AMBIO 2015, 44:82–98
DOI 10.1007/s13280-014-0550-7

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

REVIEW

Is tourism damaging ecosystems in the Andes? Current knowledge and an agenda for future research

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Received: 25 May 2014 / Revised: 18 August 2014 / Accepted: 19 August 2014 / Published online: 9 September 2014

Abstract Despite the popularity of tourism and recreation in the Andes in South America and the regions conservation value, there is limited research on the ecological impacts of these types of anthropogenic use. Using a systematic quantitative literature review method, we found 47 recreation ecology studies from the Andes, 25 of which used an experimental design. Most of these were from the Southern Andes in Argentina (13 studies) or Chile (eight studies) with only four studies from the Northern Andes. These studies documented a range of impacts on vegetation, birds and mammals; including changes in plant species richness, composition and vegetation cover and the tolerance of wildlife of visitor use. There was little research on the impacts of visitors on soils and aquatic systems and for some ecoregions in the Andes. We identify research priorities across the region that will enhance management strategies to minimise visitor impacts in Andean ecosystems.

Keywords Visitor impacts · Tourism · Mountains · Wildlife · Vegetation · Water · Soils

INTRODUCTION

Protected areas are a major mechanism for biodiversity conservation (Lockwood et al. 2006). They are also popular destinations for a range of tourism and recreation activities, with visitation to many protected areas increasingly popular including in the Andes (Bury 2008; Balmford et al. 2009; Barros et al. 2013). Visitor use of these areas can result in a range of social benefits, including improving human health and well being by promoting active lifestyles (Byrne et al. 2009). Tourism can also generate economic revenue for protected area agencies and local communities through visitor expenditures and commercial tourism concessions (Morrison et al. 2012; Steven et al. 2013).

Visitor use of protected areas can also result in a range of ecological impacts on soils, water, flora and fauna (Liddle 1997; Hammitt and Cole 1998; Hill and Pickering 2006; Newsome et al. 2013). Common visitor activities such as hiking and camping, for example, can result in reductions in vegetation cover, changes in plant composition, introduction and dispersal of weeds, and pollution of waterways (Liddle 1997; Smith and Newsome 2002; Hadwen et al. 2005; Mount and Pickering 2009; Monz et al. 2010; Pickering et al. 2010). Trampling by hikers, mountain bikers and horses can result in soil loss and compaction and alter other physico-chemical properties of soils (Liddle 1997; Cole 2004; Arocena et al. 2006; Pickering et al. 2010, Pickering et al. 2011). Human use of campsites and trails can disturb wildlife, affecting their behaviour, feeding patterns and reproduction (Liddle 1997; Monz et al. 2010; Steven et al. 2011).

Due to the increasing popularity of tourism and recreation in many protected areas and the increasing recognition of their potential negative ecological impacts, there is a growing body of research quantifying these impacts (e.g. Liddle 1997; Cole and Monz 2002; Phillips and Newsome 2002; Newsome and Davies 2009; Pickering and Growcock 2009; Törn et al. 2009). The results of some of this research has been summarised in reviews including of the research in North America (Leung and Marion 1996; Cole 2004; Monz et al. 2010; Pickering et al. 2010), Australia (Hill and Pickering 2006; Pickering et al. 2010), East Asia (Leung 2012), alpina fauna (Sato et al. 2013) and birds (Steven et al. 2011). Although these reviews have provided

Electronic supplementary material The online version of this article (doi:10.1007/s13280-014-0550-7) contains supplementary material, which is available to authorized users.

Fig. 1 Andes region in South America

some useful generalisations for protected areas management, such generalisations may not apply more broadly, due to differences in ecology and/or past human use among regions. For example, generalisations from North America mountains (Monz et al. 2010) may not necessarily apply to the Andes in South America.

The Andes accounts for about 13 % of the land area of mountains worldwide (Körner et al. 2011) and covering an area of nearly 3 million km^2 (Fig. 1). These mountains extend over 8000 km along the western edge of South America through seven countries and are the primary watershed for most of the region (Harden 2006; Garreaud 2009). The Andes have high regional biodiversity due to the compression of climatic zones along altitudinal gradients (Braun et al. 2002). These mountains also have high levels of endemism due to repeated periods of isolation and migration during glacial and interglacial periods (Simpson 1975), resulting in parts of the Andes recognised as critical biodiversity hotspots (Myers et al. 2000). These include the Tropical Andes which contain the highest number of endemic plant species in the world (20 000, 6.7 % of vascular plants globally) (Myers et al. 2000).

Past human use of the Andes was characterised by traditional agricultural practices and grazing by native camelids until the time of the Spanish conquest, when new crops and domestic livestocks such as horses and cattle were introduced to the region (Preston et al. 2003; Molinillo and Monasterio 2006). More recently, they have become important tourism destinations, particularly some of the iconic protected areas which provide opportunities for a diversity of recreational activities (Bury 2008; Zoomers 2008). These include cultural tours to heritage sites (Zoomers 2008), hiking to pristine mountains in Patagonia (Martin and Chehébar 2001; Ferreyra et al. 2005) and conquering the highest summits outside the Himalayas (Buckley 2006; Barros et al. 2013). These types of activities are likely to increase in popularity as nature-based tourism is promoted as a strategy to alleviate poverty and foster local development in many rural areas in the Andes (PNUMA-CAN 2003; Nicklin and Saravia 2006).

Despite the popularity of the Andes as tourism destinations and the regions high conservation value, there has been limited research on the ecological impacts of visitors in the Andes (Barros et al. 2013). This paper reviews this research, highlighting what is known, but also identifying critical research gaps, so that future research can be prioritised and management of Andean protected areas enhanced.

MATERIALS AND METHODS

Mountain-protected areas in the Andes and visitor use

To understand the geographic and tourism use characteristics of protected areas in the Andes, we reviewed the locations, ecosystem types and available visitor use data for the region. For the purpose of this paper, the Andes region covers all mountains along the western edge of South America including in Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile and Argentina (Fig. 1). We determined the number of protected areas and ecoregions in the Andes through combining different GIS datasets publicly available (UNEP-WCMC 2002; The Nature Conservancy 2003; IUCN and UNEP-WCMC 2010) in ArcGIS (see detailed methods used in Electronic Supplementary Material, Appendix S1). To document visitor numbers and use of mountain-protected areas in the Andes, we reviewed publicly available government and industry reports along with scientific publications.

Systematic quantitative literature review

To determine the extent of the academic literature on recreation ecology in the Andes, we conducted a systematic quantitative review following the methods outlined in Pickering and Byrne (2013) and conforming to the guidelines developed by the Preferred Reporting Items for Systematic Review Recommendations (PRISMA) (Electronic Supplementary Material, Table S1). We used this data to evaluate information on (i) where in the Andes there has been research, (ii) who undertook the research, (iii) the types of research, (iv) the methods used and (v) the key results.

First, we identified research publications in English and Spanish using searches of electronic databases of academic journals including: Google Scholar, Web of Science, Scopus and Proquest Dissertation and Theses. We regularly searched these databases between September 2013 and May 2014. The reference lists from relevant papers, along with our personal reference collections were used to ensure that the searches were thorough and identifying past work. In addition, we searched regional and national electronic databases from Latin America covering the literature in both Spanish and English (Electronic Supplementary Material, Appendix S2).

Keywords used for the electronic database searches included 'Andes' and related terms (e.g. Andean, montaña, cordillera) and a combination of the following terms: touris*, ecotourism, visitor*, hik*, climb*, trek*, horse, mule, trampl*, trail, 'recreation ecology', erosion, disturbance, damage, vegetation, soil, water, fauna, bird*, reptile*, frog*, insect*, wildlife, alien plant*, impact*. Keyword combinations varied based on the requirements or limitations of each database. For example, a search combination used in Google Scholar included the terms (Tourism* OR Visit* OR Recreatio* OR hik* OR Trampl*) AND (Vegetation OR Water OR Soil* OR Wildlife) AND (Andes OR Montaña OR Cordillera).

To limit the studies to those assessing tourism and recreation that have acknowledged, documented or demonstrated impacts on the natural environment, we first screened studies by reading titles and abstracts and excluded studies that did not match these criteria (Fig. 2). For this review, 'acknowledged impacts' refer to studies where impacts are perceived as having occurred by people participating in the research and/or are based on personal

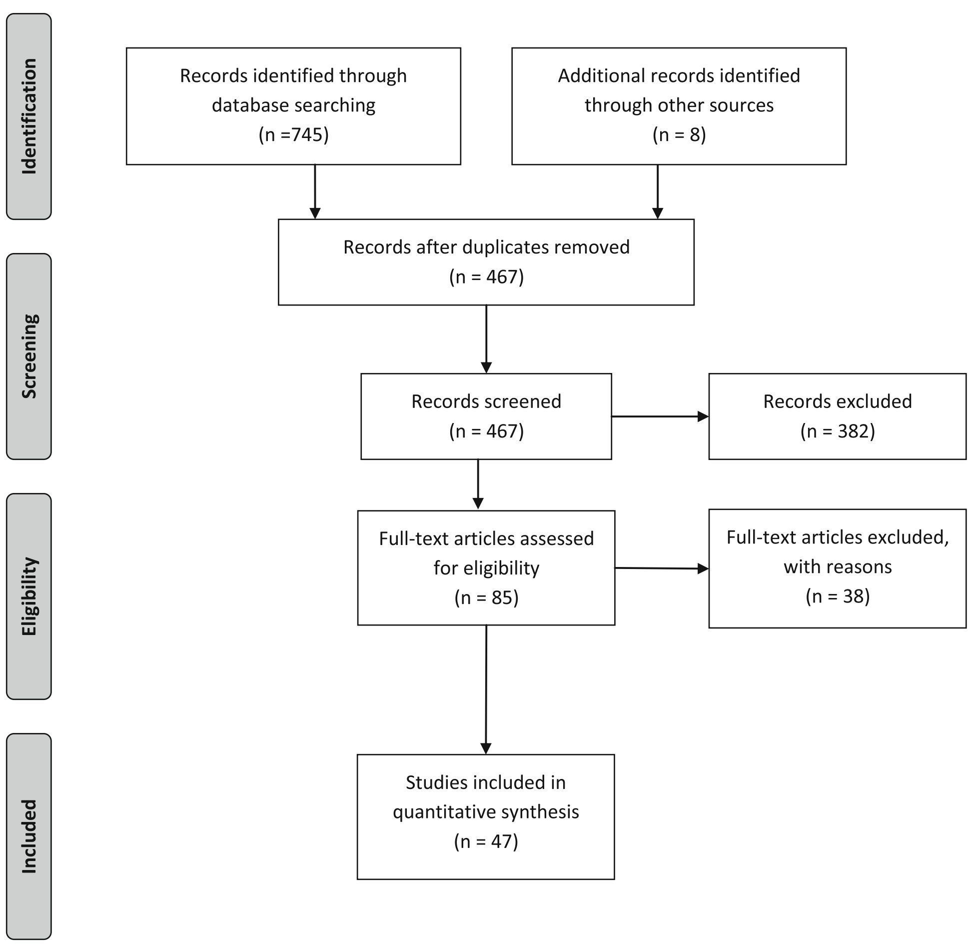

Fig. 2 PRISMA flowchart diagram detailing the steps followed for the systematic quantitative literature review

Table 1 The percentage area covered by mountains and mountain-protected areas in the seven countries containing parts of the Andes. Data based on the GIS analysis using the data from the world raster dataset of mountains and tree cover in mountain regions (UNEP-WCMC 2002) and the world database of protected areas (IUCN & UNEP-WCMC 2010). Mt = mountains, PAs = protected areas. Cat II = National/Provincial Park

Country	Area country (ha)	% mountain areas	# Mountain PAs	% PAs in mountains	% Mountain PAs Cat II	% Mountains PAs Cat. Not reported
Argentina	279 778 429	24.6	81	41.8	32.1	1.2
Bolivia	109 233 178	36.9	39	60.9	38.5	17.9
Chile	75 471 157	58.9	111	63.4	25.2	0.0
Colombia	114 516 501	26.1	387	65.0	6.2	91.0
Ecuador	26 426 261	42.4	21	75.0	38.1	0.0
Peru	130 478 826	48.5	109	60.2	10.1	52.3
Venezuela	91 668 508	9.5	54	53.5	27.8	1.9
TOTAL	827 572 862	32.2	802	59.9	22.2	52.2

observations of the authors of the studies; ‘documented impacts’ refer to studies where impacts have been recorded through inventory assessments and/or interviews of local experts and ‘demonstrated impacts’ refer to studies using an experimental design to assess impacts.

Academic publications included in the review consisted of relevant papers in refereed scientific journals, research theses and extended abstracts from academic conferences. Government or industry reports and other grey literature were not included due to the difficulties in obtaining this literature in a systematic and consistent manner, as much of it is not publicly available. For each research study included in the review, we recorded the following information in a personal database: author(s), their affiliation, year of publication, type of publication (e.g. journal, thesis, book or conference proceeding), where it was published, location of the study (country, mountain range, terrestrial ecoregion, conservation status), type(s) of activities assessed, type(s) of methods used for the research (e.g. observational, manipulative, disturbed/control, interviews, inventory assessments), main object of the research (e.g. birds, vegetation, landscape, including details) and if ecological impacts from visitor use were acknowledged, documented and/or demonstrated in the study.

RESULTS

Mountains, protected areas and tourism in the Andes

The Andes represent over 32 % of the combined territory of seven countries in South America (Table 1). It includes 47 ecoregions, including ten ecoregions considered of global conservation priority (Olson and Dinerstein 2002). Many of these ecoregions are critically endangered, including the Central Andean Yungas and the Northern Andean Montane Forest (Olson and Dinerstein 2002) (Fig. 3a, b).

There are a large number of protected areas in the Andes, many of which (22%), are classified as IUCN Category II protected areas primarily established for conservation where tourism and recreation are the main permitted human activities (Table 1). In some countries, including Bolivia, Argentina and Ecuador, over 30% of their mountain-protected areas are IUCN Category II, however, over 50% of the mountain-protected areas in the Andes currently have no designated IUCN category (Table 1).

Visitor use of protected areas in the Andes occurs in a range of ecoregions, including global priority areas for conservation such as the Northern Andean Paramo in Ecuador and the Cauca Montane Forest and Venezuelan Andean Paramo (Table 2). The number of annual visitors can be relatively low in some protected areas, ranging from less than 2500 visitors per year in more remote locations such as Tupungato Provincial Park in Argentina (Direccion de Recursos Naturales 2013) or Lauca National Park in Chile (SNASPE 2013) to hundreds of thousands per year in Machu Picchu World Heritage Site in Peru and Nahuel Huapi National Park in Argentina (Table 2). A range of activities are permitted in these areas including rafting, cultural tours, four-wheel driving, mountain biking, wildlife viewing, backcountry skiing and mountaineering (Table 2).

Systematic quantitative literature review

Status of the research

A total of 47 academic publications acknowledging, documenting and/or demonstrating visitor impacts on the

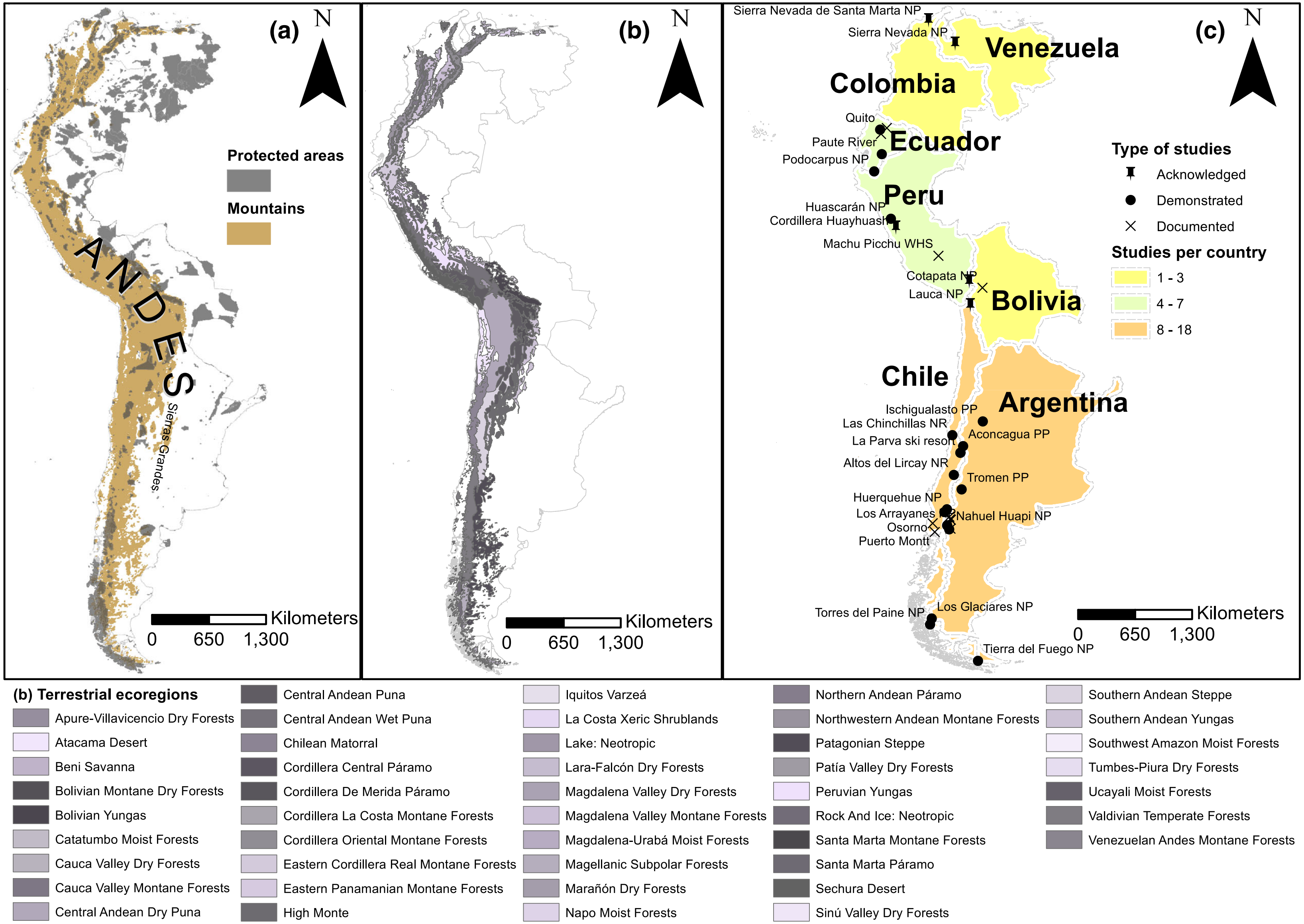

Fig. 3 Geographical location in the Andes of a mountains and protected areas, b terrestrial ecoregions, and c the number and location of studies in recreation ecology. Maps developed using the world raster dataset of mountains and tree cover in mountain regions (UNEP-WCMC 2002), the world database of protected areas (IUCN & UNEP-WCMC 2010) and the GIS dataset of terrestrial ecoregions (The Nature Conservancy 2003)

Table 2 Examples of protected areas with high visitor use across the Andes. * = part of the priority global ecoregion Northern Andean Montane Forest (Olson and Dinerstein, 2002). + Protected areas where they have a = acknowledged, b = documented, c = demonstrated visitor impacts on the natural environment, d = no studies. Visitor data compiled from: 1 = Martin and Chehébar (2001), 2 = Viciministerio de Turismo de Bolivia (2011), 3 = SNASPE (2013), 4 = Parques Nacionales Naturales de Colombia (2013), 5 = Fundación Paramo (2007), 6 = Mitchell and Eagles (2001) and 7 = Quintero de Contreras (2005)

Country	Protected area[+]	Year declared	Surface area (ha)	Elevation range (m a.s.l.)	Ecoregion	# Visitors per year	Main activities
Argentina[1]	Nahuel Huapi NP[ab]	1934	710 000	700–3554	Patagonian Steppe	300 000	Boating, camping, rafting, kayaking, canoeing, mountain biking, back country skiing, rock climbing, hiking & mountaineering
Bolivia[2]	Sajama NP[d]	1939	100 230	4200–6548	Central Andean Dry puna*	4000	Climbing & hiking
Chile[3]	Torres del Paine NP/Biosphere Reserve[b]	1959	227 298	50–3050	Magellanic subpolar forest	125 000	Hiking, ice & rock climbing, fishing and cruises
Colombia[4]	Los Nevados NP[d]	1974	58 300	2600–3261	Cauca Valley Montane Forest*[a]	50 045	Hiking, mountaineering, wildlife viewing, ice & rock climbing
Ecuador[5]	Cotopaxi NP[b]	1975	33 393	3400–5897	Northern Andean Paramo*	87 138	Hiking, climbing, sightseeing, mountain biking, horse riding & rock climbing
Peru [6]	Machu Picchu Historic Sanctuary/World Heritage Site[ab]	1981	32 592	2200–6271	Central Andean Yungas*	900 000	Cultural tours, camping, fishing, hiking and climbing
Venezuela[7]	Sierra Nevada National Park[ac]	1952	27 446	400–5007	Venezuelan Andes Montane Forest*[a]	data not available	Hiking, climbing, sightseeing, four-wheel driving, fishing and cable car.

natural environment were identified (Fig. 2; Table 3). Although recreation ecology studies from the region have been published since 1982, nearly all (96 %) were published after 2000. Studies mainly consisted of research papers in refereed scientific journals (68 %), with a few research theses (19 %), conference proceedings (8 %) and books (4 %). The majority were in English (29 studies) with 18 studies in Spanish. Research was predominantly conducted in Argentina (42 %), Chile (24 %) and Peru (12 %) with only four studies in Ecuador, two in Venezuela and one study each in Bolivia and Colombia (Table 3). All the studies were from the Andes, including the foothills, with the exception of two studies from lower altitude mountains in Argentina: the Sierras Pampeanas (Malo et al. 2011) and Sierras Grandes (Heil et al. 2007).

There were a total of 83 authors across the 47 studies, with only seven authors involved in more than one study (Table 3). Reflecting the dominance of research from Argentina and Chile, many authors were affiliated with institutions in these countries (Argentina 38 %, Chile 13 %). There were also many authors affiliated with institutions outside Andean countries (33 %), including 16 % who were from institutions in the United States.

The studies covered twenty ecoregions with research concentrated in the Southern Andean Steppe (23 %), Central Andean Wet Puna (13 %) and Magellanic Subpolar Forest (13 %). Most studies were from protected areas (85 %) with the rest either in ski resorts or natural areas with no official conservation status. There were several papers from two highly visited parks: Aconcagua Provincial Park in the Southern Steppe Ecoregion in Argentina (six studies) and Torres del Paine National Park in the Magellanic Subpolar Forest ecoregion in Chile (five studies). In contrast, no studies on visitor impacts were found for some other popular protected areas in the Andes, such as parks in the Northern Andes (Los Nevados National Park) and Central Andes (Sajama National Park) (Table 3).

Types of research and results

From the 47 studies, 53 % demonstrated visitor impacts on the natural environment using experimental research designs, 27 % documented impacts using inventory assessments and interviews primarily as part of management frameworks and 19 % acknowledged visitor impacts without directly assessing them (Table 3). Studies where visitor impacts were only acknowledged included those assessing the perception of local communities about visitor impacts (four studies) and personal observations by the authors of the publications (five studies).

Common issues raised by local communities included littering, high traffic, collection of plants and habitat degradation. Issues based on personal observations of authors, included trail erosion, damage to native plants from trampling, potential impacts on the Andean Condor (*Vultur gryphus*) due to helicopter noise and the impacts of fragmentation from ski resorts and informal trails. Publications often reported on factors that authors believed were affecting environmental impacts, including a lack of environmental education, patrolling and trail design and maintenance.

Studies documenting impacts included those from Argentina (six studies), Chile (three studies), Ecuador (two studies) and one study each from Bolivia and Peru (Table 3). A diversity of management frameworks were used, with most of the studies using inventory assessments and stakeholders interviews to determine the maximum number of visitors the environment could tolerate for specific locations, mainly trails and campsites. The frameworks included Carrying Capacity (four studies), Recreation Opportunity Spectrum (one study) and Limits of Acceptable Change (two studies), and other adapted visitor frameworks developed to conduct the research (one study). The studies using the Limits of Acceptable Change framework (Encabo et al. 2001; Gutiérrez Cuevas 2008) included an integrated field inventory assessment of trails and campsites with visitor interviews to identify their perception of environmental impacts from recreation use. Some of the issues raised by the authors concerning management frameworks included how a lack of local research, due to a lack of funding, on visitor impacts limited the capacity of management agencies to minimise impacts (Otero 2000; González and Otero 2002) and the importance of local expertise when making management decisions (González and Otero 2003; Marioni and Nakayama 2006).

Studies demonstrating impacts

Of the 25 studies demonstrating visitor impacts, 13 were from Argentina, eight from Chile, two from Ecuador and two from Peru (Fig. 3c; Table 4). These studies covered seven ecoregions, with most from the Southern Andean Steppe and Magellanic Subpolar Forest (Table 4). The methods used included comparing disturbed and undisturbed sites or control sites, observational methods and manipulative experiments (Table 4). Most of the studies examined the impacts of visitors on vegetation (14 studies) and wildlife (eight studies), with a few assessing impacts on soils (five studies) and one assessing aquatic systems (Table 4; Electronic Supplementary Material, Table S2). The most frequent visitor activities examined were hiking/walking trails, standing/observing wildlife and camping (Table 4; Table S2).

The earliest study on visitor impacts examined the tolerance of alpine plant communities to experimental trampling in Farellones and La Parva ski resorts in Chile by

Table 3 Summary of published studies from 1982 to May 2014 that acknowledged, documented and/or demonstrated visitor impacts on the natural environment across mountains in the Andes. J = Journal

Authors (year)	Location	Source
Acknowledged		
Borsdorf & Marchant (2013)	Colombia	International Symposium
Martin & Chehébar (2001)	Argentina	Journal of The Royal Society of New Zealand
Ferreyra et al. (2005)	Argentina	J - Anales Instituto de la Patagonia
Bury (2008)	Peru	J - Tourism Geographies
Quintero de Contreras (2005)	Venezuela	J - Economía
Llambí et al. (2005)	Venezuela	J - Mountain Research and Development
Mitchell & Eagles (2001)	Peru	Journal of Sustainable Tourism
Mitchell et al. (2008)	Peru	Book chapter
Rundel & Palma (2000)	Chile	J - Mountain Research and Development
Demonstrated—experimental research		
Barros (2004)	Argentina	Master's thesis
Barros & Pickering (2012)	Argentina	International Conference
Barros et al. (2013)	Argentina	Journal of Environmental Management
Barros & Pickering (2014a)	Argentina	J – Mountain Research and Development
Barros & Pickering (2014b)	Argentina	J – Plant Ecology & Diversity
Barros et al. (2014)	Argentina	J - Arctic, Antarctic and Alpine Research
Byers (2000)	Peru	J - Mountain Research and Development
Byers (2009)	Peru	Book chapter
De la Barrera et al. (2011)	Chile	J - Revista Chilena de Flora y Vegetación
Farrell & Marion (2002)	Chile	J - Leisure/Loisir
Fuentes Allende (2011)	Chile	Undergraduate thesis
Harden (2001)	Ecuador	J - Mountain Research and Development
Harris & Haskell (2013)	Ecuador	J - PLOSOne
Heil et al. (2007)	Argentina	J - Biodiversity Conservation
Hoffmann & Alliende (1982)	Chile	J - Mountain Research and Development
Lambertucci & Speziale (2009)	Argentina	J - Raptor Research
Llavallol et al. (2012)	Argentina	J - UNLaRCiencia
Malo et al. (2011)	Argentina	J - Biodiversity Conservation
Hermann et al. (2010)	Chile	J - The Geographical Review
Pauchard & Alaback (2004)	Chile	J - Conservation Biology
Puntieri (1991)	Argentina	J - Biological Conservation
Rodriguez Bergada (2012)	Argentina	Undergraduate thesis
Vazquez et al. (2011)	Argentina	International Conference
Vidal & Reif (2011)	Chile	J - Bosque
Vidal Ojeda (2005)	Chile	Undergraduate thesis
Documented—inventory assessment		
Aldás (2008)	Ecuador	Undergraduate thesis
Encabo et al. (2001)	Argentina	International Journal of Hospitality and Tourism Administration
Encabo et al. (2010)	Argentina	J - Anuario de Estudios en Turismo
González & Otero (2002)	Argentina	J - Current Issues in Tourism
González & Otero (2003)	Argentina	J - Estudios y Perspectivas en Turismo
Gutiérrez Cuevas (2008)	Chile	Undergraduate thesis
Larson & Poudyal (2012)	Peru	Journal of Sustainable Tourism
Marioni & Nakayama (2006)	Argentina	J- Anuario de Estudios en Turismo
Marozzi et al. (2011)	Argentina	J- Ciencia
Otero (2000)	Argentina	J- Aportes y Transferencias

Table 3 continued

Authors (year)	Location	Source
Rudzewicz (2006)	Chile	International Conference
Soria (2013)	Bolivia	Undergraduate thesis
Sandoval Zambonino (2012)	Ecuador	Undergraduate thesis

Hoffman and Alliende (1982). They found that repeated trampling at low rates (20 passes) resulted in decreases in species density with limited recovery of many plant species 1 year after trampling. The next study from the Andes using an experimental design, examined the response of vegetation to maintenance activities and use of a ski run in Argentina (Puntieri 1991). It found that vegetation on ski runs was dominated by ruderal and non-native species in the more disturbed areas. A more recent study compared the resistance of an Andean alpine meadow to trampling by hikers and pack animals using a manipulative experimental design (Barros and Pickering 2014b). It found that pack animals caused more damage than hikers after 300 passes, with some vegetation parameters, including plant height and the cover of an endemic species (*Eleocharis pseudoalbibracteata*) more severely affected at lower trampling rates by pack animals than hikers.

Most of the studies examining impacts on vegetation assessed the effects of trails (eight studies) and campsites (two studies) on vegetation cover, with some studies examining changes in vegetation composition (four studies) (Table 4). As found in other regions, there was reduced vegetation cover with trampling and changes in plant composition, including the increased dominance of trampling resistant species (e.g. Barros 2004; Rodríguez Bergadà 2007; Byers 2009). Similar to other mountain regions, studies found that graminoid vegetation was more sensitive to the creation of informal trails compared to woody vegetation (Farrell and Marion 2002; Barros et al. 2013).

Four studies examined the influence of roads (Pauchard and Alaback 2004) or trails (Vidal Ojeda 2005; de la Barrera et al. 2011; Barros and Pickering 2014a) on non-native plants in protected areas in Chile and Argentina (Table 4). Along road corridors in Villarica and Huerhueque National Parks in Chile, Pauchard and Alaback (2004) found that non-native species represented 11 % of the vegetation and that altitude and the type of land use influenced the success of plant invasions. In Aconcagua Provincial Park in Argentina, Barros and Pickering (2014a) found that the non-native flora represented around 11 % of the vegetation, with most non-natives associated with trails except for the common weeds, *Convolvulus arvensis* and *Taraxacum officinale* which were also found in undisturbed vegetation. In Torres del Paine National Park in Chile, Vidal Ojeda (2005) found that non-native plants represented 23 % of the vegetation with wet shrublands more susceptible to invasion compared to other plant communities. In Altos de Lircay National Reserve in Chile, de la Barrera and collegues (2011) found that 7 % of the vegetation consisted of non-native plants, but there was no clear relationship between trail distance and the occurrence of non-native species.

There are studies that evaluated impacts of visitor-related activities on vegetation, including dispersed visitor use of intensively used areas (Byers 2000; Barros and Pickering 2012), grazing (Barros et al. 2014), and human-ignited fires (Vidal and Reif 2011). The study assessing dispersed visitor use in Aconcagua Provincial Park in Argentina found extensive fragmentation of alpine vegetation due to informal visitor trails with highly disturbed sites dominated by ruderal plants (Barros and Pickering 2012). A study in Huascaran National Park in Peru using repeated photography assessed changes in land cover over 60 years (1937–1997) including impacts from climate change, grazing, natural hazards and trails (Byers 2000). It found increases in exotic pine tree species and obvious impacts of grazing by pack animals and cattle. A manipulative experiment assessing short-term effects of excluding grazing by pack animals found that alpine meadows responded rapidly to the removal of grazing, with increases in plant height and biomass over a single growing season (Barros et al. 2014). A study assessing the recovery of vegetation 4 years after a fire ignited by a tourist in mountain forest in Torres del Paine National Park in Chile (Vidal and Reif 2011), found that burnt sites had lower canopy cover and a higher frequency of non-native plants than unburnt sites.

Five of the studies on wildlife assessed bird responses to the presence of visitors while two others assessed the effects of visitor activities on the native camelid, the guanaco (*Lama guanicoe*) (Table 4; Table S2). Studies assessing birds included those that compared bird diversity and abundance on trails with control sites (Heil et al. 2007), in an intensively used area during periods with no visitation and with high visitation (Llavallol et al. 2012), bird tolerance of humans in a range of situations (Lambertucci and Speziale 2009; Herrmann et al. 2010; Vazquez et al. 2011) and the effect of simulated bird watching (using playbacks) on the vocal behaviour of two species of birds (Harris and Haskell 2013).

The study assessing the effects of birds on trails in Sierras Grandes de Cordoba in Argentina (Heil et al. 2007)

Table 4 Summary of studies demonstrating specific impacts of tourism activities in the Andes. * = studies conducted outside the Andes main range, 1 = Sierras Grandes, 2 = Sierras Pampeanas. + Ecoregions from column A – Experimental research

Experimental research	# studies	Ecoregions+
All studies	25	
In protected areas	23	
Ecoregions		
[a]Central Andean Wet Puna	2	
[b]Córdoba Montane Savannas*1	1	
[c]Eastern Cordillera Real Montane Forests	2	
[d]Magellanic subpolar forest	7	
[e]Monte*2	1	
[f]Southern Andean Steppe	10	
[g]Valdivian Temperate Forests	3	
Methods		
Observation	9	a, d, e, f
Manipulative	6	c, f
Disturbed/control sites	10	b, d, f, g
Human activity		
Simulated birdwatcher play back	1	c
Camping	5	a, c, d, f
Dispersed use	1	f
Hiking/walking trails	10	a, b, c, f
Ski run preparation	1	f
Standing/observing wildlife	5	c, e, f, g
Pack animals grazing	2	a, f
Vehicles	1	e1
Topic studied		
Vegetation	14	
Contemporary landscape change due to trails & grazing	2	a
Changes in vegetation composition due to trails & campsites	2	a, f, d
Changes in vegetation composition due to dispersed use	1	f
Changes in vegetation structure and biomass due to grazing	1	f
Habitat fragmentation from informal trails	1	f
Non-native plants on trails & roads	4	d, f, g
Reductions in vegetation cover due to trails & campsites	8	a, d, f,
Vegetation tolerance to ski run preparation	1	f
Vegetation tolerance to trampling	2	f
Vegetation recovery from tourist-ignited fires	1	d
Effects of grazing exclusion from pack animals	1	f
Soils	4	
Sediment yield & runoff	1	c
Trail depth	2	d, f
Campfire impacts on physico-chemical properties of soils	1	d
Soil compaction	1	f
Water systems	1	
Increased nutrients & associated algal growth in water bodies	1	f
Wildlife	8	
Ungulates (Lama guanicoe) response to human presence	2	d, e
Birds response to human presence	5	b, d, f, g
Birds response to simulated birdwatcher playback	1	c

found reductions in bird diversity and richness on trails including the density of birds of high conservation value. The number of visitors in these trails ranged from 12 000 to 3000 visitors per year (Heil et al. 2007). The study assessing bird responses to humans in Arrayanes National Park in Argentina (Llavallol et al. 2012) found no differences in bird diversity and abundance between periods of high visitation (e.g. 1700 visitors per day during summer) and no visitation. The study assessing bird tolerance of humans in Tromen Provincial Park in Argentina (Vazquez et al. 2011) found that the alert distance of birds varied among species, with some birds affected at distances of 180 m. The study in Tapichalaca Biological Reserve in Ecuador assessing the effects of simulated bird watching using playback (Harris and Haskell 2013) found that playbacks could induce bird habituation and change bird vocal behaviour.

Two studies examined the effects of tourism on the Andean Condor in the Patagonian region, including their response to humans and impacts on roost sites (Lambertucci and Speziale 2009; Herrmann et al. 2010). These studies found that the Andean Condor is affected by visitors particularly during the breeding season, with condors leaving the roost when visitors came within 200 m (Herrmann et al. 2010).

Research on guanaco's tolerance of humans included assessing flight distances and the frequency of sightings at different intensities of use in Argentina (Fuentes Allende 2011; Malo et al. 2011). These studies found that guanacos can tolerate some visitor use including vehicles and pedestrian use, but exceed their tolerance thresholds when there were more than 250 visitors per day (Malo et al. 2011). The presence of humans also affected the feeding behaviour of female guanacos in areas of high visitor use (Fuentes Allende 2011).

The few studies assessing the effects of visitor use on soils, included trail studies examining erosion on walking/hiking trails (Farrell and Marion 2002; Barros et al. 2013), sediment yield and run off through a portable rainfall simulator (Harden 2001), and stone displacement and soil compaction (Hoffman and Alliende 1982). One study assessed changes in the physico-chemical properties of soils due to campsites and campfires (Rodríguez Bergadà 2007). Studies assessing trail erosion found that soil loss varied based on vegetation type (Barros et al. 2013) and trail grade (Farrell and Marion 2002; Barros 2004). The study assessing soil erosion on roads and trails in mountains in Ecuador (Harden 2001) found that soil erosion occurs after just 5 min of simulated rain with more erosion on slopes. The study in Tierra del Fuego National Park in Argentina (Rodríguez Bergadà 2007) found changes in soil pH, compaction and density and decreases in organic matter content in campsites and campfires compared to soils in control sites.

The only study on visitor impacts on water systems that we were able to locate assessed the effects of campsites on a high-altitude lake and a control site in the nival zone in Aconcagua Provincial Park in Argentina (Barros 2004). It found that there was an increase in nitrate and a greater abundance of algal species tolerant of pollution in the lake near the campsite compared to the control lake.

DISCUSSION

This review assessed the current state-of-knowledge of recreation ecology in the Andes, including the geographical and environmental spread of studies. It demonstrates that there is a paucity of recreation ecology research in the Andes, with only 47 studies acknowledging, documenting and/or demonstrating ecological impacts of visitor use for a region extending over 8000 km (Garreaud 2009) and a system of protected areas totalling approximately over 480 000 km^2. This research intensity is particularly low compared to that in analogous regions on other continents that have similar types and intensities of visitor use. In North America and Australia, for example, there have been hundreds of studies in recreation ecology over the past 30 years (Hammitt and Cole 1998; Monz et al. 2010; Newsome et al. 2013). One recent review of common recreation activities in North America and Australia, for example, identified >80 studies, many from mountain regions (Pickering et al. 2010). A recent global review of recreation ecology studies (Buckley 2005) identified 768 studies, of which only 2 % were from South and Central America.

In this review, we only found 25 studies from the Andes that used experimental methods to assess impacts. These studies were from Peru, Ecuador, Chile and Argentina, and mainly from the Southern Andean Steppe and Magellanic Subpolar forest ecoregions. Visitor impacts in some popular protected areas in the Andes, including those in critical global biodiversity hotspots, such as Northern Andean Montane Forests, do not appear to have been assessed in the recreation ecology literature. The current research focus on the southern Andes may be because these areas are less densely populated compared to the northern Andes (Cajal 1998; Sarmiento 2000; Harden 2006), and hence visitors may be one of the few sources of direct anthropogenic disturbance in the southern Andes (Barros et al. 2013).

Although the scarcity of research for the Andes precludes us from making some generalisations, there are some important implications of the current research. The current Andean research highlights again that: (i) visitors can have a wide range of impacts on soils, vegetation and wildlife (Fig. 4), (ii) activities can differ in the types and severity of their impacts and (iii) ecosystems vary in both their resistance and speed of recovery from these impacts.

Some key studies including those assessing impacts on flagship species such as the Andean Condor (Lambertucci and Speziale 2009; Herrmann et al. 2010) and the guanaco (Fuentes Allende 2011; Malo et al. 2011) provide information on species tolerance thresholds for visitor use. Research on the impacts of trails on vegetation and soils in the Andes (e.g. Farrell and Marion 2002; Barros et al. 2013) support research from other alpine environments, by again highlighting that informal trails are more likely to be created where vegetation is low such as in meadows and other communities dominated by graminoids, compared to sites dominated by taller shrubs and trees.

Priorities for future research to address key gaps

Priorities for recreation ecology research in the Andes include expanding the geographical range of studies and addressing key knowledge gaps, including diversifying the types of activities assessed, and their impacts on major environmental components (Figs. 2, 3). As previously highlighted, the absence of research on important ecosystems and regions within the Andes, such as the Northern Andes, limits our capacity to understand and minimise impacts. For example, differences in biophysical features of the Northern Tropical Andes, including cooler and wetter conditions, deeper soils and greater human use in the past (Sarmiento 2000; Harden 2006; Bader and Ruijten 2008) compared to the drier sections of the Southern Andes (e.g. Southern Andean Steppe), may result in differences in the response of their ecosystems to disturbance from recreation and tourism.

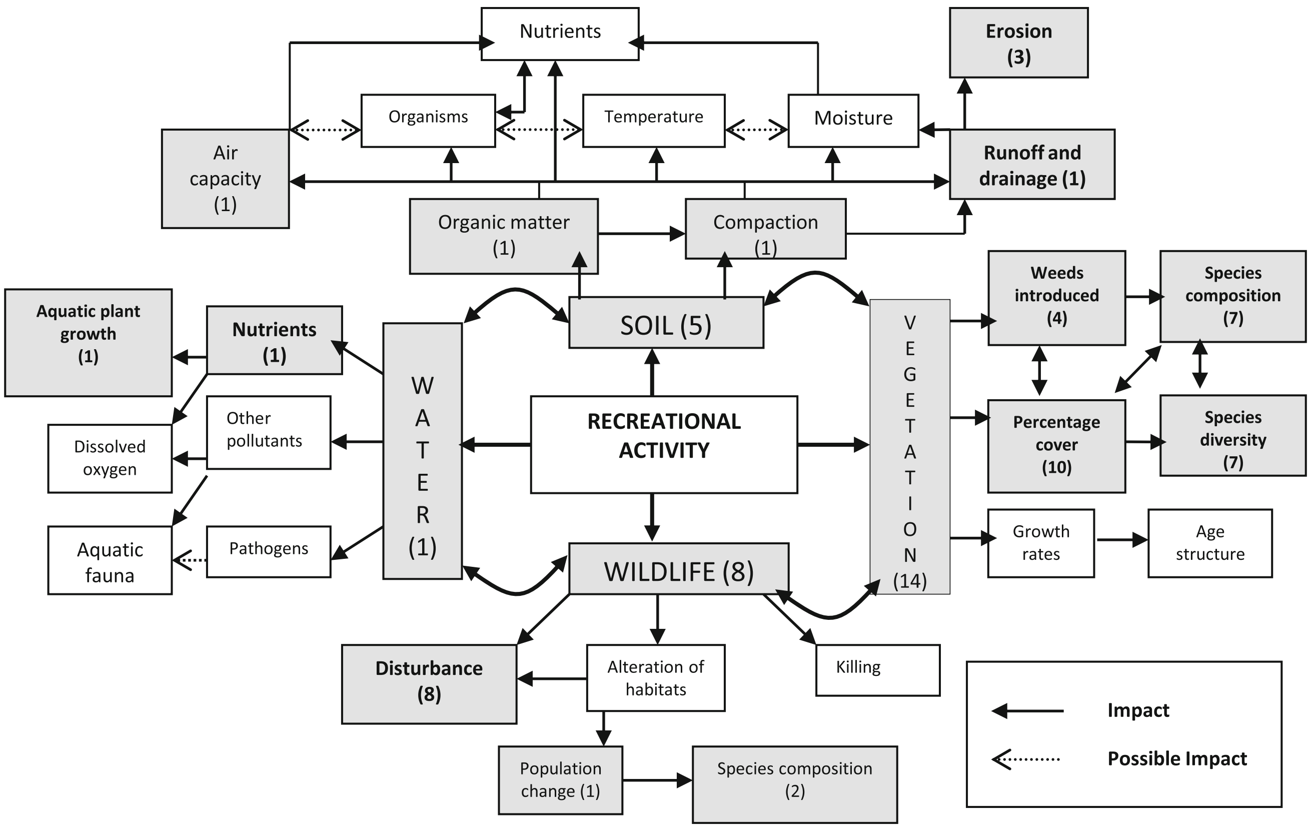

Fig. 4 Impacts of recreational use on different environmental components that have been assessed in the Andes region (in grey) including the number of studies in relation to the more general conceptual model of recreation impacts on the natural environment developed by Wall and Wright (1977)

There is limited research on some common recreational activities in the Andes, including impacts of four-wheel driving, horse riding, mountain biking, rock climbing, skiing and helicopter use (Table 2). Research on the impacts of visitor-related activities, such as grazing and trampling from pack animals, is an important issue for the Andes as these animals are increasingly used by mountaineers and hikers to transport equipment (Byers 2010; Barros et al. 2014). Grazing and trampling by pack animals are of particular concern because Andean vegetation evolved in the absence of large hard-hoofed grazing mammals such as horses and bovids, and subsequently Andean plants may be less tolerant of impacts from these animals compared to those from the smaller native Andean camelids (Molinillo and Monasterio 2006). Similar issues are faced in other alpine grasslands that have no large native herbivores, including in Australia and New Zealand, where impacts from grazing by horses and mules can be more severe (Newsome et al. 2002; Pickering et al. 2010).

A range of well-recognised impacts of visitors are yet to be assessed in the Andes (Fig. 4). One of the most important gaps is research on aquatic systems. Dealing with human waste is an increasing problem for protected area managers in many remote mountain regions, (Robinson 2010; Goodwin et al. 2012; Ghimire et al. 2013) including in the Andes (Carr et al. 2002). Removal of human waste from remote environments is often very expensive; particularly fly-out systems (e.g. helicopters) and/or the use of advanced technologies for on site treatment at high altitudes (Robinson 2010; Goodwin et al. 2012). It is, therefore, important to examine the impacts of human waste and other sources of contamination from visitors (e.g. detergents) on high-altitude lakes, snow and glaciers in popular destinations in the Andes. Recent research in other alpine areas has found that bacteria from human waste can persist in water bodies for extended periods even under harsh climatic conditions (Goodwin et al. 2012). As the Andes are the main headwaters for South America (Harden 2006), contamination of water sources is of particular concern.

Other activities that need special consideration but have not yet been covered in the recreation ecology literature for the Andes and elsewhere are adventure races (Newsome et al. 2011; Newsome 2014). These events are becoming increasingly popular in areas of high conservation value in the Andes, including in protected areas in Patagonia (e.g.

http://www.proyectoaventura.com/, http://tierraviva.com.ar/2013/?lang=en) and tropical forests in Ecuador (e.g. http://patagonianexpeditionrace.com/). They often involve the participation of hundreds of competitors undertaking multiple recreational activities such as orienteering, running, mountain biking and kayaking on natural settings during a period between 3 and 5 days (Newsome 2014). Due to the nature of these races, including the high amount of use in a very short-time period and the potential to traverse undisturbed areas during the race, there is potential to adversely affect important ecosystems in the Andes.

Research on unstudied taxa in the Andes such as reptiles and amphibians should be prioritised as these groups can be particularly susceptible to anthropogenic disturbance (Rodríguez-Prieto and Fernández-Juricic 2005; Andrews et al. 2008). There is a scarcity of recreation ecology research on amphibians and reptiles more globally, with very few studies from any alpine region. For example, a recent global review of the impacts of winter recreation on alpine and subalpine fauna found 41 studies, of which just two assessed impacts on reptiles in ski resorts in Spain and Australia (Sato et al. 2013).

Plant invasions and the role of visitors in facilitating invasions are important including in the Andes. Research on plant invasions in alpine environments, including four studies in the Andes (Pauchard and Alaback 2004; Vidal Ojeda 2005; de la Barrera et al. 2011; Barros and Pickering 2014a), found that even high-altitude mountains are susceptible to plant invasion, particularly by plants native to Europe. In mountains, humans and pack animals can introduce weed seeds in horse dung, on hiking shoes and on vehicles, contributing to the dispersal of non-native plants in remote-protected areas (Ansong and Pickering 2013a, b). Disturbance by trampling from hikers and horses and the construction and use of roads and hiking trails benefit ruderal species including many weeds (Hill and Pickering 2006).

Determining vegetation tolerance to visitor use (e.g. Hoffman and Alliende 1982) and comparing relative impacts from different activities (e.g. Barros and Pickering 2014a) in the Andes is important as it provides information on ecosystem use thresholds for different activities. For example, the study comparing impacts of trampling by hikers and pack animals on alpine vegetation in Argentina (Barros and Pickering 2014a) demonstrated that there were greater impacts per pass by pack animals than hikers. Restricting and managing pack animals may, therefore, achieve greater conservation benefits than focusing only on hikers. Research has recently demonstrated that the relationship between increasing intensity of use and damage to the environment does not always show a curvilinear response (Monz et al. 2013). This is an important point as a common management strategy of concentrating visitor use is based on assuming that initial use has the greatest impact. In some cases, the relationship between use and impact is sigmoidal or linear, indicating that different management responses may be more appropriate. Therefore, testing the shape of the relationship between increasing use and damage is important in the Andes, particularly where sites are of high conservation value.

In addition to assessing environmental components, it is important to integrate recreation ecology with social science, including assessing visitor's perceptions of environmental impacts and usage patterns (Monz et al. 2010). These types of approaches can provide information not only about the type and severity of ecological impacts from visitor use, but also about visitor tolerance of these impacts. In our review, we were only able to locate two studies documenting ecological impacts that also assessed social components (Encabo et al. 2001; Gutiérrez Cuevas 2008). More integrated studies using innovative methods, such as those developed in mountain-protected areas in the United States (e.g. D'Antonio et al. 2013 and Walden-Schreiner and Leung 2013), should be encouraged.

Research challenges and opportunities

Limited funding and expertise restrict recreation ecology research in many regions including in the Andes (Monz et al. 2010; Newsome et al. 2013), despite the regions' global importance. In other regions such as the United States, some management agencies recognise and support such research as part of their requirements for assessing and monitoring visitor impacts. In the Andes, recreation ecology research could be fostered through existing regional networks and organisations that promote research on global change and sustainable development such as the American Cordillera Transect (http://mri.scnatweb.ch/en/) and the Consortium for Sustainable Development of the Andes Ecoregion (www.condesan.org). These networks and other initiatives could be used as a platform to set research priorities at the ecoregion level which can be more cost-effective and useful for protected area managers. Also, improving communication between protected area agencies and universities in the region and abroad would foster improved management practices, based on the limited research that has already been completed in the Andes.

CONCLUSIONS AND LIMITATIONS

This review found that recreation ecology in the Andes is patchy, concentrated in a few ecoregions and protected areas, mainly those in the Southern Andes and mostly involving assessments of trail impacts on vegetation and the tolerance of some mammals and birds to visitor disturbance. It appears that research on other important environmental components, such as aquatic systems, is missing or hard to access electronically, despite the importance of the Andes as a watershed for South America.

This review only identified studies available via searchable databases and personal reference collections and subsequently is likely to have missed many PhD and Master's theses not available on-line. It did, however, include the publications in English and Spanish, and used the international, national and regional databases enhancing our capacity to identify and assess much of the research from the Andes.

By focusing on recreation ecology, the review did not address other components of visitation including social and economic dimensions such as visitor usage patterns, attitudes, perceptions, conflicts or how visitation may be affecting local communities due to environmental and other impacts (Newsome et al. 2013). Given the popularity of tourism and recreation in the region, more research in recreation ecology and other aspects of visitation in the Andes, should be prioritised, particularly popular parks of high conservation value and global significance.

Acknowledgments We thank Mercedes Ibañez and Stephan Halloy from The Nature Conservancy Southern Andes Conservation Program, Miguel Saravia and Manuel Peralvo from CONDESAN, Graeme Worboys, Fausto Sarmiento and Luis Alonso Ortega Fernandez for providing information about conservation status, protected areas and tourism in the Andes. We thank Clare Morrison for reviewing the manuscript prior to submission. Funding for this research was provided by the Griffith University, Australia.

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