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RESEARCH ARTICLE

Using crowd-sourced photos to assess seasonal patterns of visitor use in mountain-protected areas

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Abstract Managing protected areas effectively requires information about patterns of visitor use, but these data are often limited. We explore how geotagged photos on Flickr, a popular photo-sharing social-media site, can generate hotspot maps and distribution models of temporal and spatial patterns of use in two mountain-protected areas of high conservation value. In Aconcagua Provincial Park (Argentina), two routes to the summit of Aconcagua were used in summer, but most visitors stayed close to the main road, using formal and informal walking trails and the Visitor Centre, while in winter, there was very limited visitation. In Kosciuszko National Park (Australia), alpine walking trails were popular in summer, but in winter, most visitors stayed in the lower altitude ski resorts and ski trails. Results demonstrate the usefulness of social-media data alone as well as a complement for visitor monitoring, providing spatial and temporal information for site-specific and park-level management of visitors and potential impacts in conservation areas.

Keywords Aconcagua Provincial Park · ALPINE · Geotagged photos · Informal trails · Kosciuszko National Park · MaxEnt modelling

INTRODUCTION

Protected areas are key mechanisms for conserving biodiversity while also providing opportunities for human–environment interactions through recreation and tourism (Newsome et al. 2012; Watson et al. 2014). These interactions offer a host of health and well-being benefits (Romagosa et al. 2015), along with economic benefits to local communities (Worboys et al. 2015). In mountain-protected areas, including parks established to conserve outstanding natural features, tourists can engage in a range of activities including mountaineering, hiking, sightseeing, skiing, bird watching, and fishing (Martínez Pastur et al. 2016; Musa et al. 2016). As a result, some mountain-protected areas are popular tourism destinations, with estimates of 15–20% of the over one billion international tourists each year visiting these regions (Debarbieux et al. 2014). Visitor use of protected areas can also have negative impacts on natural resources, including wildlife, soil, water, and vegetation (Hammitt et al. 2015). Alpine environments are particularly sensitive to impact, including from visitor-created informal trails, because of the limited ability of alpine vegetation to recover from trampling due to short growing seasons and soil characteristics (Leung et al. 2011; Barros et al. 2013). Monitoring visitor numbers and the spatial and temporal patterns of use inform management strategies intended to mitigate and minimize these negative impacts while maintaining opportunities for quality visitor experiences (Hadwen et al. 2007; Newsome et al. 2012).

Data on visitor use of protected areas can be collected through a variety of manual and digital methods, including direct observation, trail counters, and on-ground or web-based-tracking technology (Newsome et al. 2012; Eagles 2014; Shoval and Ahas 2016). However, the data collected are often limited by multiple constraints, including a shortage of personnel and/or funding to obtain detailed data across large regions, inconsistencies in how monitoring is conducted, and practical limitations associated with some technology resulting in inaccurate data (Newsome et al. 2012; Eagles 2014). A dearth of reliable visitor data for protected areas is often credited as a major limitation for proactive management (Hadwen et al. 2007; Worboys et al. 2015).

Crowd-sourced data are increasingly used as an efficient and complementary approach for visitor monitoring in protected areas (Levin et al. 2017). Crowd-sourced data are information generated by many individuals, often accessed through web-based platforms (See et al. 2016). This includes geotagged photos shared publicly on social-media and other social-media-derived sources of volunteered geographic information (i.e., GPS tracks), which can be used for tourism (Bizarro et al. 2016; Campelo and Nogueira Mendes 2016; Santos et al. 2016; Levin et al. 2017) and visitor infrastructure research (Hennig 2017; Walden-Schreiner et al. 2018). Social media provide outlets for visitors desiring to share information about their travel, including intense experiences in areas known for their conservation value, remoteness, and iconic features. Summiting peaks, especially the highest in a region, is often seen as a personal achievement (Musa et al. 2016) and sharing experiences has been found to be a key motivation in sharing photos on social media (Oeldorf-Hirsch and Shyam Sundar 2016).

Geotagged images can serve as proxies of visitor numbers, as well as reflect spatial and temporal variations in visitor use. Studies using geotagged photos have found correlations between photo numbers and empirical visit counts at large spatial scales (Wood et al. 2013; Levin et al. 2015; Spalding et al. 2017), contributed to models of economic impacts (Sonter et al. 2016), explored the distribution of cultural ecosystem services (Richards and Friess 2015; Martínez Pastur et al. 2016), and modelled visitor flows at more local levels (Orsi and Geneletti 2013). Data from popular photo-sharing sites such as Instagram, Panoramio, and Flickr are accessible through application-programming interfaces. A recent study by van Zanten et al. (2016) highlighted how Panoramio, Flickr, and Instagram revealed high spatial agreement for geotagged photos across Europe, including for mountainous terrain. Specific to protected areas, recent estimates suggest that 11% of the 20.6 million geotagged photos shared on Flickr are taken within protected areas, of which 6.4% are from remote locations (Levin et al. 2015). These areas include parks of high conservation value, such as those conserving the highest mountains on every continent. Research also suggests that social-media data provide reliable alternatives for understanding tourists' preferences for nature-based experiences, specifically for biodiversity, with Flickr aligning best with preferences for less charismatic biodiversity (Hausmann et al. 2017).

Often, research has examined visitor counts and patterns at a large spatial scale, such as for large parks or even at national and international scales (Wood et al. 2013; Levin et al. 2015). Fewer studies, however, have examined visitor use patterns at smaller scales (Richards and Friess 2015) or examined seasonal visitor–environment interactions (Sessions et al. 2016) based on infrastructure and environmental factors, critical for understanding such interactions and mitigating impacts. The aims of this study are to assess the utility of using social-media geotagged photos to determine spatial and temporal visitation patterns in remote mountain-protected areas. Specifically, this paper: (1) examines metadata characteristics of geotagged photos; (2) compares geotagged photo locations with visitor data to assess if the photos can be used as proxies for visitation patterns in the parks; (3) analyses the temporal and spatial distributions of visitors based on geotagged photos; and (4) assesses what factors are associated with the spatial distribution of photos in the parks. The research on geotagged photos was conducted in two mountain parks of high conservation value containing iconic summits and popular for a range of tourism activities, but that differ in the types of activities available and the extent and types of infrastructure for visitors: Aconcagua Provincial Park in Argentina and Kosciuszko National Park in Australia.

MATERIALS AND METHODS

Study areas

Aconcagua Provincial Park in the Andes Mountains of Argentina is an IUCN Category II protected area that conserves alpine ecosystems, endemic flora and fauna, glaciers, rivers, as well as contains the highest summit in the Southern Hemisphere, Mt Aconcagua (6962 m a.s.l.) (Fig. 1a). Over 120 plant species are conserved in Aconcagua, present below 4400 m a.s.l., with most occurring in the valley floors, where campsites, infrastructure, and formal and informal trails are also located (Barros et al. 2013) (Fig. 2a, b). Only one road accesses the park, the international highway connecting Argentina and Chile, with people entering via the two valleys intersecting the road: Horcones Valley and Vacas Valley (Fig. 1a). During the summer months, approximately 40 000 people visit the park, of which around 35 000 are day visitors (Barros et al. 2015). Day visitors only use the Horcones Valley, where there is a Visitor Centre and self-guided circuit walk of 2 km with views of Mt Aconcagua (Barros et al. 2015). Mountaineers and trekkers travel further into the park to attempt the summit or reach base camps through Horcones Valley (30 km) or Vacas Valley (42 km). In winter, nearly, all visitation consists of day trippers using the Visitor Centre and an adjacent short walk (300 m) in Horcones Valley, with nearly no attempts on the summit due to severe weather conditions.

In contrast, Kosciuszko National Park in southeastern Australia is lower in elevation, receives more visits, is easier to access, and is popular with visitors in winter as

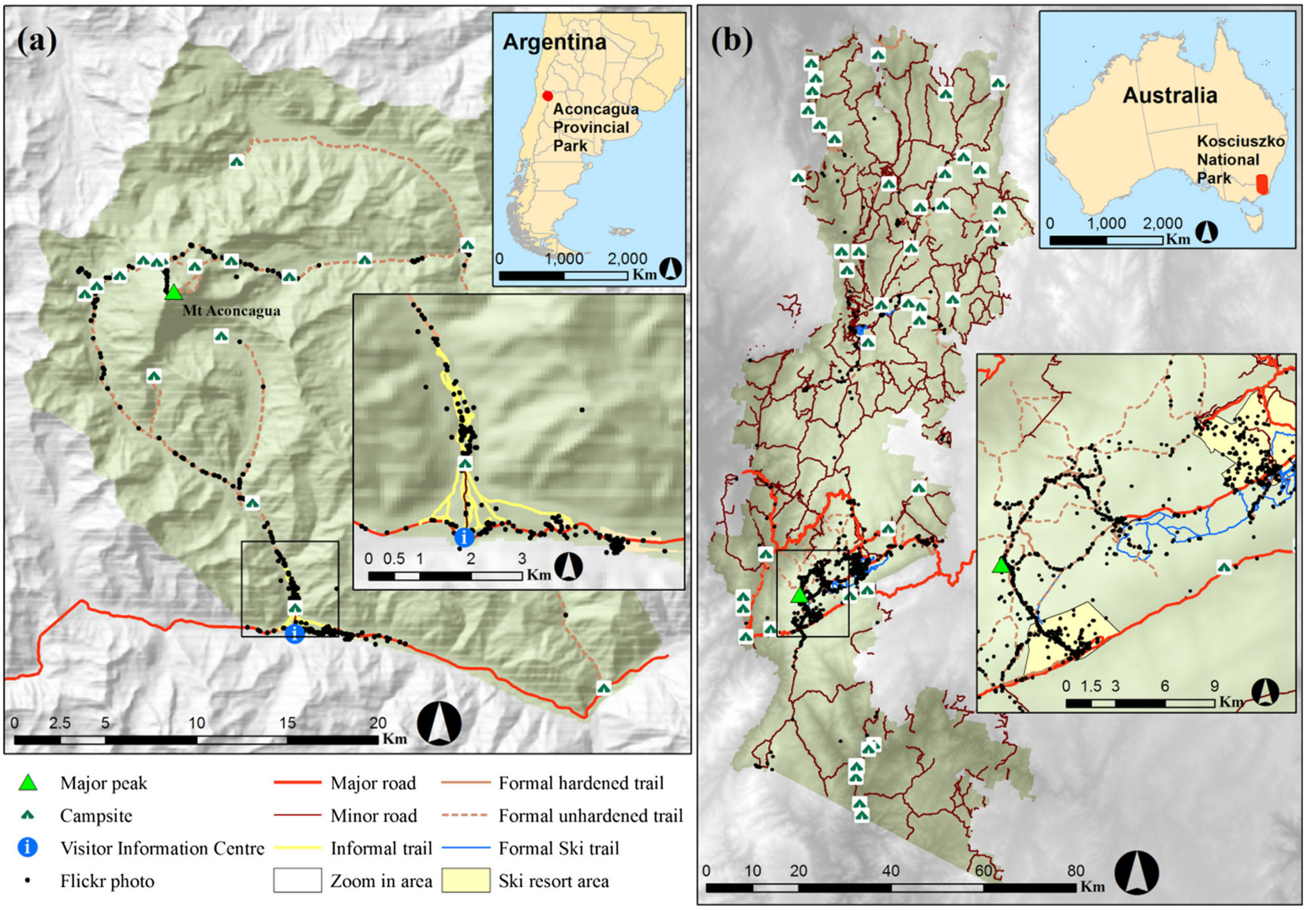

Fig. 1 Locations of the two parks in Argentina and Australia with road networks, formal and informal trails and main visitation areas. Aconcagua Provincial Park (**a**) is located in the Central Andes in Mendoza, Argentina and Kosciuszko National Park (**b**) is located in the Snowy Mountains in New South Wales, Australia

well as summer. The park protects unique montane and alpine habitats with several endemic and endangered species, and includes the highest summit on the continent (Mt Kosciuszko, 2228 m a.s.l.) (Fig. 1b). Kosciuszko is an IUCN Category II protected area, UNESCO Biosphere Reserve, and a biodiversity centre identified by the World Conservation Monitoring Centre with over 1.4 million visits a year (Fig. 2c, d) (Roy Morgan Research 2015). Although winter is the most popular time to visit the park for snow-based activities, including skiing in the major resorts located in the subalpine zone, walking in the alpine areas around Mt Kosciuszko is popular in summer with over 100 000 visitors in this part of the park in 2005 (Johnston and Growcock 2005). There are eight entry points, including a series of paved and unpaved roads, some of which traverse the park facilitating year round access (Fig. 2b). The summit of Mount Kosciuszko is also easily accessed by a 5–8 h walk from one of the two ski resorts when the alpine area is snow free, and by skis in winter (Pickering and Buckley 2003).

Existing visitor monitoring data

Both parks collect visitor count data, but by different methods. For Aconcagua, park rangers collect data from November to March when conditions are warmer and most people use the park. This includes data from entry permits (fees) and a registration book at the main entrance. Data include information on the number of days visitors intend to stay in the park, locations, and activities undertaken (i.e., day visit, short or long trek, climb) (Barros et al. 2015). Data from permit fees indicate that there are over 40 000 day visits to the Horcones Valley per year, but only around 5000 people travel further into the park to go hiking or climbing (Massarelli 2016). The timeframe informed and matched the date range of photos requested from Flickr.

In Kosciuszko, visitor data are collected from park entry gates, surveys, and traffic counters on several roads and trails (Worboys and Pickering 2002), at different temporal and spatial scales. Data are often fragmentary due to resource limitations and occasional equipment

Fig. 2 Mountain-protected areas of high conservation value and popular with tourists in Argentina and Australia. **a** Park visitors congregate in Horcones Valley at the entrance to Aconcagua Provincial Park, Argentina. **b** Visitors hiking through Vacas Valley in Aconcagua Provincial Park. **c** Visitors hiking on a steel mesh track in Kosciuszko National Park, Australia. **d** View of glacial lakes in Kosciuszko National Park

malfunctions. Therefore, limited visitor data were available for this analysis for the park.

Crowd-sourced visitor data

Crowd-sourced geotagged photos from the two parks were obtained from Flickr. This source of geotagged photos has been used for other research, including in protected areas, and has an accessible application-programming interface (Alivand and Hochmair 2017). All publicly shared photos on Flickr containing a geotag over several years and seasons of use (1 November 2010 and 31 March 2016) were requested from the Flickr API on 14 September 2016, and located within the boundaries of the parks, were obtained using the application-programming interface. Photo metadata included where and when it was taken (longitude and latitude), when it was uploaded, owner ID, image URL, and camera type. Data were written to comma-separated values (csv) files for statistical analysis and also converted to geographic information system (GIS) as shapefiles.

Two of the authors with extensive site knowledge of both parks examined the photos to determine whether they were correctly geotagged. Specifically, all photos more than 250 m from park features (i.e., roads, trails, visitor centres, and ski resorts) were inspected. If an image was no longer accessible (i.e., owner had removed or changed viewing permissions after the metadata were captured in the sample), the title and text tags were checked. Only 3.3% (33 photos) for Aconcagua and 0.17% (10 photos) for Kosciuszko appeared to be in the wrong location, including outside the park, or not taken from the ground (i.e., from a plane). For Aconcagua, the content of the photos was diverse including landscapes, natural features, campsites, and people hiking or sightseeing. The potential outliers were clearly incorrect (e.g., showing the international highway outside of the park) and, therefore, removed from the data set. The potential outliers from Kosciuszko were retained as it is possible, and common, for visitors bushwalking or participating in snow-based activities to be far from formal infrastructure and, therefore, difficult to determine if they were actually outside the large park boundaries or if the photos were in the wrong location. Ten MaxEnt iterations were performed, each using a different random sample of photo data, to converge on a distribution model solution. This was also an attempt to mitigate the influence of potentially incorrect geotags.

Analyses

Visitation statistics and correlations

Visitor statistics recorded on ground from the two parks were compared with the number of geotagged Flickr photos to assess if the photos reflected empirical visitation patterns. For Aconcagua, Spearman's rho correlations compared data for the 5 month visitor season over the 5 year period, where visitor count from park registries and permits were available (n.b., aggregated by week for analysis). Spearman's rho correlations were used as data violated the assumptions of parametric tests. For Kosciuszko, data from infrared trail counters and park ranger observations were descriptively compared to Flickr photos as visitor data were only available to the authors for specific days (i.e., Easter Sunday) or weeks (i.e., time period between the Christmas and New Year holidays).

Visitor spatial distribution

To assess patterns of visitor use, including use of park infrastructure and environmental features, GIS data were obtained from the park management agencies. Data included visitor infrastructure (e.g., roads, trails, informal trails (Aconcagua only), campsites, buildings, and parking areas) and environmental characteristics [e.g., vegetation cover types, elevation, slope, rivers, and location of glaciers (Aconcagua only)]. For Kosciuszko, the boundaries of the ski resorts were also included, as well as other facilities (e.g., toilets, changing rooms, and offices), which were part of the buildings layer for the park.

To analyse the spatial and temporal distributions of visitors, and visitors' use of infrastructure and environmental features, a near distance analyses was conducted in ArcGIS 10.3 for the two parks separately. This was done for all data, and separately for summer (December through February) and winter (June through August). Features included infrastructure (i.e., bridges, buildings, and facility points), campsites, formal and informal trails (Aconcagua only), boundaries of two ski resorts (Kosciuszko only), and other environmental features accessible to visitors (i.e., rivers for Kosciuszko and glaciers for Aconcagua) and salient to managers due to environmental impact concerns (Walden-Schreiner et al. 2018). Trail layers in Aconcagua included formal trails designated by the park agency and informal trails created by users and mapped in the field using a Garmin Oregon 450 GPS (Barros and Pickering 2017). For Kosciuszko, trails were classified as either hardened, unhardened, or designated for snow activities (i.e., cross-country skiing, snowshoeing) based on metadata or confirmed by the park's website.

The machine-learning algorithm MaxEnt further examined the associations between multiple environmental and infrastructure factors and the spatial distribution of visitors assumed from geotagged photos. MaxEnt is a distribution modelling approach that examines covariate conditions at presence locations (i.e., geotagged photo location) and compares it to random locations in the greater area of potential occurrence (i.e., park boundaries) (Elith et al. 2011). Studies demonstrate MaxEnt to be successful in modelling species distributions of flora (Koch et al. 2017) and fauna (Morán-Ordóñez et al. 2017), including with limited sample sizes (Elith et al. 2011). The algorithm assumes data coverage is incomplete and provides probability of presence based on combinations of factors for locations in the broader area of potential occurrence. Model outputs include maps of the probability of occurrence, ranking of variable importance, variable response curves, and evaluations of the models fit.

It is important to note that MaxEnt model results, specifically response curve interpretation, may be complicated by strongly correlated variables if many variables changing together elicit change in another variable. To address this, individual MaxEnt models created with only one variable were also examined to explore variable values and predicted presence. Halvorsen et al. (2016) point out that spatial dependence among predictor variables can be part of the overall landscape and results from their study suggest that MaxEnt models were unaffected in terms of predictive performance.

MaxEnt has explored distributions of visitors (Westcott and Andrew 2015), recreation impacts (Braunisch et al. 2011; Coppes and Braunisch 2013), and types of cultural ecosystem services (Richards and Friess 2015) within protected areas. As with any modelling approach, MaxEnt is sensitive to model parameters, specifically the selection of background data for the potential area of occurrence. To address these concerns, this analysis followed recommendations in the literature as summarized by Walden-Schreiner et al. (2017). For vector data, the factor was characterized by the distance to the polygon (e.g., campsite and ski resort) or line (e.g., trail and road) feature for the model. For continuous data (e.g., elevation), the model used the value at that location. The overall contribution of each factor was evaluated through permutation importance, which reflects the change to model fit when values of a specific factor are randomly permuted. The resulting percentages do not depend on the path taken by the algorithm to arrive at a solution. MaxEnt model fit is described by the area under the curve (AUC) for the receiver operator characteristics (ROC), with values above 0.75 considered acceptable and a maximum value of 1 indicating perfect prediction of presence (Richards and Friess 2015).

RESULTS

Flickr data characteristics

A total of 981 photos for Aconcagua and 5965 photos for Kosciuszko were obtained in September 2016 from Flickr for the specified sample period. Clear seasonal patterns emerged based on when the photos were taken for both parks. Nearly, 80% of the Aconcagua photos were taken between December and March during the warmest months, while both the ski season (June to September) and summer (December to end of February) were both popular times for photos for Kosciuszko, along with major public holidays such as Easter in autumn (March/April) (Fig. 3). Photos from Aconcagua were uploaded by 130 unique user accounts, with a median of 2 photos in the park per users. In Kosciuszko, photos were posted from 316 unique user accounts with a median of 3 photos per user in the park.

Comparisons with visitor counts

During the sampling period, there were 199 387 visits to Aconcagua, 27 706 of which involved hiking between one and 20 days and 171 681 used the Visitor Centre and the short walk in the Horcones Valley. When visitation data were compared to Flickr photo data using Spearman's rho, there were significant correlations between the number of photos and the total number of visits to Aconcagua ($r = 0.249$, $p < 0.05$), as well as the number of photos and the number of hikers ($r = 0.312$, $p < 0.05$).

Data from trail counters in the alpine area around the summit of Kosciuszko estimated over 4400 people visited the summit of Mt. Kosciuszko during the popular 5-day period in summer between Christmas and New Year's (i.e., 25 December 2015 to 1 January 2016). Other popular periods include Easter Sunday when over 1500 visitors were observed hiking the summit and more than 700 visitors hiking in the alpine area on 27 March 2016 alone (Christopher Darlington, pers. com. 2016). For the ski resorts, winter is popular, including late in the season when there are major school holidays in August. The number of Flickr photos followed a similar trend, with clear increases associated with holidays in December/January (i.e., Christmas, New Year's), March/April (Easter) within the alpine area, and in the resorts in August when there is snow on the ground and coinciding with 2 weeks of school holidays (Fig. 3).

Visitor distributions

Based on spatial coordinates extracted from geotagged photos, most visitors to the parks were on or near visitor infrastructure (Fig. 4a) (n.b., the following mentions of photos refer to the spatial locations). Kernel density maps of Aconcagua in summer revealed hotspots of use near the Visitor Centre, as well as the main trails and campsites on

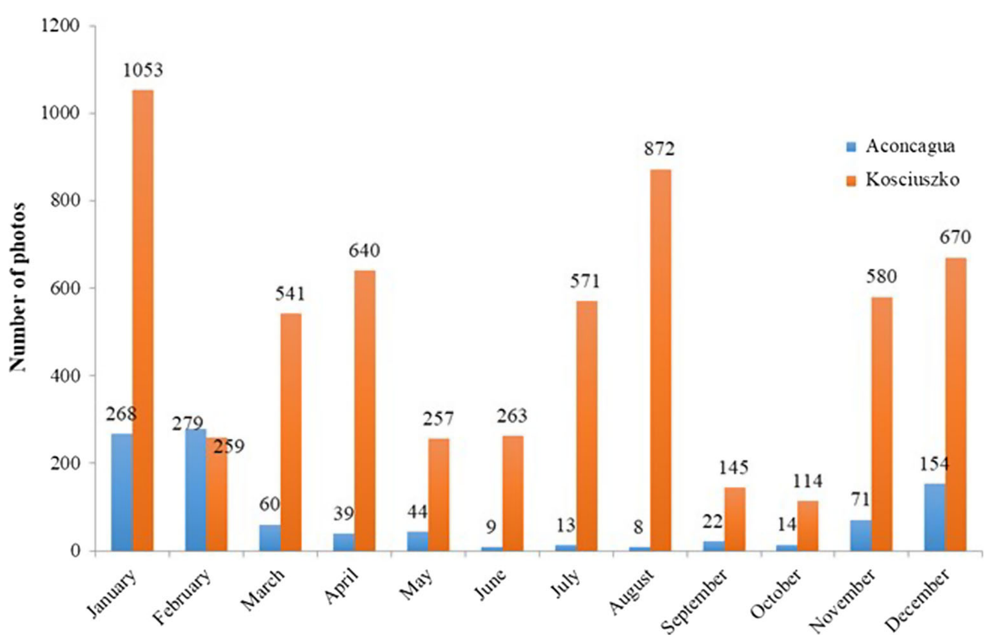

Fig. 3 Total number of photos taken per month for Aconcagua Provincial Park and Kosciuszko National Park from November 2010 to March 2016

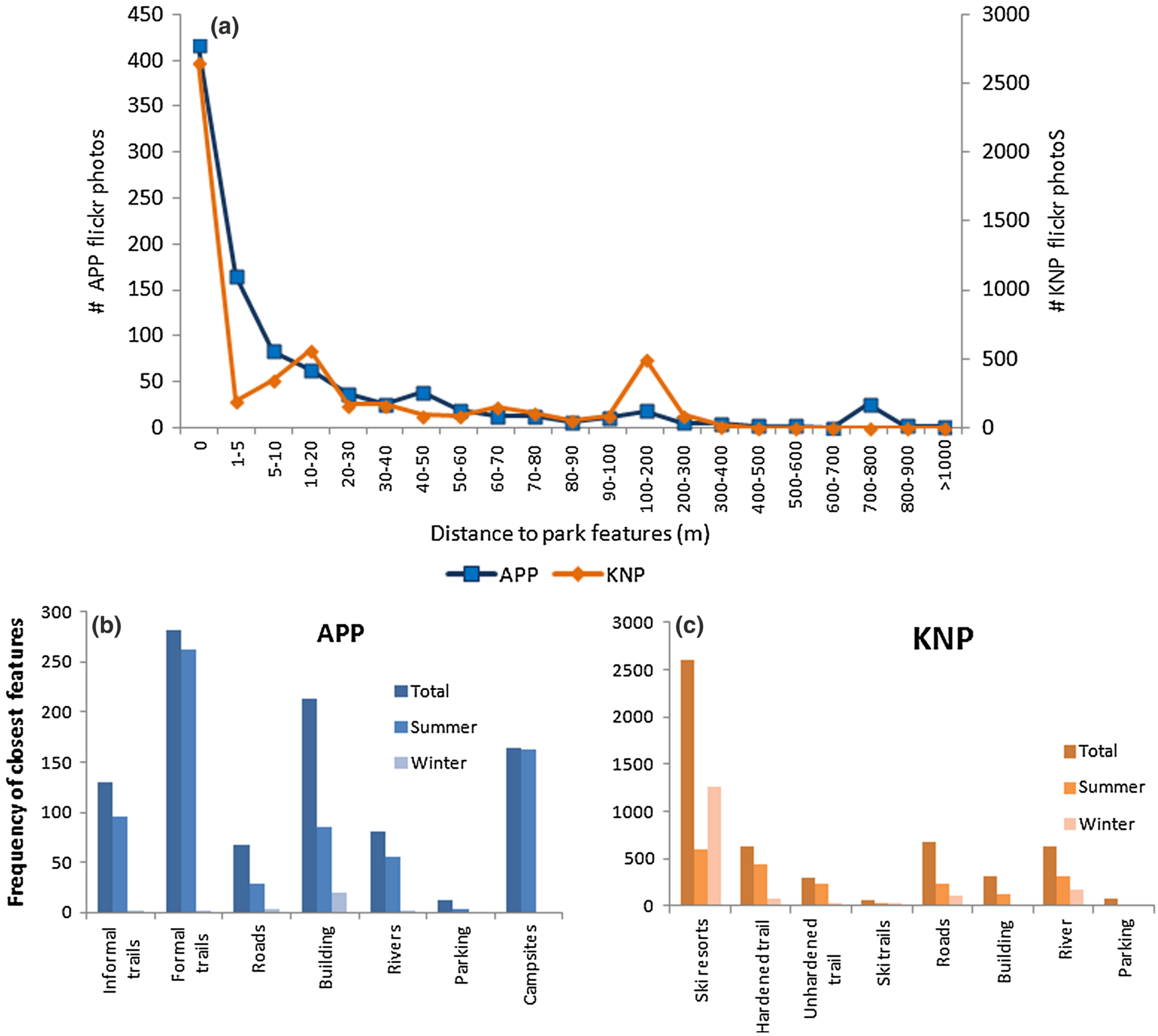

Fig. 4 Number of Flickr photos per distance band for the two parks (**a**) and frequency of the closest park feature for Aconcagua Provincial Park (APP) (**b**) and Kosciuszko National Park (KNP) (**c**) for the summer (December through February) and winter (June through August) months

the way to the summit of Mt. Aconcagua. Overall, most photo locations in Aconcagua were within 5 m of a feature (62%), with the closest features formal trails (30%), the Visitor Centre (22%), and campsites (17%), and some use of informal trails (14%) (Fig. 4b). During the summer months, the closest features were formal trails (38%) and campsites (24%), while in winter, it was the Visitor Centre (67%).

Over half of all photos from Kosciuszko were also taken within 5 m of a feature (54%), with the closest features the ski resorts (49%) and major roads (13%) (Fig. 4a). There were also clear differences in the distribution of photos between summer and winter in the park (Fig. 4c). In summer, the ski resorts that are open year round were popular (30%), with people golfing, walking, sightseeing, and going to cafes. However, visitors used other features in summer such as hardened walking trails (22%) often in the alpine area, or went to the rivers which are popular for fishing and camping (16%). In winter, nearly three-quarters of all photos were taken closest to ski resorts (74%), followed by rivers (10%) and roads (6%).

Factors associated with visitor distributions

When modelled using MaxEnt to explore combinations of factors in predicting presence beyond sampled locations (i.e., locations, where photos were taken), similar patterns emerged to those found with the descriptive summaries of the closets features to photos (Fig. 5). For Aconcagua in summer, models indicated high probabilities that photos were taken near the Visitor Center and the day use area in the Horcones Valley at the southern boundary of the park. In addition, high probabilities extended into the park along the two trails used to access the Mt Aconcagua summit (Fig. 5a, b). Clusters of high probabilities of presence in winter were almost entirely restricted to the Visitor Centre in Horcones Valley, as the park is effectively closed to hiking and climbing, with the exception of short trails near the Visitor Centre (Fig. 5c, d).

During the summer in Kosciuszko, the popularity of hiking trails from the road leading to the summit of Mt Kosciuszko and other hikes in the subalpine and alpine area in the southern third of the park (co-located in and near ski resorts) are apparent as hotspot lines, with clusters in other key destinations such as Yarrangobilly Caves in the middle of the park (Fig. 5e, f). In winter, probability hotspots are more concentrated in and around the ski resorts (Fig. 5g, h), with limited use of areas further away in the southern part of the park, likely by visitors snow camping, cross-country skiing, and/or snowboarding.

For both parks, there were differences in the most important explanatory variables from the MaxEnt modelling, reflecting key differences in infrastructure use patterns and locations between winter and summer, as well as between the two parks (Table 1). In Aconcagua, formal trails were the most important explanatory factor in summer (permutation importance of 80.6%), with buildings (i.e., Visitor Centre) the second most important factor (9.2%). Informal trails contributed little to the summer model (3.3%). In winter, a different pattern was observed with buildings (i.e., Visitor Centre) the most important explanatory factor (64%), and informal trails more important (11.5%) than formal trails (0.2%), reflecting more dispersed use of the flat open areas around the entrance to the park. With respect to environmental factors, slope contributed over 30% to the autumn and spring

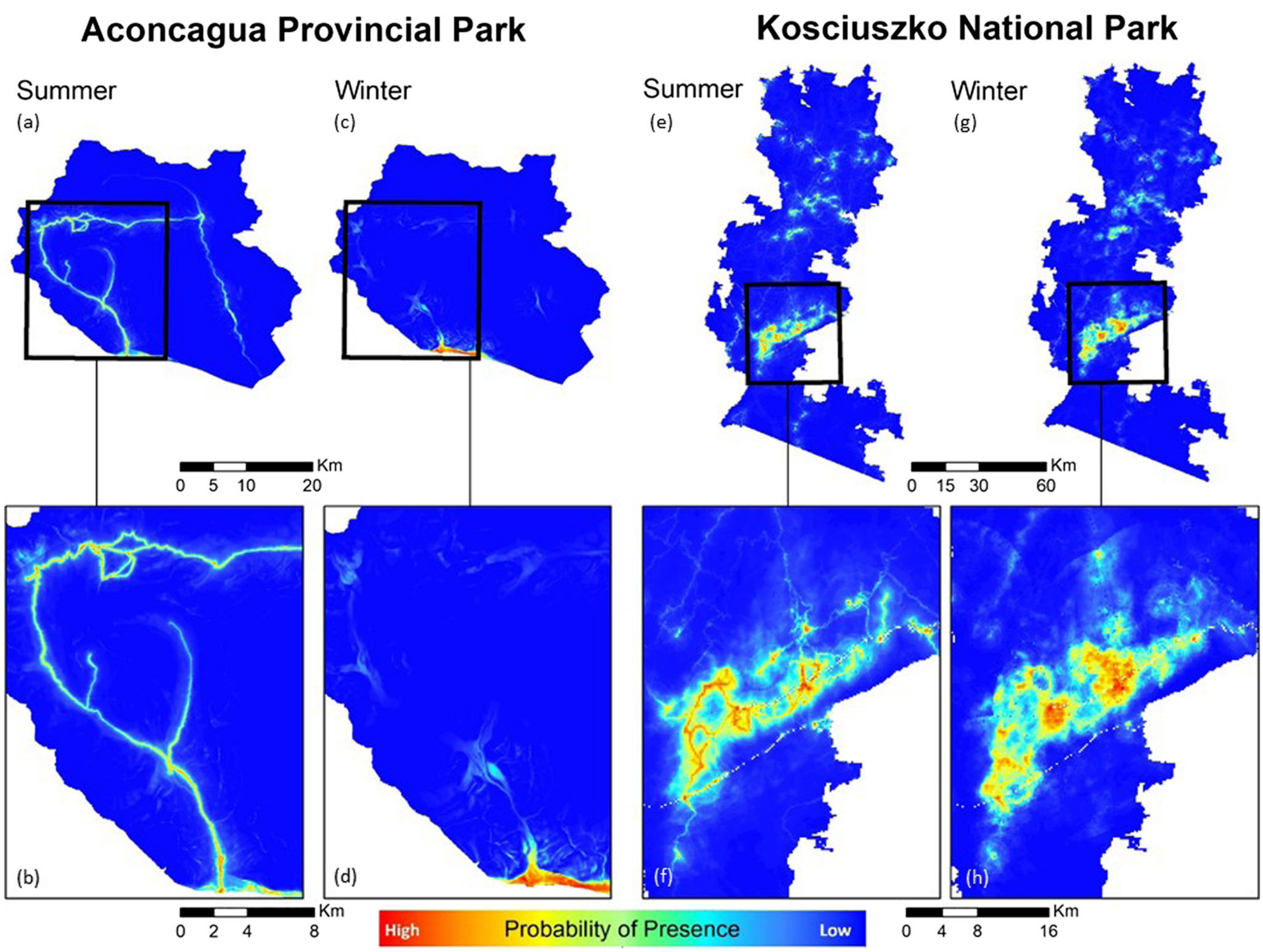

Fig. 5 Presence of photos based on logistic probability modelling for Aconcagua Provincial Park (left) and Kosciuszko National Park (right) during the summer (December through February) and winter (June through August) months. Warmer colors (yellow to red) indicate greater predicted probabilities of photo presence

Table 1 Permutation importance of factors included in the MaxEnt models for Aconcagua Provincial Park and Kosciuszko National Park during the summer and winter months

	Aconcagua Provincial Park						Kosciuszko National Park				
	Summer Dec–Feb Permutation importance	Autumn Mar–May	Winter June–Aug	Spring Sep–Nov	All		Summer Dec–Feb Permutation importance	Autumn Mar–May	Winter June–Aug	Spring Sep–Nov	All
Infrastructure						*Infrastructure*					
Formal trail	80.6	3.1	0.2	0.6	63.7	Hardened trail	26.7	18.7	3.8	5.5	3.5
						Unhardened trail	10.9	3.2	4.6	17.2	9.6
Informal trail	3.3	27.1	11.5	10.6	7.8	Informal trail	Not applicable				
Ski trails	Not applicable					Ski trails	3.9	22.1	22.2	9.1	9.4
Road	1.1	1	9.1	0.3	3	Road	16.8	33.1	21.6	7.2	22.4
Parking	0.6	0.2	0	0.1	0.4	Parking	7.8	2.7	6.6	19.1	7.8
Ski resorts	Not applicable					Ski resorts	14.8	13.2	21.1	22.9	32.3
Building	9.2	27.3	63.6	44.2	15.7	Building	5.2	1.6	2	5.7	4.8
Campsite	1.8	0.2	0.3	0.1	3	Campsite	2	0.7	2.4	1	1.9
Environmental						*Environmental*					
Elevation	0.4	1	0	6	0.6	Elevation	4.9	1.1	9	3.1	5.2
Slope	2.8	34.9	15.1	37.4	5.8	Slope	3.1	1.7	0.8	3.1	0.7
Vegetation type	0	0	0.1	0.4	0	Vegetation type	2.2	0.5	2.1	1.4	1.2
River	0.2	0.5	0	0	0.1	River	1.8	1.3	3.8	4.8	1.2
Glacier	0	4.7	0	0.2	0	Glacier	Not applicable				
AUC	0.98	0.991	0.96	0.996	0.978	AUC	0.947	0.962	0.969	0.959	0.936
(St. Dev.)	(0.002)	(0.006)	(0.055)	(0.002)	(0.003)	(St. Dev.)	(0.009)	(0.012)	(0.006)	(0.010)	(0.007)

models, with increased probabilities of presence at slope values of less than five degrees. This finding coinciding with terrain conditions near the Visitor Centre.

In Kosciuszko, there were also differences between summer and winter in the importance of various factors. In summer, hardened (26.7%) and unhardened trails (10.9%) ranked among the most important explanatory variables, along with roads (16.8%) and ski resorts (14.8%). In winter, ski trails (22.2%), roads (21.6%), and ski resorts (21.1%) contributed collectively to almost two-thirds of the model, with hardened and unhardened trails far less important, reflecting differences in recreational opportunities and access in the park between periods with, and without, snow cover. Environmental factors contributed 5% or less across all models for Kosciuszko. In the overall model, elevation was the highest ranked environmental factor at 5.2%, with greater probabilities of presence predicted at elevations in and around ski resorts.

DISCUSSION

Geotagged social-media photos can provide protected area managers with timely and useful data about spatial–temporal patterns of use and the popularity of different types of infrastructure as a complement to, and in concert with, other visitor monitoring approaches. The availability (Levin et al. 2015), and relative spatial accuracy (Zielstra and Hochmair 2013) of social-media data, is particularly important in situations when resources and/or remote locations limit on ground visitor monitoring. Therefore, access to social-media data on how visitors access, use, and value, different areas and infrastructure in protected areas will be increasingly critical for those responsible for their management (Hausmann et al. 2017; Heikinheimo et al. 2017).

Flickr data can provide a proxy for visitation counts at the park scale as documented in other studies (Wood et al. 2013; Levin et al. 2015, 2017; Sonter et al. 2016), as well as provide detailed site and infrastructure-specific information of where people go and when in large and remote mountainous protected areas. The significant correlations found between the number of photos and the visitation numbers in this study offer further evidence of support, even though the correlation values are lower than those reported in Wood et al. (2013) and Keeler et al. (2015), possibly due to smaller sample sizes in larger, more remote areas in our study.

The results for Aconcagua and Kosciuszko highlight how Flickr data can provide insights into spatial and seasonal patterns of visitor use. With nearly, 97% correctly geotagged to the parks, Flickr photos provide increasingly accurate data on visitor use of these areas. With the increasing use of mobile devices such as smartphones globally (Poushter 2016), social-media data provided by visitors are only likely to further increase in quality, accuracy, volume, and area. This can be seen already for the two parks as over the more than 5 years of data, there was increasing use of mobile devices to capture images shared on Flickr, potentially reducing any inaccuracies introduced when manually geotagging digital photographs.

The spatial and temporal patterns of use for the parks differed reflecting differences in access, recreational opportunities, and facilities between the parks and over seasons within each park. Aconcagua is a summer use park, mainly by short stay visitors using walking trails and the Visitor Centre, with the use of the rest of the park limited to the two main routes to the summit. In contrast, far more of Kosciusko is used year round by visitors, but with differences in where people go and which facilities they use between winter and summer as snow cover influences what visitors do and where.

The MaxEnt distribution models provide more detailed analysis of the relative importance of different types of infrastructure in shaping patterns of use: a critical issue for managers when deciding what types of infrastructure to provide and how to minimize resource impacts. In summer, both formal (Aconcagua) and hardened (Kosciuszko) trails ranked as the top explanatory factors in the models, reflecting how well they are used by visitors. Such concentrated use of trails designed and provided by parks agencies is heartening for managers, as trails are a major way in which they try to minimize damage from tourism (Ballantyne and Pickering 2015). These trails can enhance the visitor experience by providing comfortable and safe access to desirable sites while also minimizing impacts including from trampling of sensitive and easily damaged environments off trails (Ballantyne and Pickering 2015; Barros and Pickering 2017). This is particularly important in alpine areas, where the recovery of vegetation from damage, including by trampling off trails, is notoriously slow and limited (Pickering and Growcock 2009).

In winter in Kosciuszko, there was concentrated visitor use of ski resorts and ski trails. Ski resorts in mountains are very popular sites for tourism, including in Australia (Morrison and Pickering 2013). However, they do have a wide range of environmental impacts which need to be minimized and managed. In addition, with reductions in snow cover in this and many other mountain regions as a result of climate change, there are new economic, social, environmental, and management issues with visitor use of mountain resorts (Morrison and Pickering 2013). As a result, some mountain resorts, including Kosciuszko as well as in North America and Europe, are increasingly promoting new activities in summer, such as mountain biking, to help offset reductions in winter use. Changes in where people go, when, and for what, create new challenges for conservation. Consequently, timely data on visitor use of these areas will be increasingly important when modelling and managing responses to changes in snow cover and the popularity of specific locations and activities. Exploring how climate conditions, like fluctuating winter snowfall, influence visitation estimates derived from social media is an important area for future research.

A limitation inherent to geotagged photos and other social-media-based data is sampling bias (Richards and Friess 2015; Levin et al. 2017). Not all visitors take and share photos, and for those that do, there are a range of photo-sharing platforms available that vary in their popularity, aims and if the data are publicly available. In addition, the availability and use of smartphones and other devices to take and share photos online vary among and within countries (Poushter 2016). As a result, geotagged photos and other social-media data will not be representative of all visitors, all activities, or all types of people engaged in a given activity in protected areas. Some sites and activities are also more 'shareable' than others, resulting in additional biases. Photos from the two parks assessed here, for example, were more likely to be of stunning natural landscapes than restrooms or carparks. This study attempted to minimize the impacts of this phenomenon by leveraging MaxEnt, which assumes that data coverage is incomplete and provides predicted probabilities of presence based on combinations of factors. However, it may still miss site-specific patterns in some locations and activities. Indeed, future research efforts can explore the photo content of shared pictures providing useful insights for monitoring; assessing cultural ecosystem services and potentially identifying specific visitor impact concerns such as wildlife–visitor interactions.

Spatial accuracy can be a concern when leveraging volunteered geographic information, especially geotagged photos where users may manually assign the photo's location. Previous research has found visitors have tagged the photo's contents as the location as opposed to where it was taken from (Orsi and Geneletti 2013). The analysis of the photos in this study revealed that less than 3% were inaccurately geotagged, yet the accuracy could still be within several meters depending on the device used. For formal and informal trails very closely collocated, challenges in interpreting where a visitor was standing when taking a photo could arise without examination of the photo contents. However, for many of the informal trails in this study, the marked separation from the formal trails reduced this concern and it is important to capture considering the fragmentation effects associated with this type of visitor impact and the spatial accuracy identified in other studies (Antoniou et al. 2010).

Geotagged photos provide point or area of interest information, and, therefore, do not capture the route a visitor uses. Research on other platforms that share GPS route data such as Strava, GPSies, Wikiloc, and MapMyRide are also increasingly being used to study visitor use of protected areas. This includes generating hotspot maps of trail use by visitors engaged in different activities and use of informal trail networks (Campelo and Nogueira Mendes 2016; Santos et al. 2016; Korpilo et al. 2017). Finally, some studies are using a combination of onsite visitor surveys and social-media data or public partition GIS (PPGIS) to assess how different visitor groups use trails, including for visitor conflict (Wolf et al. 2017) and the influence of natural features and visitor infrastructure quality on visitor experience (Pietilä and Kangas 2015).

CONCLUSION

This study highlighted how geotagged social-media data, specifically photographs from Flickr, can support and complement on ground visitor use and impact monitoring in mountain-protected areas of high conservation value. Social-media data contribute insights into seasonal and temporal patterns of visitor use. This includes the ability to detect spatial use patterns of informal trails in Aconcagua and dispersed winter use in Kosciuszko, which otherwise would be difficult or not possible to capture through park registration permits or trail counters. The availability of social-media data, even in light of the limitations discussed, provides opportunities to address urgent and dynamic management challenges associated with visitor use in protected areas when data may otherwise be unavailable or limited. Understanding patterns of visitor use and how infrastructure and environmental conditions influence such patterns helps inform monitoring programs and management strategies to protect high conservation value resources and provide for quality visitor experiences in these and other popular parks.

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