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Non-native Plant Invasion in Relation to Tourism Use of Aconcagua Park, Argentina, the Highest Protected Area in the Southern Hemisphere

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Although mountain regions are thought to be at lower risk of plant invasions, the diversity and cover of non-native plants is increasing in many alpine ecosystems, including the Andes. We reviewed vegetation surveys in Aconcagua Provincial Park in the dry Andes of Argentina to determine what non-native plants occur in the park and if their distribution is associated with tourism use. This high-altitude park is a popular tourism destination for hikers, with nearly all access by foot and pack animals (mules and horses) that are used for transport. Non-native plant diversity was low (21 species in the region, 16 species in the park) compared to some other mountain regions but included common mountain species from Europe, most of which can be dispersed by tourists and commercial operators on clothing and by pack animal dung. Nearly all non-native plants were restricted to lower altitudes, with no non-natives found above 3420 masl. Most non-native plants were restricted to sites disturbed by tourism use, particularly areas trampled by hikers and pack animals, except for 2 common non-native species, Taraxacum officinale *and* Convolvulus arvensis, *which were also found in undisturbed vegetation. The relatively low cover and diversity of non-native plants at higher-altitude sites may reflect one or a combination of the following: climatic barriers, less human disturbance, and a lag in the dispersal of non-native species from lower altitudes within the park. This study highlights that even protected mountain areas with limited prior human use and nearly no road access can be invaded by non-native plants because of their popularity as mountaineer destinations. Management actions that could help minimize the further spread of non-native plants include limiting the introduction of non-native seeds on vehicles, clothing, and equipment and in dung; reducing trampling damage by restricting visitor use to designated trails; and restoring damaged sites.*

Keywords: *Weeds; alien plants; alpine vegetation; human disturbance; tourism; Andes.*

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Introduction

Non-native plants are a major threat to biodiversity conservation in many areas, including in many mountain ecosystems (McDougall et al 2011). They can outcompete native plants, as well as alter fire regimes, hydrological cycles, and soil conditions (Weber 2003). Impacts in mountains from non-native plant invasions include changing the dominant vegetation type from shrubs to trees, altering the tree line, changing habitat quality for animals, and competing with native species for pollinators (Pauchard et al 2009). These impacts are of particular concern because mountain regions have high levels of endemism and provide important ecosystem services to lowland regions (Körner 2004; Kollmair et al 2005). Reflecting their high conservation value, 11.4% of mountain regions globally are conserved within protected areas (Kollmair et al 2005).

Although mountain regions were thought to be at a lower risk of plant invasions, the diversity and cover of non-native plants is increasing in many protected mountain areas (Johnston and Pickering 2001; Pauchard and Alaback 2004; Pauchard et al 2009; McDougall et al 2010; Seipel et al 2012). These increases in non-native plant diversity and cover are often associated with increased human use of these regions, including for tourism (Pickering and Hill 2007; Pauchard et al 2009; McDougall et al 2010). People intentionally and unintentionally introduce non-native seeds into mountain parks (Mount and Pickering 2009; McDougall et al 2010; Pickering et al 2011). Intentional introductions include the use of non-native species with weedy tendencies in gardens, during rehabilitation of disturbed sites, and on ski slopes in resorts (Johnston and Pickering 2001; McDougall et al 2005). Unintentional introductions of non-native seeds can occur via seed carried on vehicles and other machinery; in introduced materials such as soil, hay, and mulch used in parks; on clothing; and on the fur and in the dung of pack animals (Campbell and Gibson 2001; Lee and Chown 2009; Loydi and Zalba 2009; Mount and Pickering 2009; Pickering and Mount 2010; Pickering et al 2011; Ansong and Pickering 2013a).

Human use can also disturb natural ecosystems in mountain parks in ways that favor the establishment of non-native plants (Pauchard et al 2009). Non-native plants generally benefit from anthropogenic disturbance, so where native vegetation is damaged, non-native plants often flourish (Weber 2003; Pauchard et al 2009). This includes disturbance during the construction and maintenance of tourism infrastructure such as trails, roads, ski slopes, and campsites (Johnston and Pickering 2001). Disturbance from common tourist activities can also reduce native vegetation cover, potentially benefiting non-native plants; this includes damage from trampling by hikers and pack animals, mountain bike riding, and four-wheel driving (Pickering et al 2010). Nutrient addition, from the deliberate use of fertilizers, promotes the growth of introduced species in gardens, ski slopes, and rehabilitation sites (Johnston and Pickering 2001). Pack animal manure also facilitates the invasion of non-native plants by creating microhabitats for their establishment (Loydi and Zalba 2009).

There is increasing interest in assessing the diversity and distribution of non-native plants in mountain parks and in minimizing their impacts (Pauchard et al 2009; McDougall et al 2010, 2011). Much of this literature is from mountains in Europe (Alexander et al 2009; McDougall et al 2010), Asia (McDougall et al 2010), North America (Rew et al 2005), Australia (McDougall et al 2005), and New Zealand (Jesson et al 2002), with few studies from the Andes in South America (Morales and Aizen 2002; Pauchard and Alaback 2004; Jiménez et al 2008; McDougall et al 2010), including the dry Andes (González and Gianoli 2004; Cavieres et al 2005; Badano et al 2007; Cavieres et al 2007). This is despite the Andes accounting for 23% of all alpine areas in the world (Körner et al 2011) and containing a great diversity of ecosystems with high biodiversity and endemism (Braun et al 2002).

Most non-native plants found in the high Andes are native to Eurasia, with deliberate introductions of these species following from European colonization (Figueroa et al 2004; Speziale and Ezcurra 2011). Some introduced species have become problematic invasive species, such as *Pinus contorta* in the Patagonian Andes and *Taraxacum officinale* in the dry Andes (Pauchard et al 2009). The diversity and cover of non-native plants at high elevations is often less than in lowland areas, with climate an important constraint on establishment, as has been found in other mountain regions (Pauchard and Alaback 2004). As a result, native cushion plants can facilitate establishment of some non-natives by ameliorating microclimatic conditions, particularly under dry and cold conditions in the Andes (González and Gianoli 2004; Cavieres et al 2005, 2007; Badano et al 2007). Anthropogenic factors also facilitate the establishment and spread of non-native plants in the Andes, with greater diversity and cover of these species with increasing proximity to agricultural and urban areas, density of roads, and grazing by introduced domestic animals (Figueroa et al 2004; Pauchard and Alaback 2004; McDougall et al 2010; Speziale and Ezcurra 2011).

Another anthropogenic factor facilitating non-native plant introductions that has not been addressed in the literature for the Andes is the potential for non-native plants to establish and disperse along hiking trails. This is despite the popularity of the region for mountaineering and hiking, with many protected mountain areas mainly accessed by foot (Buckley 2006; Barros et al 2013). This includes the highest protected area in the Andes and hence in the Southern and Western Hemisphere, Aconcagua Provincial Park (2400–6962 masl), in the dry Andes of Argentina.

There was limited human use of Aconcagua Provincial Park before its declaration as a park in 1983, but in the last 2 decades visitation has increased on average 10% annually, with more than 6000 hikers and mountaineers and 25,000 day visitors using the park in 2011 (Barros et al 2013). This is of particular concern because tourism use is often concentrated in the few areas within the park with vegetation. Therefore, it is important to assess the current status of non-native plants in the park, including their association with tourism infrastructure such as trails. Using data from vegetation surveys within the park, we determined (1) which non-native species occur in the park, (2) where they occur, and (3) how non-native plant cover and composition vary with altitude and disturbance associated with tourism use and hiking trails.

Methods

Study site

Aconcagua Provincial Park is a Category II World Conservation (International Union for Conservation of Nature) protected area in the Central Andes (69°56′W, 32°48′S) that protects 70,000 hectares of glaciers, watersheds, and alpine ecosystems around Mt Aconcagua. Temperatures are low all year, with winter averages of 0°C and summer averages of 11°C at 2900 masl (Departamento General de Irrigacion 2011). Above 2700 masl, there is snow cover for more than 4 months of the year, with an annual average snow water equivalent for the last 10 years of 100 mm. Summers are generally very dry, with only occasional snowstorms above 4000 masl.

Until recently, human use of the area was limited to transient use by indigenous communities (Barcena 1998), military training in the mid-1900s, and a few climbing expeditions (Quiroga 1996). Over the last 2 decades, tourism use has gone from around 1000 hikers and 600 pack animals in 1990 to more than 6000 hikers and 5600 pack animals in 2011, with visitor use mainly concentrated between November to March (Dirección de

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TABLE 1 Details of vegetation surveys and incidental observations used to identify non-native species in Aconcagua region and Aconcagua Provincial Park.

Date surveyed	Source	Survey location	Survey method and sampling size
1983–1993	**Méndez et al** 2006. La vegetación del Parque Provincial Aconcagua (Altos Andes Centrales de Mendoza, Argentina). *Boletín de la Sociedad Argentina de Botánica* 41:41–69.	1. Steppe and alpine meadows 2. Low to high alpine belt 3. Natural and disturbed vegetation in the park, adjacent valley, ski resort	1. Braun-Blanquet phytosociological analysis 2. 253 plots (10 × 10, 5 × 5, 1 × 1 m)
2001–2002	**Barros et al** 2013. Impacts of informal trails on vegetation and soils in the highest protected area in the Southern Hemisphere. *Journal of Environmental Management* 127:50–60.	4. Steppe and alpine meadows 5. Low and intermediate alpine belt 6. Trail and adjacent natural vegetation	1. Systematic random sampling (every 300 m) 2. 60 × 15 m line transects; point quadrats every 20 cm 3. 60 × 1 m plots; presence/absence data
2010–2011	**Barros et al,** in press. Short-term effects of pack animal grazing exclusion from Andean alpine meadows. *Arctic, Antarctic and Alpine Research.*	7. Alpine meadows 8. Intermediate alpine belt 9. Disturbed vegetation (grazing)	1. Random sampling (3-m minimum distance between plots) 2. 40 × 1 m plots; 100-point quadrats for each plot
2011–2012	**Barros and Pickering** 2012. Informal trails fragment the landscape in a high conservation area in the Andes. *Proceedings of the 6th International Conference on Monitoring and Management of Visitors in Recreational and Protected Areas.* Stockholm, Sweden, 21–24 August, pp 360–361.	1. Steppe and alpine meadows 2. Low alpine belt 3. Natural and disturbed vegetation (trampling off trail)	1. Random sampling (50-m minimum distance between plots). 2. 102 × 20 m plots; visual cover estimation for each species in 20 × 1 m^2 subplots
2010–2011	**Barros and Pickering** 2013a. Vegetation along road verges in Aconcagua Provincial Park. Unpublished data. Available from the authors of this paper.	1. Steppe and alpine meadows 2. Low alpine belt 3. Road verge	1. Systematic random sampling (every 100 m) 2. 12 × 20 m plots; visual cover estimation for each species in 20 × 1 m^2 subplots
2010–2011	**Barros and Pickering** 2013b. Weeds along an altitudinal gradient in alpine meadows. Unpublished data. Available from the authors of this paper.	1. Alpine meadows 2. Low alpine and intermediate alpine belt 3. Natural and disturbed vegetation (grazing and trampling off trail)	1. Systematic random sampling (each meadow a replicate, random start) 2. 19 × 20 m plots; visual cover estimation for each species in 20 × 1 m^2 subplots
2006–2011	**Barros** 2011. Incidental observations of weed species in Aconcagua Provincial Park. Unpublished data. Available from the authors of this paper.	1. Steppe and alpine meadows 2. Low to high alpine belt 3. Natural and disturbed vegetation (trails, grazing, and trampling off trail)	GPS records of non-native plants observed during field visits

Recursos Naturales 2011). Based on an estimated ∼11,000 pack animals staying overnight and grazing in the park per year, is estimated that 228 tons of manure (22 kg of horse manure per day, Tao and Mancl 2008) are deposited in the park. To access the highest and most remote campsites, hikers traverse 40 km of trails in the alpine zone and 10 km of trails in the nival zone (Dirección de Recursos Naturales 2009). In addition to use by hikers and mountaineers, the start of the Horcones Valley, which is close to the international highway connecting Argentina and Chile, is used by more than 25,000 day visitors per year. In this highly used area, there is a network of unhardened trails created by visitors and pack animals (Barros et al 2013).

More than 120 native plant species are found in the Aconcagua region (Méndez et al 2006). Within the park vegetation is scarce, covering 30% of the park, and is mainly restricted to valley floors, which are also where

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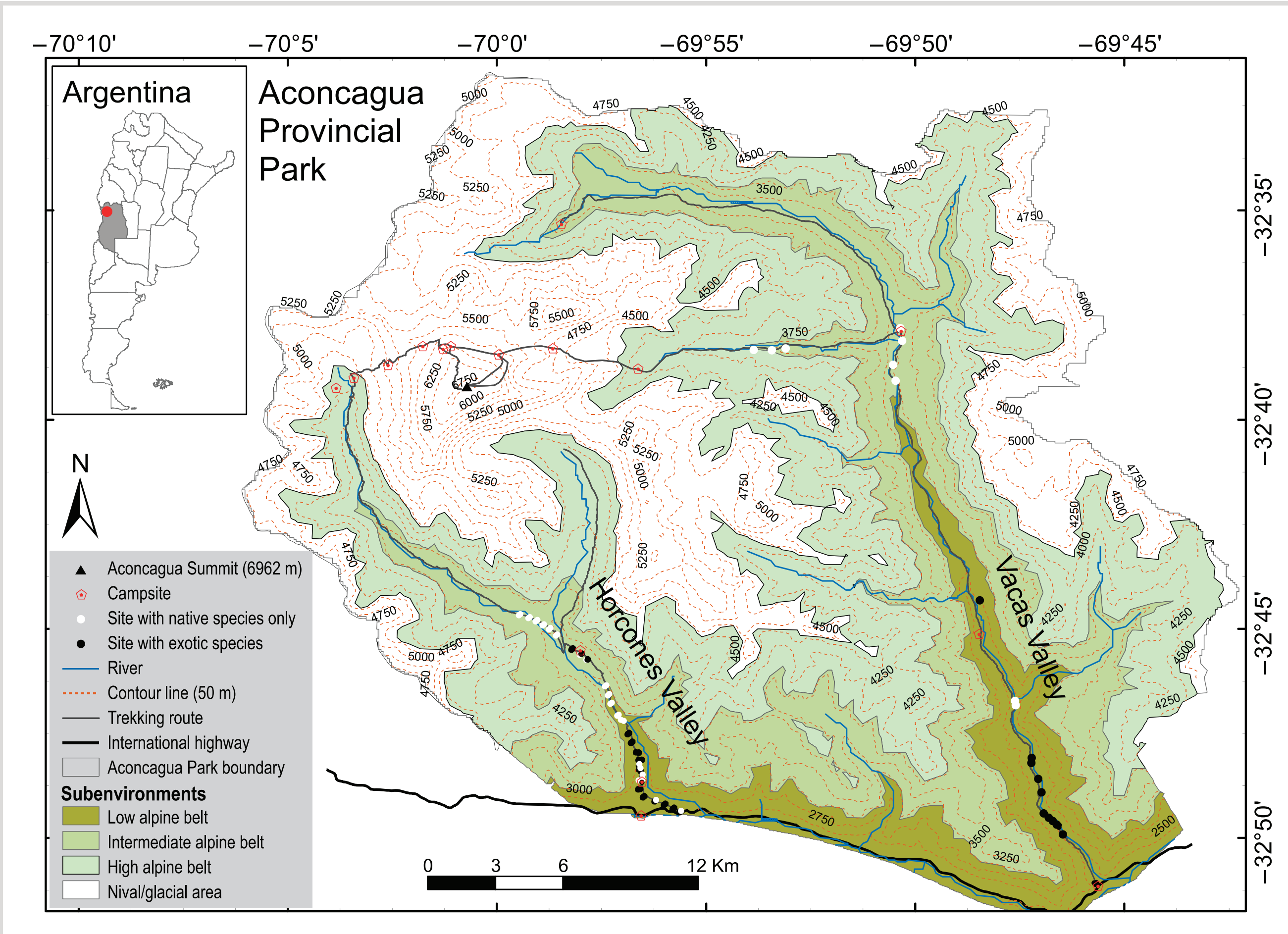
FIGURE 1 Location of the sites surveyed across the 2 main valleys (Horcones and Vacas) used to access the summit of Mt Aconcagua in Aconcagua Provincial Park, Mendoza, Argentina. Sites with exotic taxa and those with only native species are marked. (Map by the authors)



most visitor use is concentrated (Barros et al 2013). The alpine zone consists of 3 zones: low alpine (2400–3200 masl), intermediate alpine (3200–3800 masl), and high alpine (3800–4400 masl) (Méndez et al 2006). The 2 main vegetation types are steppe vegetation (29.5%) and alpine meadows (0.4%). Steppe vegetation occurs on thin mineral soils and rocky slopes and is mainly characterized by sparse shrubs, grasses, and perennial herbs, while alpine meadows have a high vegetation cover of graminoids and herbs that occurs on deeper and wet soils along rivers, springs, or areas that have subsurface water (Barros et al 2013).

Data on non-native plants in the park

A complete list of non-native plants was obtained for the Aconcagua region above 2400 masl from a range of sources (Table 1). This included a plant survey conducted between 1983 and 1993 of 253 plots in the broader Aconcagua region that included the park, an adjacent ski resort, and the international highway that connects Chile and Argentina (Méndez et al 2006).

More recent park-specific data were obtained from vegetation surveys of 233 sites in the 2 main valleys in the park conducted from 2001 to 2011 by one of the authors (Figure 1). For each site, the following data were recorded: presence or absence and cover of any non-native species, spatial coordinates, vegetation type altitude, and type of anthropogenic disturbance (Table 1 and *Supplemental data,* Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1). Incidental observations of additional non-native plants by one of the authors during fieldwork in the park were also included (Table 1). Details regarding the methods used for each vegetation survey are included in Table 1.

For each non-native species identified in one or more of these surveys, additional information was collected from standard databases, including family, growth form, and life form. Broader data on the weed status of each species were also obtained, including (1) whether the species is considered a weed, using data from a comprehensive database of more than 28,000 species of weeds from more than 1000 sources (Randall 2007, 2012);

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TABLE 2 Non-native species recorded in one or more vegetation surveys of Aconcagua Provincial Park and adjacent areas.

Non-native species	Family	GF	LF	Origin	Mendez et al 2006	233 Surveys	Inc. obs
Achillea millefolium	Astaraceae	H	P	Europe			1
Cirsium vulgare	Asteraceae	H	A/B	Europe		1	
Convolvulus arvensis	Convolvulaceae	H	P	Europe, Asia	1	1	
Lactuca serriola	Asteraceae	H	A/B	Europe, Asia, N Af	1		
Matricaria chamomilla	Asteraceae	H	A	Europe, Asia		1	
Medicago lupulina	Fabaceae	H	A/P	Europe, Asia, N Af		1	
Medicago sativa	Fabaceae	H	A/P	Mediterranean, Asia	1	1	
Plantago lanceolata	Plantaginaceae	H	P	Europe, N Af, Asia		1	
Poa annua	Poaceae	G	A	Europe	1		
Poa compressa	Poaceae	G	P	Europe		1	
Poa pratensis	Poaceae	G	P	Europe, N Af, Asia, NA	1		1
Rumex acetosella	Polygonaceae	H	P	Europe, N Af, temp Asia			1
Rumex pulcher	Polygonaceae	H	P	Eurasia and N Af	1		
Rumex crispus	Polygonaceae	H	P	Europe, N Af, Asia	1		
Salsola kali	Amaranthaceae	H	A	Eurasia	1	1	1
Sisymbrium orientale	Brassicaceae	H	A/B	W Asia, Mediterranean	1	1	1
Tamarix ramosissima	Tamaricaceae	S	P	Europe, Asia			1
Taraxacum officinale	Asteraceae	H	P	Europe	1	1	
Trifolium repens	Fabaceae	H	P	Europe, N Af, temp Asia	1	1	
Urtica dioica var. *mollis*	Urticaceae	H	P	Europe, Asia, N Af, NA	1		
Veronica anagallis-aquatica	Scrophulariaceae	H	B/P	Europe, Asia, Africa, SA	1	1	

GF, growth form; G, graminoid; H, herb; S, shrub; LF, life form; A, annual; P, perennial; B, biennial; Inc. obs, incidental observations; N Af, North Africa; NA, North America; SA, South America; W Asia, western Asia; temp Asia, temperate Asia.

(2) whether the species is considered a global environmental weed, based on a list of 400 species of major invasive plant species internationally (Weber 2003); and (3) whether the species is considered non-native in other mountain regions, including in Australia, the United States, and South and Central Chile in South America (McDougall et al 2005; Bear et al 2006; Seipel et al 2012). The term "weed" is used here to refer to any non-native plant growing where it is not wanted and that often has economic and environmental impacts (Richardson et al 2000). The term "environmental weed" is used to refer to non-native plants that can invade natural

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TABLE 3 Status as a weed in different locations and potential unintentional human-mediated seed dispersal for each of the non-native plant species recorded in one or more vegetation surveys of Aconcagua Provincial Park and adjacent areas. See the Methods section for details regarding the sources of information. (Table extended on next page.)

	International		Mountain weed in		
Weeds	**Weed**	**Env. weed**	**AA**	**Mont.**	**Or.**
Achillea millefolium	Yes		Yes		
Cirsium vulgare	Yes	Yes	Yes		Yes
Convolvulus arvensis	Yes				Yes
Lactuca serriola	Yes		Yes	Yes	Yes
Matricaria chamomilla	Yes				
Medicago lupulina	Yes		Yes	Yes	Yes
Medicago sativa	Yes				
Plantago lanceolata	Yes	Yes	Yes	Yes	Yes
Poa annua	Yes		Yes		
Poa compressa	Yes		Yes	Yes	Yes
Poa pratensis	Yes	Yes	Yes	Yes	Yes
Rumex acetosella	Yes	Yes	Yes		Yes
Rumex pulcher	Yes				
Rumex crispus	Yes	Yes	Yes		
Salsola kali	Yes	Yes			
Sisymbrium orientale	Yes				
Tamarix ramosissima	Yes	Yes			
Taraxacum officinale	Yes		Yes	Yes	Yes
Trifolium repens	Yes	Yes	Yes	Yes	Yes
Urtica dioica var. *mollis*	Yes				
Veronica anagallis-aquatica	Yes				

Env., environmental; AA, Australian Alps; Mont., Montana; Or., Oregon; PA, pack animals.

ecosystems and pose a threat to biodiversity conservation (Randall 1997).

Data on the potential for the seed of each species to be unintentionally dispersed, including on clothing, on vehicles, or in pack animal dung or fur, were obtained from the Pickering and Mount (2010) database that was updated in 2013 (Ansong and Pickering 2013a). The distribution of each non-native species in the park was mapped using data from the surveys of 233 sites using the ArcGIS program (version 9.3). The altitude and the maximum distance of each non-native species from the road head were calculated using the Spatial Analyst tool in ArcGIS.

To determine whether the 233 sites surveyed give an approximation of the total number of non-native species in the park, a species accumulation curve was generated by plotting the cumulative number of non-native species against the number of sites using the Ugland, Gray, and Elingsen index in the PRIMER ordination package (version 6.0) (Ugland et al 2003). The resulting species accumulation curve showed that the occurrence of additional non-native species tended to flatten out after 150 sites, indicating that the number of sites surveyed was able to collect close to the total number of non-native species occurring in the park.

To determine how non-native plant cover and composition varied with human disturbance (tourism), we compared undisturbed sites and sites disturbed by tourism use. This included one-way analyses of variance and nonparametric Kruskal-Wallis tests comparing the difference between non-native species richness and cover in steppe and alpine meadows in the intensively used area of the park and cover of non-native plants along the main track in the Horcones Valley. We also compared non-native species count data in steppe and alpine meadows in the intensively used area using chi-square tests and non-

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TABLE 3 Extended. (First part of Table 3 on previous page.)

	International		Seed dispersed by		
Weeds	South Chile	Central Chile	Clothing	Vehicles	PA
Achillea millefolium	Yes		Yes	Yes	Yes
Cirsium vulgare	Yes			Yes	
Convolvulus arvensis	Yes	Yes	Yes		Yes
Lactuca serriola	Yes	Yes		Yes	
Matricaria chamomilla		Yes			
Medicago lupulina			Yes	Yes	Yes
Medicago sativa			Yes	Yes	
Plantago lanceolata	Yes	Yes	Yes	Yes	Yes
Poa annua			Yes	Yes	Yes
Poa compressa				Yes	Yes
Poa pratensis	Yes		Yes	Yes	Yes
Rumex acetosella	Yes	Yes	Yes	Yes	Yes
Rumex pulcher					
Rumex crispus			Yes	Yes	Yes
Salsola kali				Yes	Yes
Sisymbrium orientale				Yes	
Tamarix ramosissima					
Taraxacum officinale	Yes	Yes	Yes	Yes	Yes
Trifolium repens	Yes	Yes	Yes	Yes	Yes
Urtica dioica var. *mollis*			Yes	Yes	Yes
Veronica anagallis-aquatica				Yes	Yes

native plant cover and frequency for all sites using descriptive statistics.

Results

At least 21 non-native plant species occur in the Aconcagua region, of which 16 were recorded within the park during the more recent surveys between 2001 and 2011 (Tables 1 and 2). All of them are native to Europe, including the 3 graminoids, 17 herbs, and 1 shrub, the salt cedar *Tamarix ramosissima*. Most species were perennial (12), with other species annual/biennial, annual/perennial, or annual (Table 2). All are considered "weeds" somewhere in the world, and 8 are international invasive environmental weeds (Table 3). At least 14 species have also been recorded as non-native species in other mountain regions, including 12 species in the Australian Alps, 10 species in the Blue Mountains of Oregon (USA), 7 species in the Rocky Mountains (USA), 9 species in South Chile, and 7 species in Central Chile in the Andes. Seeds of many of the species may have been unintentionally introduced into the park on vehicles, on clothing, or in the dung of pack animals and then dispersed farther into the park on clothing and in the dung and fur of pack animals (Table 3). Most non-native species recorded in the park can be dispersed by these mechanisms, including the 5 most common non-native species: *Convolvulus arvensis, T. officinale, Trifolium repens, Plantago lanceolata,* and *Salsola kali* (Table 3).

Nearly all non-native species recorded in the Aconcagua region and within the park were restricted to the low alpine zone (>3200 masl), with only 1 species reaching up to 3420 masl, *C. arvensis* (Table 4, Figure 1, *Supplemental data,* Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1). In the 2 main valleys used by tourists to access high-altitude campsites and the summit of Mt Aconcagua, non-native species can be found 16 km into the park at an altitude of 2961 masl in the Vacas

TABLE 4 Average cover (± SE), frequency (Freq., percentage of sites), vegetation type (Veg. type), maximum altitude (Max. alt.), and maximum distance to road head (Max. dist.) for each of 12 non-native plant species recorded across 233 sites (183 in disturbed vegetation and 50 in natural vegetation) surveyed in Aconcagua Provincial Park. (Table extended on next page.)

	Total		Disturbed	
	Cover	Freq.	Cover	Freq.
All weeds	11.3 ± 1.1	48.9	11.9 ± 1.2	51.9
Cirsium vulgare	0.006 ± 0.005	0.4	0.01 ± 0.01	0.5
Convolvulus arvensis	8.3 ± 1.0	36.9	8.1 ± 1.1	37.2
Matricaria chamomilla	0.004 ± 0.004	0.4	0.01 ± 0.01	0.5
Medicago lupulina	0.01 ± 0.01	0.9	0.02 ± 0.02	1.1
Medicago sativa	0.002 ± 0.002	0.4	0.003 ± 0.003	0.5
Plantago lanceolata	0.07 ± 0.03	2.6	0.08 ± 0.04	3.3
Poa compressa	0.1 ± 0.1	1.3	0.2 ± 0.1	1.6
Salsola kali	0.9 ± 0.4	6.4	1.2 ± 0.5	8.2
Sisymbrium orientale	0.02 ± 0.02	0.4	0.02 ± 0.02	0.5
Taraxacum officinale	1.2 ± 0.3	9.4	1.5 ± 0.4	11.5
Trifolium repens	0.4± 0.2	3.4	0.6 ± 0.2	4.4
Veronica anagallis-aquatica	0.1 ± 0.1	1.3	0.2 ± 0.1	1.6

S, alpine steppe; M, alpine meadow.

Valley and 9 km in at an altitude of 3420 masl in the Horcones Valley (Figure 1). Many non-native plants do not extend so high in the park but are limited to areas below 2500 masl. These included the non-native herbs *Cirsium vulgare, Matricaria chamomilla, Medicago lupulina,* and *Medicago sativa* (Table 4). Also, more non-native species were found in alpine meadows (10 species) compared to alpine steppe (5 species), with 3 non-native species common to these vegetation types (Table 4).

Tourism disturbance favored non-native species in the park, with non-native plants recorded more frequently in disturbed vegetation (52%) than in natural vegetation (38%) (Table 4, Figure 1). Total non-native cover was also greater in disturbed sites compared to natural vegetation (12% disturbed versus 9% natural) (Table 3). The total number of non-native species recorded in disturbed sites (12 species) was greater than in natural vegetation (2 species, the environmental weeds *C. arvensis* and *T. officinale*) (Table 4). Along the verge of the short concrete entrance road into the park (Figure 1), non-native species were found in all 12 of the 20-m^2 plots surveyed, including *C. arvensis* (10 plots, 12% cover), *S. kali* (9 plots, 17% cover), and *T. officinale* (1 plot, 1.8% cover) (*Supplemental data,* Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1).

The lowest part of the Horcones Valley close to the entrance to the park is intensively used by sightseers, hikers, mountaineers, and the pack animals used to transport equipment for tourists (Figures 2 and 3). Although there is a network of informal trails in this area, a lot of trampling occurs off trail. In this intensively used low-altitude area, 81% of 102 randomly located plots (not on trails) showed obvious signs of human disturbance, with all 12 plots in meadows disturbed, 71 plots in steppe vegetation disturbed, and 19 steppe plots with no signs of anthropogenic disturbance. Five non-native species were recorded in this area: *C. arvensis, P. lanceolata, Poa compressa, S. kali,* and *T. officinale,* with 68% of the plots containing non-native species (Figure 2). Overall non-native species occurrence and cover were greater in disturbed meadows (21%) and disturbed steppe vegetation (14%) than in the undisturbed steppe vegetation (8%, all of which was *C. arvensis*) (Kruskal-Wallis, $H = 7.916$, $P = 0.01$; Chi-square, $\chi^2 = 11.463$, $P = 0.001$) (*Supplemental data,* Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1). In addition, non-native species richness per 20 m^2 was higher in disturbed meadows (1.3 ± 0.2) and disturbed steppe vegetation (0.8 ± 0.1) compared to natural steppe vegetation (0.4 ± 0.1) (ANOVA, $F = 6.033$, $P = 0.003$).

Farther up the Horcones Valley along the main access trail to the high campsites and summit of Mt Aconcagua (Figure 1), 3 non-native species were recorded in the 60 plots (48 plots in steppe vegetation, 12 in meadows), including *T. officinale* in meadows and *C. arvensis* and *Sisymbrium orientale* in steppe vegetation. *S. orientale* was recorded in just 1 plot on the trail verge. The frequency and cover of non-native species in steppe vegetation was greater in adjacent natural vegetation (10 plots, 12.4%) compared to trail verges (7 plots, 7%), but this was not statistically significant (Kruskal-Wallis, $H = 3.117$,

TABLE 4 Extended. (First part of Table 4 on previous page.)

	Natural				
	Cover	Freq.	Veg. type	Max. alt. (m)	Max. dist. (km)
All weeds	9.1 ± 2.3	34.5		3420	15.6
Cirsium vulgare			M	2457	4.3
Convolvulus arvensis	9.0 ± 2.4	32.7	S, M	3420	9.3
Matricaria chamomilla			M	2569	7.7
Medicago lupulina			M	2484	4.5
Medicago sativa			M	2484	4.5
Plantago lanceolata			S, M	2985	4.8
Poa compressa			M	2995	1.6
Salsola kali			S	3050	1.2
Sisymbrium orientale			S	3010	3.7
Taraxacum officinale	0.1 ± 0.1	1.8	S, M	2995	7.7
Trifolium repens			M	2961	15.6
Veronica anagallis-aquatica			M	2961	15.6

$P = 0.37$). For alpine meadows, the frequency and cover of *T. officinale* was greater on trail verges (4 plots, 6%) compared to the adjacent natural vegetation (1 plot, 0.6% cover) (*Supplemental data,* Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1).

In 19 meadows surveyed along the less popular Vacas Valley (Figure 1), all but the highest-altitude alpine meadow (3780 m) showed obvious signs of anthropogenic disturbance. These alpine meadows are intensively grazed by pack animals used by commercial tour operators to transport equipment to those staying in remote campsites during summer. Non-native species occurred in more than half of the 19 meadows (10 meadows), but only those at lower altitude (2400–2961 masl) (Figure 1). Non-native plant diversity was relatively high in these meadows, with 8 species recorded *(C. vulgare, M. chamomilla, M. lupulina, M. sativa, P. lanceolata, T. officinale, T. repens,* and *Veronica anagallis-aquatica),* although the only common non-native species was *T. repens* (8 meadows, 9% cover) (*Supplemental data,* Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-13-00054.S1).

Discussion

Non-native plant species diversity, cover, and distribution were relatively low for Aconcagua Provincial Park compared to some other protected mountain areas outside Europe that have longer histories of human use and more extensive road networks (McDougall et al 2010; Seipel et al 2012). With 16 non-native species recorded in Aconcagua Provincial Park (~11% of the flora of the park), non-native plant diversity is lower than in the Australian Alps (102 species), Yellowstone National Park in North America (33), and along roads extending into the Andes in South Chile (84). However, the diversity of non-native plant species in Aconcagua was similar to the site in Central Chile at equivalent elevation (eg fewer than 10 species per 100 m^2 at 2500 masl) and climate (dry and cold) to Aconcagua (Seipel et al 2012). The low diversity and cover of non-native plants in Aconcagua could be the result of a range of factors that have been found to affect non-native diversity in other mountains, including climatic barriers due to elevation, landscape characteristics, a lag in the dispersal of non-native plants from lower-altitude sites, and less human disturbance (Pauchard and Alaback 2004; Mallen-Cooper and Pickering 2008; Pauchard et al 2009; Alexander et al 2011).

The few non-native species occurring in the park were mainly limited to lower-altitude disturbed sites (>3200 masl), with only *C. arvensis* found up to 3420 masl. This could be the result of changes in climatic factors, with altitude limiting the establishment of non-native plants at higher-altitude sites in many mountains (Pauchard and Alaback 2004; Alexander et al 2011). For example, above 3200 masl, there are permafrost soils in Aconcagua (Roig et al 2007), which could act as an environmental filter, restricting the establishment of non-native plants above this altitude (Callaghan et al 2004; Roalsø 2012). Also, evapotranspiration stress due to increased solar radiation with increasing altitude and high winds could be limiting the establishment of non-native species, as has been

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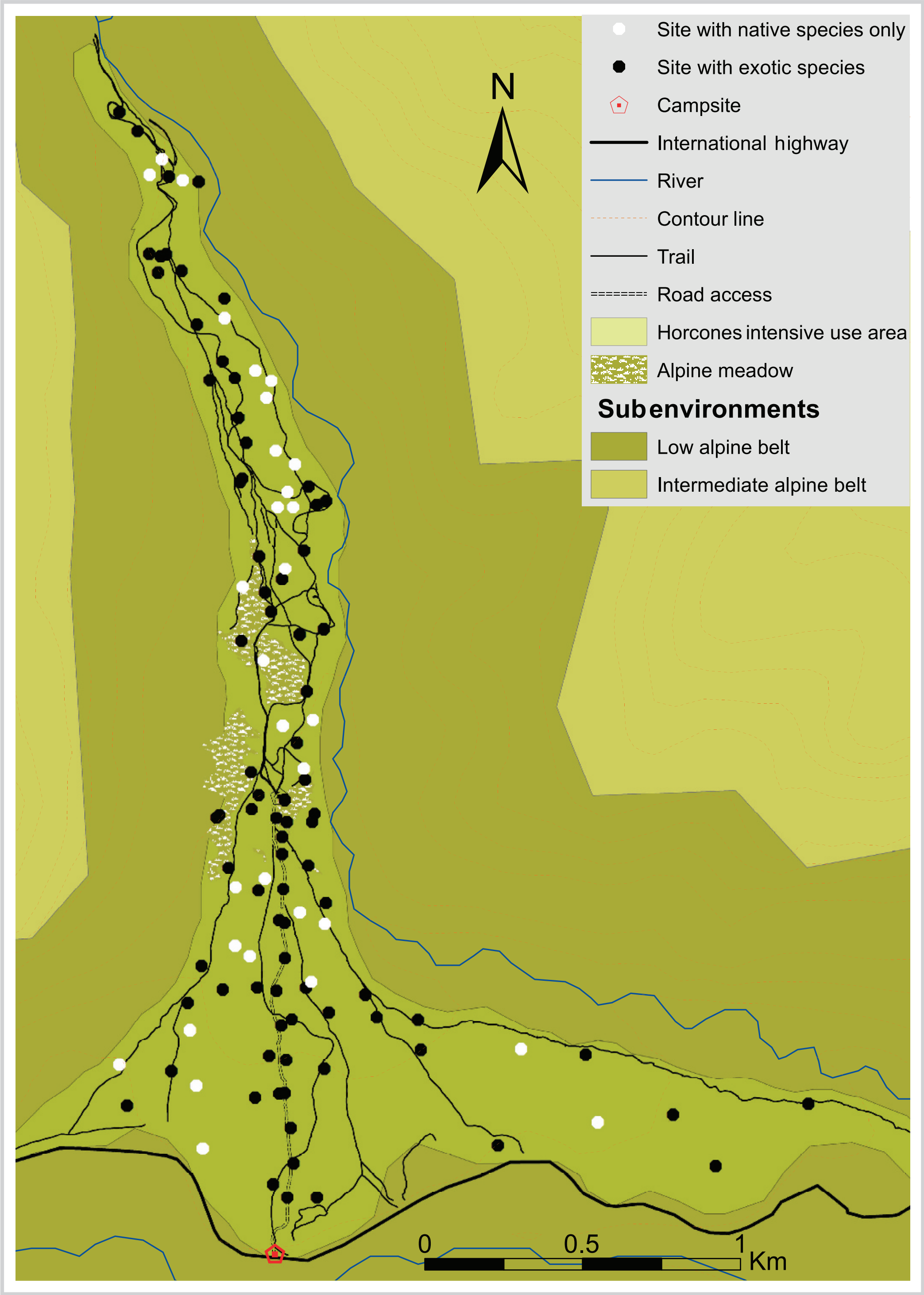
FIGURE 2 Location of the sites surveyed in the intensively used lower-altitude area of the Horcones Valley (69°56′W, 32°48′S) in Aconcagua Provincial Park, Mendoza, Argentina. Sites with exotic taxa and those with only native species are marked. (Map by the authors)



observed elsewhere (Cavieres et al 2005; Jakobs et al 2010). If climate has been acting as a limit on the distribution of non-natives, predicted increases in temperature due to climate change in the region (Marengo et al 2009; Christie et al 2011) may therefore reduce the resistance of Aconcagua to non-native plants invasions, including in the areas that are intensively used by tourists (Pauchard et al 2009).

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FIGURE 3 Trail use by visitors and pack animals in Horcones Valley, Aconcagua Provincial Park, Mendoza, Argentina. (Photo by Agustina Barros)

Reduced propagule pressure at higher elevations, more remote areas of park, or both may also be limiting the spread of non-natives farther into the park, as has been found in other regions (Pauchard and Alaback 2004; Pauchard et al 2009; Speziale and Ezcurra 2011). Paralleling reduced propagule pressure is reduced disturbance by trampling by tourists and by trampling and grazing by pack animals of the natural vegetation higher and farther in the park, which is also likely to be restricting the establishment and spread of non-natives. The relative importance of these factors is difficult to determine, because they are all correlated with elevation, as has been found in other research that examined non-native species distributions along a gradient in the Patagonian Andes (Pauchard and Alaback 2004).

The presence of non-native plants in the lower-altitude and more accessible areas of Aconcagua is of concern, with tourism use of the park contributing to the problem. For example, the first survey of the vegetation of the Aconcagua region, which was conducted between 1983 and 1993, recorded 13 non-native species, mostly in highly disturbed sites outside the park, including a ski resort and the verge of the international highway (Méndez et al 2006). The more recent surveys and incidental observations by one of the authors in the park identified 8 new non-native species. This apparent increase in diversity over time may be due to differences in sampling intensity but could also be due to an increase in the diversity of non-native species over the last 30 years, potentially reflecting increased tourism use of the park. Further surveys within the park and in adjacent lowland areas may identify additional species and highlight species that may become more of a problem in the future with changes in climate and land use, including tourism.

Potential vectors for the seed of non-native plants in the park include vehicles, hikers, and pack animals, with nearly all of them dispersed by one or more of these vectors in other studies. Because of the limited vehicle access within the park and isolated nature of the region, it is possible that at least some species were unintentionally

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introduced into the park on clothing, on shoes, and in the dung, fur, or both of pack animals (Whinam et al 1994; Loydi and Zalba 2009; Pickering and Mount 2010; Ansong and Pickering 2013a, 2013b). Also, the seed of non-native species could be carried on mountaineering equipment (Whinam et al 2005); most mountaineers in Aconcagua use their own equipment, which may have been used on other summits, including outside South America.

Once non-native seeds reach a site, trampling may facilitate their establishment and spread. Trampling on and off trails by tourists and pack animals in the park has disturbed sites in ways that favor the establishment of some non-native species. This includes reductions in the diversity and cover of native vegetation and alterations in soil conditions, including increased erosion (Barros et al 2013). Grazing by pack animals in the park, combined with the accumulation of manure in campsites, may also increase the risk of plant invasions in the park, as has been found in other regions (Whinam et al 1994; Van Dyk and Neser 2000; Campbell and Gibson 2001; Mouissie et al 2005; Cosyns et al 2006; Wells and Lauenroth 2007; Quinn et al 2008; Törn et al 2010; Stroh et al 2012). Although many non-native seeds in horse dung may not be able to establish, because they are often associated with fertile soils (Mouissie et al 2005), some may benefit from favorable microsite conditions in the park, such as those found close to cushion plants (milder soil temperatures and higher nutrient content) and in alpine meadows (wetter organic soils) (Stohlgren et al 1999; Cavieres et al 2005, 2007).

Alpine meadows in Aconcagua support a greater diversity of non-native species (10 species) than are found among the sparser alpine steppe vegetation (5 species). This may be because alpine meadow soils have high organic content and are moister than areas with alpine steppe vegetation. Wetter soils in meadows may well have contributed to the invasion of non-native species adapted to these conditions, such as *V. anagallis-aquatica* and *T. repens* (Morales and Aizen 2002; San Martín et al 2011). The greater diversity of non-natives in meadows may also be due to more intense grazing by pack animals, because these are often left to graze overnight on meadows rather than on the less productive steppe vegetation (Barros et al, in press). Previous research has found that increased soil fertility and disturbance both facilitate the establishment of non-native plants, including in riparian vegetation (Stohlgren et al 1999; Speziale and Ezcurra 2011).

While most non-native species in Aconcagua were restricted to lower-altitude sites, often on disturbed alpine meadows, the 2 species *C. arvensis* and *T. officinale* were also found in undisturbed vegetation. Both are common components of the alien flora of the dry Andes and can be found in disturbed and undisturbed native vegetation in the Central Chilean Andes (González and Gianoli 2004; Cavieres et al 2005; Badano et al 2007). More generally, they are widely dispersed non-natives with high seed outputs and are considered environmental weeds in many countries outside their natural range in Eurasia, including being considered weeds in North and South America (Weber 2003; Randall 2012). *C. arvensis* produces a taproot and can spread by seeds and rhizomes, which can grow in relatively close understories, including in the Andes (González and Gianoli 2004). *T. officinale* is a deeply rooted perennial herb that is a common weed to disturbed sites in many regions of the world outside its native distribution (Weber 2003; Randall 2012). In the alpine areas of the Andes, including in Aconcagua, their spread may be facilitated by cushion plants (eg *Azorella monantha* and *Adesmia subterranea*), as found for the Central Chilean Andes (Badano et al 2007; Cavieres et al 2007).

The non-native plants in Aconcagua were predominantly from Europe, reflecting the dominance of European species in non-native floras in many mountain regions, including the Andes (McDougall et al 2010). Many of them are also common non-native species from mountain ranges more generally (Seipel et al 2012). They were not mountain specialists but rather species that can be found in lowland areas and mountains in, and beyond, their native ranges (McDougall et al 2010). They were predominantly herbaceous, rather than woody: the same pattern that was found in McDougall et al's large-scale comparative study of mountain non-native floras. Although there were several annual or biennial species in Aconcagua, most were perennial, whereas equal numbers of perennial and annual non-native plants have been found in other mountain regions.

Conclusion

The results of this study highlight that, although the number and cover of non-native species in Aconcagua Provincial Park are limited compared to some other more intensively used mountain regions, even isolated, high-elevation protected areas are susceptible to plant invasions through trampling and inadvertent human-mediated seed dispersal. To prevent the spread non-native plants in the park and in mountains elsewhere with a similar type of visitor uses, it is important to limit human disturbance, including the spread of trails and the potential of humans, pack animals, and vehicles to disperse non-native seeds. Educational programs for mountaineers and tour operators addressing their potential to carry non-native seeds should be implemented, including requiring the use of weed-free fodder for pack animals before they enter the park and when they are in the park and cleaning boots and other equipment before entering the park (Pickering and Mount 2010). Rehabilitating sites that are already damaged should also be undertaken, and for problematic non-native species such as *C. arvensis* and *T. officinale*, integrated control strategies should be considered.

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Supplemental data

TABLE S1 Presence or absence of non-native plants across the 233 sites for the different vegetation surveys and incidental observations in Aconcagua Provincial Park. P, presence; A, absence.
TABLE S2 Average cover (± SE) and frequency (number of plots) for each of 12 non-native species recorded across 233 sites for the different vegetation surveys in Aconcagua Provincial Park.
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