reasons, visitation rates to protected areas changed during the COVID-19 pandemic (McGinlay et al., 2020; Souza et al., 2021; Venter et al., 2021). In some countries there was increasing emphasis on the benefits of spending time in nature for physical and mental health during the COVID-19 pandemic (Venter et al., 2021). Research during periods with COVID-19 pandemic restrictions found that visitation to some protected areas and other green spaces increased in Sweden (Beery et al., 2021; Fredman & Wolf-Watz, 2021; Hansen et al., 2021) and Norway (Venter et al., 2021). Most of the increases were for areas in or close to cities while there was decreased visitation in some more remote protected areas (Bates et al., 2020; Souza et al., 2021). When restrictions eased across Europe there was initially increased visitation to many protected areas, both urban and remote (McGinlay et al., 2020). Significant increases in visitation were also observed in some protected area in the United States during the COVID-19 pandemic (Ferguson et al., 2022a, 2022b; Templeton et al., 2021) and in some situations they were associated with crowding and conflict negatively affecting both visitor experiences and protected areas (Ferguson, Lynch et al., 2022; Templeton et al., 2021). Contrastingly, another United States study found decreases in visitation during the initial stages of the COVID-19 pandemic, with more remote National Parks experiencing greater declines in visitation than more urban National Parks (Miller-Rushing et al., 2021). However, visitation then returned to pre-pandemic levels (Miller-Rushing et al., 2021). For Australia, the impacts of COVID-19 pandemic on visitation to protected areas also varied among places and during different periods of the pandemic (Borusjeni et al., 2021; Rose, 2021). Information about the impacts of COVID-19 pandemic on the popularity of protected areas is important for management. Prolonged decreases in visitation may lead to a decline in funding for some protected areas (Souza et al., 2021), while increased visitation can place higher demands on resources and result in increased environmental impacts such as trampling and erosion (McGinlay et al., 2020). Finally, the ability to monitor sudden changes in use quickly and remotely will remain important, not only during the...
COVID-19 pandemic, but also for other events such as fires and floods which can also abruptly alter patterns in visitation (McGinlay et al., 2020).

1.4. Aims

The aims of this study were to determine how COVID-19 pandemic affected the popularity of different protected areas for mountain biking and remote area hiking in Australia using volunteered geographic data from two online platforms, Trailforks and Wikiloc. These data were used to assess if there were changes in the relative use and predictors of the popularity of protected areas in South-East Queensland pre (2019) and during (2020 and 2021) COVID-19 pandemic. Volunteered geographic data sources were also compared with trail counter data to assess the validity of such online data. Based on the literature above and the COVID-19 pandemic restrictions that occurred in South-East Queensland, it was predicted that there would be changes in the use of protected areas when restrictions occurred and changes in what makes protected areas popular during the pandemic compared to pre-pandemic.

2. Methods

2.1. Study site

This study assessed the popularity for mountain biking and remote area hiking of 40 protected areas across South-East Queensland, Australia using volunteered geographic information. This rapidly urbanising region has a population of 3.6 million people who mostly live in cities including Brisbane (2.3 million residents) and the Gold Coast (635,000 residents) (Fig. 1) (Mortoja & Yigitcanlar, 2021; Queensland Government, 2020). The subtropical climate is suitable for a range of outdoor activities year-round and recreation activities, including mountain biking and hiking, are popular (Norman & Pickering, 2019; Pickering & Rossi, 2016). South-East Queensland is also a global biodiversity hotspot, with 10% of the region conserved within a protected area network managed by Queensland Parks and Wildlife Service (Queensland Government, 2022a).

These protected areas vary in size, facilities and access, with some within or close to Brisbane and the Gold Coast, while others are more remote including further away from the coast or on islands off the coast. The network of protected areas contributes significantly to the overall economy, with $419 million dollars spend as a direct result of visiting National Parks in Queensland in 2018 alone (Driml et al., 2020). The 40 protected areas, including National Parks and Conservation Parks, were chosen so the results of this study could also be compared to previous research (Norman & Pickering, 2019) examining the relative popularity of the protected areas for different recreational activities (Fig. 2). The primary goals of both National Parks and Conservation Parks in Queensland are to preserve natural resources and values while providing educational and recreational opportunities (Queensland Government, 1992). However, Conservation Parks can be used commercially for activities such as fishing and grazing, as opposed to National Parks which can only be used for nature-based recreation activities (Queensland Government, 1992).

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Fig. 1. Population density of South-East Queensland based on data from Queensland Government.

Fig. 2. Location of 40 protected areas in South-East Queensland, Australia assessed in this study. Those in blue had hiking routes, purple had both mountain biking and hiking routes, and yellow were protected areas with no routes from the two online sources (Trailforks and Wikiloc) used in this study.
2.2. COVID-19 pandemic effects in South-East Queensland

The first COVID-19 infections in Australia were detected in March 2020 (Spennemann & Whited, 2021), with infections and hence impacts from the pandemic continuing past the end of 2021. There were three major waves of infection during this time with tight restrictions on movement throughout 2020 and 2021 including closing the international border from March 2020 to December 2021 and only allowing international arrivals through special exemptions. The States and Territories within Australia also imposed their own border restrictions and localised lockdowns at different times, further restricting travel within Australia (Spennemann & Whited, 2021). At times there were even tighter lockdowns where movement was limited to within a few kilometres of people’s homes during severe COVID-19 outbreaks.

In Queensland there was less time spent in hard lockdowns than many other regions in Australia although South-East Queensland experienced more lockdowns than other parts of the State (Fig. 3). There were a series of general restrictions on peoples’ movements to control different COVID-19 outbreaks, particularly in the first month of the pandemic. In addition, some parts of popular protected areas in South-East Queensland were closed to prevent the spread of COVID-19 in April 2020 including Cooloola Recreation Area, Kondalilla, Main Range, Mapleton Falls, Mt Coolum, Noosa, Springbrook and Tamborine National Parks. In the second half of 2020 and 2021, many restrictions were lifted within South-East Queensland while the Queensland border with other States and Territories was opened in December 2021, with no further lockdowns.

In addition to COVID-19 pandemic restrictions affecting visitation to protected areas, some national parks (Cooloola Recreation Area, D’Agullar, Lamington, Main Range, Mount Barney, and Noosa) were affected by bushfires in late 2019, limiting visitation, with some areas, including in Lamington National Park, remaining closed into 2020 due to damage to roads and other infrastructure.

2.3. Volunteered geographic information sources

To assess the popularity of protected areas before and during the pandemic, volunteer geographic information was obtained for 2019, 2020 and 2021 from two online fitness platforms: Trailforks and Wikiloc. Trailforks is a popular platform where mountain bikers post information about their rides with over 1.1 million users at the time of the study (Trailforks, 2022). It was possible to obtain information on the number of routes posted on Trailforks for specific locations and times by searching the website. Only 17 of the 40 protected areas had either mountain biking records on Trailforks and/or permit mountain biking. Here we obtained data for those 17 protected areas by first searching an infrared scope (TRAFx, 2022), for the most popular protected areas. To investigate potential differences in visitation to the protected areas in each of the three years, data from Trailforks and Wikiloc were used to examine visitation to protected areas in Australia previously (Norman & Pickering, 2019), were not included as Strava now limits the amount of temporal and spatial data it releases publicly, and MapMyFitness is no longer popular in the region.

2.4. Characteristics of protected areas

There are many factors affecting the popularity of protected areas. Previous research by Norman & Pickering (2019) assessed 18 variables relating to management, environmental, topographical and geographic factors to see which best predicted popularity among the 40 protected areas. Management variables included presence of trails, length of trails and if mountain biking was promoted. Environmental variables related to the dominant vegetation communities as well as the percentage and total area of rainforest. Topographical variables were the highest elevation, average slope (degrees) and elevation range, while geographical variables were total area, the shortest distance to urban areas and city centres from the protected area and the road distance from protected area facilities (trail heads, visitor centres and car parks) to urban areas. Norman & Pickering (2019) found that distance from the protected area boundary to the closest urban area was the most important predictor for mountain biking, hiking and running on fitness platforms MapMyFitness and Strava, while elevation gradient and presence of recreational trails were most important for Wikiloc hikers. In this study, the same 18 variables were used. They were tested for collinearity using Pearson’s bivariate correlation in R Studio (R Core Team, 2022) to identify if variables were correlated. Values over 0.7 indicates that variables are collinear and hence should not be used in the same models. The variables “combined track length”, “elevation range”, “highest points”, “rainforest area”, “town centre to edge” and “with mountain bike trails” were removed after this process, leaving 12 explanatory variables to be tested.

2.5. Data analysis

For remote area hiking, all 40 protected areas were included in the analysis. For mountain biking only 17 protected areas were included. This was because mountain biking is not permitted or promoted in many protected areas. To investigate potential differences in visitation to the protected areas in each of the three years, data from Trailforks and Wikiloc were analysed using paired t-tests in R Studio (R Core Team, 2022).

Protected areas in South-East Queensland are free to visit, with trail counters used by managers on selected trails to estimate visitation within protected areas. Generally, trail counters have medium accuracy and medium costs associated with them (Job et al., 2021). Data from trail counters, which record the number of passes at a specific location using an infrared scope (TRAFx, 2022), for the most popular protected areas on both platforms, Nerang National Park and Lamington National
3. Results

3.1. Mountain biking

Mountain biking was popular pre-COVID-19 pandemic with 26,936 routes on Trailforks in 2019. However, it was highly variable with route data for just 12 protected areas on Trailforks, and they were most from just three urban protected areas that have extensive mountain bike trails: Nerang (28%), Daisy Hill (21%) and Bunyaville (19%) (Fig. 4). There was a 40% increase in the number of routes posted to Trailforks in 2020 compared to 2019 (p < 0.001), then a 22% decrease in 2021 compared to 2020 (p = 0.04), but no significant differences between 2019 and 2021 (p = 0.42) across the 12 protected areas (Fig. 4). The number of unique mountain bike riders posting on Trailforks showed a different pattern among years, with the number of riders increasing by >40% between 2019 and 2020 (p = 0.009), but they were similar between 2020 and 2021 (p = 0.07). This potentially indicates that many people who started riding mountain bikes and posting routes to Trailforks in 2020 continued to participate in mountain biking in 2021, but they may not have ridden as often and/or posted as many routes in the second year of the pandemic.

The protected areas within 2 km of an urban area were far more popular for mountain biking than protected areas further away. In 2019 and 2021, protected areas close (<2 km) to urban areas had approximately 22 times more routes on Trailforks than more remote protected areas while it was 28 times in 2020 when there were the most restrictions on movement due to the pandemic.

There were fewer female than male mountain bikers posting on Trailforks. Only 9% of mountain bike riders identified as female in 2019 and 8% in 2020. Even fewer riders, 6%, identified as female in 2021, a significant decrease compared to 2020 (p = 0.046) and 2021 (p = 0.01) (Table 1). Between 60% and 70% of mountain bike riders were between 30 and 50 years old. There was very little change in the percentage of riders in the under 20, 20–30 and over 60 age categories. Some significant changes were observed in other age brackets, for instance there was an increase in riders aged 40-50 from 2019 to 2020 (p = 0.004) and 2021 (p = 0.01) but decreases from 2020 to 2021 (p = 0.005). Furthermore, the proportion of riders aged 50–60 increased from 14% in 2019 to 18% in 2020 (p = 0.006) to 22% in 2021 (p = 0.001).

Mountain biking was most popular in winter and spring in 2019 and 2020 (Table 2), but in 2021 there was less seasonal effect with relatively consistent visitation for most of the year (Table 2). Overall, August was the most popular month for mountain biking in South-East Queensland (Table 2), while the decrease in routes from February 2020 to March 2020 could potentially be due to tighter COVID-19 pandemic

| Age Category | 2019 | 2020 | 2021 |
|--------------|------|------|------|
| Female       | 9%   | 8%   | 6%   |
| Male         | 91%  | 92%  | 94%  |
| <20          | 3%   | 3%   | 2%   |
| 20–30        | 10%  | 7%   | 7%   |
| 30–40        | 36%  | 24%  | 22%  |
| 40–50        | 33%  | 43%  | 40%  |
| 50–60        | 14%  | 18%  | 22%  |
| 60+          | 4%   | 4%   | 7%   |

![Fig. 4. Number of mountain bike routes in South-East Queensland protected areas from Trailforks in 2019, 2020 and 2021. NP are National Parks, CP are Conservation Parks, R are remote protected areas and U are urban protected areas.](image-url)
restrictions on people’s movements during this early stage of the pandemic.

3.2. Remote area hiking

In contrast to the large number of routes available for mountain biking on Trailforks, there were only 4367 hiking routes from Wikiloc across the three years, but they covered 36 protected areas, with four remote protected areas being particularly popular: Lamington, Glass House Mountains, Main Range and Mt Barney National Parks. There was more variability between years in Wikiloc data, where eight protected areas had more routes in 2019 than 2020 and 2021, while 25 had more routes in 2020 compared to 2019, and 20 had more routes in 2021 than both 2019 and 2020 (Fig. 5), although this could be because of low numbers. The protected areas with the largest increases were Glass House Mountains, Lamington, Main Range and Mount Barney National Parks. Across the 36 protected areas combined there were no significant changes in visitation from 2019 to 2020 (p < 0.004), with a total increase from 2019 to 2021 of 73% (p < 0.001) with an R² value of 0.45 (Fig. 6b). When comparing each year, 2019 (p < 0.001) and 2020 (p = 0.004) were significantly correlated but 2021 was not (p = 0.69).

3.4. Factors explaining the popularity of protected areas in 2019, 2020 and 2021

Variables that best predicted the popularity of protected areas for mountain biking were the presence of mountain biking-only trails and the distance to urban areas (Table 3), where more mountain biking-only trails had a positive effect, and larger distances from urban areas had a negative effect. The popularity of hiking was best predicted by average slope and if there was an extensive trail network (e.g., more than 10 km of walking and biking trails) (Table 3) with both variables resulting in increased visitation. Average slope had more effect on popularity than an extensive trail network and its effect was constant over the three years.

4. Discussion

4.1. Which protected areas were popular and why?

Popular protected areas in South-East Queensland for mountain biking differed to those for remote area hiking based on Trailforks and Wikiloc data. The three most popular protected areas for mountain biking (Nerang National Park, Daisy Hill Conservation Park and Bunyaville Conservation Park) are in, or adjacent to urban areas, and have extensive mountain bike trail networks. Of the 17 protected areas with mountain bike route data, those within 2 km of urban areas were 22–28 times more popular than those further away with people using Trailforks. These results are similar to those from Norman & Pickering (2019) who found that parks within 2 km of urban areas had between five and 15 times as many routes posted to Strava and MapMyFitness than those further away (Norman & Pickering, 2019). The effect of distance on visitation to protected areas is a common pattern seen in a wide range of studies (Jones et al., 2010; Norman & Pickering, 2019; Rossi et al., 2015), but what was important here was the scale of the effect on mountain biking with dramatic differences in visitation to urban compared to more remote protected areas. In addition to distance, presence of trails and other infrastructure specifically for mountain biking was also important in this and other studies (Norman & Pickering, 2019; Wolf et al., 2015).

Three large National Parks (Lamington, Main Range and Glass House Mountains) were more popular with those using Wikiloc in 2019–2021, with steep, long trail networks the most important predictors of popularity. Lamington and Main Range National Parks are the steepest across the 40 protected areas in the study and Lamington has by far the most extensive walking trail network in South-East Queensland. The importance of more challenging terrain for hikers was also observed in Norman & Pickering (2019) where elevation range best predicted protected area popularity for Wikiloc in the past. Trails that are more challenging due to steepness and terrain have also previously been found to be preferred by hikers (Wolf & Wohlfart, 2014). While the factors that predict the popularity of protected areas in South-East Queensland remained similar to those found previously (Norman & Pickering, 2019), the intensity of visitation for mountain biking and hiking changed as a result of the COVID-19 pandemic.

4.2. Impacts of COVID-19 pandemic on popularity of protected areas

People in South-East Queensland spent less time in COVID-19 monthly and yearly trends to Wikiloc data. The difference between 2019 and 2020 was only 400 passes (p = 0.99) but there were approximately 73,000 more passes in 2021 than 2020 (p = 0.01) and in 2019 (p < 0.001). Pearson’s correlations showed a significant correlation between Wikiloc and trail counter records overall for Lamington National Park (r² = 0.001) with an R² value of 0.45 (Fig. 6b). When comparing each year, 2019 (p < 0.001) and 2020 (p = 0.004) were significantly correlated but 2021 was not (p = 0.69).
pandemic lockdowns than most other regions in Australia and for many other countries. Therefore, the impact of COVID-19 pandemic on recreation in parks was not as great as for some areas in Europe (Hansen et al., 2021; Power et al., 2022; Venter et al., 2021) or the United States (Landry et al., 2021; Rice et al., 2020). However, there does appear to be an effect in terms of where and when people went mountain biking and hiking during the pandemic (2020 and 2021) compared to pre-pandemic (2019). The increase in Trailforks records for 2020 compared to the year before and after, indicates that tighter COVID-19 pandemic restrictions may have resulted in some locals taking up new activities during the pandemic, as occurred elsewhere (Hansen et al., 2021). That the effect of distance to protected areas was greatest when restrictions on movements due to COVID-19 pandemic were greatest (here in 2020) is consistent with other studies. Similar results were observed in the United States where the distance travelled to participate in outdoor recreation declined significantly for urban populations during early stages of the pandemic (Landry et al., 2021). Furthermore, in Germany cycling in urban green spaces increased by an average of 55% during periods of COVID-19 pandemic restrictions, whereas no significant change was observed in the number of people cycling in rural green spaces (Schweizer et al., 2021). Then in 2021, the number of mountain bike routes returned to close to pre-pandemic levels based on Trailforks data. As there were similar numbers of people posting in 2021 compared to 2020, the increase in routes may reflect how those people had more time to go mountain biking and/or more opportunity and motivation to upload their routes in 2020 compared to 2021. During the pandemic in 2020, Australians increased the time they spend on their smartphones (38%) and social media apps (12%) compared to 2019 (Watson, 2020a, 2020b). As volunteered geographic information sources are often seen as social platforms and not just fitness apps (Lupton, 2018; Rivers, 2020), people may have been more active on Trailforks in 2020 so they could communicate with others about their rides, when they were less able to gather in person.

The data on Trailforks again show how mountain biking remains a predominantly male pursuit, with 92% of those posting demographic information identifying as male. Previous research interviewing
mountain bikers in some of the same protected areas also found that riding was mainly a male pursuit (Rossi et al., 2015) and across Australia 80% of riders identify as male (Pelling & Jones, 2021). Men are more likely to participate in moderate to vigorous outdoor activities generally, which includes mountain biking (Nash & Moore, 2021; Pelling & Jones, 2021). As women are often the primary caretakers of children (Pérez-Tejera et al., 2018), during the COVID-19 pandemic it may have been even harder for women to participate in recreational activities when children were also at home, school classes were online and women took on most of extra care duty (Power, 2020; Xue & McMunn, 2021). It is important to promote moderate to vigorous outdoor activities, such as mountain biking, to groups currently underrepresented in these activities, as more intense exercise is correlated with increased health benefits (Nash & Moore, 2021). Strategies discussed in the literature to achieve this include targeting women in marketing and education campaigns, women-only sporting events, providing child-friendly trails and mitigating safety concerns (Derose et al., 2019; Pérez-Tejera et al., 2018). Although it was not possible to get demographic data from Wikiloc, previous surveys in some of the same protected areas, but on less remote trails found a more even gender ratio, but still with more males hiking (Rossi et al., 2015).

Most riders were between 30 and 50 years old, which is similar to previous studies of both mountain biking and other moderate to vigorous physical activities (Pelling & Jones, 2021; Roberts et al., 2018). There was little change in age demographics of mountain bikers over the three years. There was, however, no age category for children. This was a limitation of collecting demographic data. To the best of the authors’ knowledge there are no studies on how COVID-19 pandemic may have impacted participating in mountain biking by gender and age to compare with these findings.

### Table 3

Results from generalised linear models showing models that best explain the popularity of protected areas for each year on Trailforks and Wikiloc with p-values and odds ratios for each variable and the R² value for the model.

| Explanatory variables for popularity | p-value | Odds ratios | R²   |
|-------------------------------------|---------|-------------|------|
| Trailforks 2019                     |         |             |      |
| Length of biking-only trails       | 0.07, 0.02 | 5.9, 0.16   | 0.59 |
| Direct distance to urban area       |         |             |      |
| boundary                            |         |             |      |
| Trailforks 2020                     |         |             |      |
| Length of biking-only trails       | 0.09, 0.02 | 5.9, 0.16   | 0.59 |
| Direct distance to urban area       |         |             |      |
| boundary                            |         |             |      |
| Trailforks 2021                     |         |             |      |
| Direct distance to urban area       | 0.01    | 0.15        | 0.59 |
| boundary                            |         |             |      |
| Wikiloc 2019                        |         |             |      |
| Average slope + walking and         | <0.001  | 2.6, 1.3    | 0.47 |
| biking trails longer than 10 km     |         |             |      |
| Wikiloc 2020                        |         |             |      |
| Average slope                       | <0.001  | 2.7         | 0.43 |
| Wikiloc 2021                        |         |             |      |
| Average slope + walking and         | <0.001  | 2.9, 1.3    | 0.55 |
| biking trails longer than 10 km     |         |             |      |

Fig. 6. Scatter plots of the (6a) distribution of Trailforks and trail counter records in Nerang National Park and (6b) distribution of Wikiloc and trail counter records in Lamington National Park.
Remote area hiking numbers were lower in 2019 and 2020 compared to 2021, in part due to the impact of bushfires as well as COVID-19 pandemic restrictions. Furthermore, all but one of the protected areas that closed in South-East Queensland during the pandemic were visited by remote area hikers and not mountain bikers. The increase in 2021 can partially be explained by easing of restrictions allowing people to travel further, and hence the potential to visit protected areas that may better suit their recreational preferences (McGinlay et al., 2020). Similar results for remote protected areas were observed across Europe where, when restrictions began to ease in 2020, visitation to remote protected areas increased (McGinlay et al., 2020).

4.3. Management implications

Visitation to many protected areas is increasing and changing, including in Australia (Norman & Pickering, 2019; Sisneros-Kidd et al., 2021; Svobodova et al., 2019), with mountain biking becoming far more popular (Norman & Pickering, 2019). Managers can better tailor infrastructure and education, improve visitor experiences and reduce social conflict and environmental damage when they have better information about visitor preferences, including for specific activities (Hansen et al., 2021; Mann & Absher, 2008; Norman & Pickering, 2019). For datasets experiencing increased use for mountain biking, management responses can include restricting some activities on some trails, hardening trails, provisioning new single use trails, as well as increase the use of signage to highlight length, type of activities permitted and difficulty of trails (Norman et al., 2019; Rice et al., 2020; Wolf et al., 2015). These strategies can potentially reduce environmental impacts, crowding and conflict (Norman et al., 2019; Rice et al., 2020; Wolf et al., 2015). Managers increasingly need to engage with stakeholder groups via traditional communication methods but also via social media and fitness platforms including when communicating about facilities, changes to access, trail etiquette and best practices (Ferguson, Lynch, et al., 2022; Miller-Rushing et al., 2021; Pröbstl-Haider et al., 2017). Such approaches are part of broader engagement strategies with diverse stakeholder groups, including recreational users, adjacent landowners, other types of protected areas as well as conservation organisations (Worboys et al., 2015). There are increasing examples of the co-design and co-construction of trails, although conflicting mandates among stakeholders and with the primary purpose of the protected areas for conservation will occur (Newsome, 2014; Wolf et al., 2015; Worboys et al., 2015). Opening mountain biking specific trails and facilities outside of protected areas, such as on council lands, commercial forests, or private land, can also help address the increasing demand for riding experiences in and close to urban areas while reducing environmental impacts in areas that are primarily for conserving biodiversity (Hardiman & Burgess, 2013; Wolf et al., 2015).

The characteristics which influence protected area popularity remained the same during the study period, despite visitation fluctuating due to the COVID-19 pandemic. This reinforced the importance of distance in determining visitation to protected areas as well as the presence of mountain biking specific trails, and long, steep slopes for hiking in South-East Queensland. Although the current research provides insights relevant to the specific protected areas assessed and others with similar characteristic, further research covering other areas that differ in climate, terrain, and communities would provide even more insights.

Differences in visitation patterns for mountain biking and remote area hiking seen in this study also demonstrate how multiple volunteered geographic information sources are required to provide insights into different activities (Norman & Pickering, 2017, 2019). Studies have found that platforms vary in how they are used and for which activities, in access to data, and in popularity between regions and over time (Campelo & Nogueira Mendes, 2016; Norman & Pickering, 2019; Santos et al., 2022; Walden-Schreiner et al., 2018). The volunteered geographic information platforms used in this study were correlated to trail counter data provided by the Queensland Government but varied among years and for activities in how well the records matched. This could partially be due to trail counters not differentiating between activities, which is a benefit of volunteered geographic information sources. It may also be due to fluctuations in the popularity of the platforms, who uses them and why.

Having ways to measure changes in visitor numbers over large scales both remotely and almost instantaneously are some of the benefits that volunteered geographic information provides (Heikinheimo et al., 2017). As the popularity of protected areas for visitors and different recreational activities can change over time, understanding these changes and trends can assist in developing appropriate management strategies for protected areas (Hansen et al., 2021; Heikinheimo et al., 2017; Souza et al., 2021; Venter et al., 2021). For instance, the increase in the number of unique users of Trailforks in 2020 demonstrates that there were a lot of new visitors and beginner mountain bike riders. Understanding this may lead to managers increasing education for example (Beery et al., 2021). Furthermore, knowing that there were more people visiting protected areas more often allows managers to provide adequate infrastructure and limit environmental impacts (Beery et al., 2021). Finally, the knowledge gained from this study and others that examined visitation during the COVID-19 pandemic may be important for future instances of restrictions and other rapidly changing situations where managers may be able to predict protected area popularity based on what was observed during the COVID-19 pandemic (McGinlay et al., 2020).

4.4. Limitations

Volunteered geographic information platforms vary in popularity and access to data (Cui et al., 2021). For example, MapMyFitness was not used in the current study due to the decline in its popularity in the region, despite being a valuable source of volunteer geographic information in the past (Norman & Pickering, 2019), whereas Trailforks was included following its growth in Australia in recent years. Track closures and changes to what is permitted in certain protected areas can also impact the popularity of protected areas which can be reflected on fitness platforms. For instance, a dramatic decline was observed in mountain biking routes at the end of 2021 for Daisy Hill Conservation Park, which can partially be explained by riders moving to the newly opened mountain bike trails close by at Mount Cotton in Brisbane. The popularity of different activities also varies among platforms; therefore, it is difficult to compare activities across volunteered geographic information sources (Farias-Torbidoni et al., 2022; Norman & Pickering, 2019). There were also other influences on the popularity of protected areas that were not the focus on the study. As mentioned previously, the impact of the 2019 fires affected access to several of the more remote protected areas in the region, therefore information from Wikiloc was influenced by the fires more than Trailforks records. Access to data on volunteered geographic information sources has also changed as platforms increasingly monetarising access while increasing recognition of the importance of privacy is also restricting access and use of some data (Norman & Pickering, 2019; Raturi et al., 2021). For example, Strava has increased in popularity for a range of activities, especially cycling, (Raturi et al., 2021), however, it was not used in this study due to increasing limitations on access to free data for research. Furthermore, Trailforks previously allowed access to individual historic routes, however, by the beginning of 2022, this feature was no longer available.

Infrared trail counter records were compared to volunteered geographic information sources to determine how well online data can be used as a surrogate for on-ground data. Suitable trail counter data were only available to the authors for two protected areas for the study period. However, there were multiple gaps in the trail counter data with 1396 days with missing data out of a total of 5976 days of sampling in Nerang National Park and 1280 days with missing data out of a total of 4980 days of sampling in Lamington National Park. Missing data is
common in trail counter records due to malfunctioning equipment or external factors such as debris or animals blocking the counters (Anderson et al., 2014; D’Antonio et al., 2016; Norman & Pickering, 2017; Tenkansen et al., 2017). Trail counters also may either not effectively record some activities, or often do not distinguish between recreational activities, and large groups making it difficult to compare patterns of visitation for specific activities (Granner & Sharpe, 2004; Job et al., 2021). Furthermore, trail counter data, as well as other monitoring carried out by Queensland Parks and Wildlife Service, such as health checks and basic monitoring, are very rarely published online (Queensland Government, 2022b), making it difficult to obtain relevant data.

There was no international tourism in Australia from March 2020 until after the end of 2021 (Australian Government, 2022), which may have affected visitation to protected areas in South-East Queensland. However, as seen in other studies that despite the assumption that visitation to protected areas would decrease, there was often more visits during the COVID-19 pandemic (Templeton et al., 2021). This even occurred in some protected areas that were previously mainly popular with international visitors (Templeton et al., 2021). There were increases in visitation to many local tourism destinations in Australia during periods in 2020 and 2021, in part, due to the severe limitations on Australian’s capacity to leave the country during most of 2020 and 2021 (Australian Government, 2022), resulting in far more local tourism.

5. Conclusion

This study has implications for the management of protected areas and the use of volunteered geographic information for research. The results show how volunteered geographic information can provide information about different types of recreation in protected areas remotely in rapidly changing situations, such as the COVID-19 pandemic. It also demonstrated how the Covid-19 pandemic affected the popularity of protected areas for mountain biking and hiking with some increases in use, particularly for urban protected areas, but that the changes were not as dramatic in some other locations where restrictions were greater and/or for longer. The findings also showed that these changes were more significant in 2020 for mountain biking, but in 2021 for hiking. Finally, it showed again how the popularity of protected areas is driven by distance and then the opportunities for specific types of recreation within the protected area, including the presence of infrastructure such as trail networks. This is important for managers and others when deciding what facilities to provide where and how that may influence specific cohorts of visitors.

Declaration of competing interest

None.

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