Peatlands of the Peruvian Puna ecoregion: types, characteristics and disturbance

F. Salvador[1,3], J. Monerris[2] and L. Rochefort[3]

[1] Museo de Historia Natural, Lima, Peru
[2] Université de Québec à Montréal, Québec, Canada
[3] Peatland Ecology Research Group and Center for Northern Studies, Université Laval, Québec, Canada

SUMMARY

Peatlands represent one of the most important water resources in the Puna grassland ecoregion, but this fact is not yet widely recognised. Puna peatlands also provide key environmental services such as increasing the regional biodiversity of the Andean Altiplano plateau and contributing to the wellbeing of high-altitude human populations by providing grazing land and cooking fuel. We conducted a study in the Peruvian Puna ecoregion to describe the current condition of peatlands in terms of their vegetation, physical and chemical characteristics and disturbance status. Our results suggest that peat thickness, organic matter and degree of humification are good indicators for identifying peatlands in the Puna ecoregion. In general, the peatland sites that we sampled were dominated by mixtures of cushion and acaulescent rosette forming plants such as *Distichia muscoides* Nees & Meyen and *Plantago tubulosa* Decne. These *Distichia* and *Plantago* peatland sites were characterised by a mean surface water pH of 6.3, corrected electrical conductivity (*K* corr.) in the range 300–1814 µS cm^{-1} and presented the following mean exchangeable cation values: Ca^{2+} 48 mg L^{-1}, Mg^{2+} 9.6 mg L^{-1}, Na^{+} 8.2 mg L^{-1} and K^{+} 2.1 mg L^{-1}. The most common causes of disturbance we encountered were grazing, peat extraction and roads. Disturbance was most severe in mining sites, where peatlands are especially vulnerable because they are not under legal protection.

KEY WORDS: bofedales; cushion vegetation; High Tropical Andes; peat; Peru; water chemistry; wetlands

INTRODUCTION

In South America, the greatest variety of aquatic environments (i.e. rivers, streams, lakes, peatlands and other types of wetlands) is found in the Páramo and Puna ecoregions (Sierra 2006, Maldonado *et al*. 2011), which cover a high-Andean area from above 3000 m a.s.l. to over 5000 m a.s.l. (Izurieta 2007). In the Puna ecoregion, peatlands called “bofedales” (Weberbauer 1945), which belong to a unique type not found elsewhere on the planet, provide key environmental services that support both Andean mountain biodiversity and the wellbeing of high-altitude human populations (Baied & Wheeler 1993, Earle *et al*. 2003, Maldonado *et al*. 2011). Puna peatlands are located along the margins of rivers and springs and occur throughout the Andean territories of Peru, Bolivia, Chile and Argentina from 3200–3500 m a.s.l. up to the base level of glaciers (Maldonado *et al*. 2011). In Peru, peatlands are used mostly for traditional grazing by domestic herds of alpaca (*Vicugna pacos*), llama (*Lama glama*) and sheep (*Ovis aries*), which often form the basis of the local economy (Blench 2001). In central Peru, where no alternative is available, peat is the primary fuel resource for cooking and heating. In southern Peru, the local inhabitants cut networks of shallow channels to divert water within and around pre-existing natural peatlands in order to increase their extent and fodder production (Morlon *et al*. 1982). Many bird species, about one-third of which are threatened, depend upon the peatlands for feeding, nesting and water. Native camelid species like vicuña (*Vicugna vicugna*) and guanaco (*Lama guanicoe*) also rely on these peatlands for grazing and water supply (Villagrán & Castro 1997, Renaudeau d’Arc *et al*. 2000).

Although peatlands cover a smaller total area here than in northern latitudes, some studies indicate that they have significantly higher rates of carbon accumulation than northern peatlands (Earle *et al*. 2003, Chimner & Karberg 2008). Puna peatlands are poorly known ecosystems that face new challenges in the context of traditional and modern management, as well as from recent climate change.

Increasing economic activities place new demands on the water and minerals of the nascent watercourses where peatlands are located, to satisfy the needs of the Peruvian private and public sectors (Salvador & Cano 2002, Salvador *et al*. 2010).

These demands clash with traditional uses, promoting social conflicts especially in dry areas where water is the limiting factor for functioning of the socio-ecological system (Millenium Ecosystem Assessment 2005). Furthermore, recent climate change processes in the Andes (i.e. deglaciation, temperature increase, precipitation decrease) (Vuille & Bradley 2000, Soruco *et al*. 2009) introduce new issues of water availability, salinisation, reduction in area and increased carbon emissions (CO_2 in particular) for Puna peatlands (Anderson *et al*. 2011).

Nowadays, the need for conservation and wise use of peatlands is increasingly being recognised. However, we cannot conserve and manage what we do not know, so the first step in the conservation and sustainable use of a resource is to understand the resource itself. Relevant information about the Peruvian Puna peatlands (i.e. characteristics and functions) is still very scarce. Therefore, the objectives of this study were to (1) identify and describe some physical, chemical and vegetation characteristics of Peruvian Puna peatlands; and (2) document the range of anthropic disturbance to help identify threats to peatlands and pointers to responsible management actions.

STUDY AREA

The peatland sites are located in the central and southern Peruvian Puna at altitudes ranging from 3800 to 4700 m a.s.l. Precipitation is markedly seasonal. The rainy season occurs in the austral summer (December to March) and the eight-month dry (moisture stress) season occupies the remainder of the year, although seasonal and inter-annual variability is significant (Martínez *et al*. 2011). Snow, which begins at about 5150 m (Thomas & Winterhalder 1976), makes up a small percentage of total annual precipitation (Troll 1968). The diurnal temperature range is greater than the annual range, and freezing temperatures occur nightly throughout the year (Tosi 1960). The predominant plant life forms in the ecosystems of the Puna ecoregion are prostrate, cushion and rosette herbs such as *Azorella*, *Baccharis*, *Gentiana*, *Geranium*, *Lupinus*, *Nototriche*, *Valeriana* and *Werneria*. The numerous wetlands and cushion peatlands that occur in depressions buffer the effects of dry periods for nearby vegetation (Young *et al*. 1997). Plants of *Distichia muscoides* Nees & Meyen, *Oxychloe andina* Phil. and *Plantago rigida* Kunth are often conspicuous, forming large cushions. Other types of vegetation include carpets of *Plantago tubulosa* Decne. and *Werneria pygmaea* Gillies ex Hook. & Arn. Some species of *Gentiana*, *Hypsela*, *Isoëtes*, *Lilaeopsis*, *Ourisia*, *Phylloscirpus*, *Zameioscirpus* and *Carex* are also present in Puna peatlands (Salvador *et al*. 2009). The most common aquatic plants in ponds and streams include *Myriophyllum quitense* Kunth, *Elodea potamogeton* (Bertero) J.F. Macbr. and *Potamogeton* spp. (León 1993, Salvador *et al*. 2006, 2009).

Brief description of the study sites

In order to encompass a broad and typical array of anthropic disturbance, peatlands located in natural reserves and private mining sites were chosen. Natural reserves were selected according to the abundance of peatland sites, accessibility and logistics. To identify peatlands located in industrial mining areas, we contacted 21 Canadian polymetallic mining companies undertaking exploration or exploitation activities in the Peruvian Puna. On the basis of the information collected, the following three study sites were selected.

1. *Junín National Reserve (JNR)*

The Junín National Reserve (JNR) is located in the Department (State) of Junín and the Department (State) of Pasco (10º 50´ S, 75º 59´ W and 11º 09´ S, 76º 15´ W). It is mostly occupied by Junín Lake, which is the second-largest lake in Peru, and was declared a Ramsar site in 1997 (INRENA 2008). The extent of the reserve is 53,000 ha and the altitude range is 4080–4125 m a.s.l. Annual precipitation is 940 mm and mean annual temperature ranges from 3 ºC to 7 ºC. The local population of the JNR is around 32,000 people, distributed among 47 villages (INEI 2005).

2. *Huaron mining site (HMS)*

The Huaron silver-zinc underground polymetallic mine (11° 00' S, 76° 25' W) is located at an altitude of 4250–4650 m a.s.l. within the drainage basin of the Mantaro River, 320 km north-east of Lima and around 16 km west of the Junín Lake. The mine consists of 252 concessions spanning 63,822 ha. Average annual temperature ranges from 3 ºC to 10 ºC and annual precipitation ranges from 925 mm to 1370 mm.

3. *Salinas y Aguada Blanca National Reserve*

This National Reserve (acronym 'SABNR') covers an area of 366,936 ha in the Arequipa (15º 45´ 05'' S, 71º 34´ 00'' W) and Moquegua (16º 11´ 50'' S, 71º 51´ 27'' W) Departments. It is characterised by high mountain plains, volcanoes, hillsides, cliffs and wetlands at altitudes ranging from 3400 to more than 6000 m a.s.l., and sources eight sub-basin rivers. It also includes the Salinas and Indio-Dique Lakes, which were designated as a Ramsar site in 2003 (INRENA 2007). Mean annual temperature ranges from 2 ºC to 8 ºC, and annual precipitation from 336 mm to 526 mm with high intra- and interannual variability (Holmgren *et al*. 2001).

METHODS

Field assessments

Field assessments were carried out in March–April 2010 at a total of 24 peatland sites. Peatland sites were defined as wetlands where a layer of peat (with organic matter content > 30 % of dry mass) at least 30 cm thick had accumulated (Joosten & Clarke 2002). Each peatland site was first identified in the field by the presence of peatland plants (Salvador 2008), then further assessed by digging several soil pits to 30 cm depth and examining for organic content using field-based (visual and tactile) methods. At each site selected for sampling, all assessments were systematically noted using a form (Appendix 2).

For all of the peatland sites surveyed we recorded location, co-ordinates, ownership, general site characteristics and any signs of disturbance. Each peatland was classed as a slope or basin type following the hydrogeomorphological aproaches of Brinson (1993) and Squeo *et al*. (2006). Sloping peatlands occur along steep valley bottoms and can be a few kilometres long and only tens of metres wide. The basin type includes peatlands that have developed behind end moraines and in cirque basins, shallow depressions and other areas of low relief, and are typically more closely isodiametric with a flat surface.

For the purposes of this study, we defined a stand as a homogenous area (20 × 20 m) in terms of vegetation composition. We collected data on physicochemical characteristics of peat, surface pore water chemistry and vegetation for one stand at each peatland. We classified the stands by broad vegetation types (e.g. cushion, acaulescent rosettes, herbaceous). To evaluate more precisely the plant species composition, vegetation cover was documented using the 'relevé' method (Mueller-Dombois & Ellenberg 1974) in one randomly placed 10 m^2 quadrat per stand.

The approximate thickness of the peat layer was measured using a 230 cm tile probe and the level of humification (a concept that describes how well-decomposed the peat is) was determined by the von Post method (Rydin & Jeglum 2006). Soil samples were collected, at depths of 25 cm and 50 cm, and analysed for organic matter content. Organic matter content (%) was determined following the methods recommended by the American Society of Testing and Materials (ASTM 1993).

The pH, temperature and electrical conductivity (*K* corr., corrected for temperature at 25 ºC and hydrogen ion content) of surface water were measured at three locations in each sampled stand using a Hanna HI-98129 Combo pH/EC/TDS Tester. Samples of surface water were collected from pools. When possible, three water samples were collected per stand. Each water sample was placed in a 50 ml scintillation vial, sealed immediately, and kept refrigerated until analysis. The samples from JNR and SABNR were taken to ALS Environmental Laboratory Group in Lima (Peru) and filtered in the laboratory. Chemical attributes (dissolved metals) were determined using standard methods recommended by the American Public Health Association (APHA 2005). Ca, Cu, Mg and Fe were determined using the direct nitrous oxide-acetylene flame method (APHA 3111-D), and Na and K using the flame photometric method (APHA 3500-Na-B and APHA 3500-K-B). No data are reported for the samples collected at the Huaron mining site (HMS) because these were to be analysed at a local laboratory from which no results were received.

Sources of disturbance were identified by looking at topographical maps and walking the sites. The severity of each disturbance was assessed and ranked on the basis of how much of the peatland surface was affected by the disturbance. A disturbance affecting < 1 % of the surface was ranked as low severity, 1–5 % as moderate, 5–15 % as high and > 15 % as very high. Any disturbance to hydrology, vegetation and soil level was also noted. Hydrological disturbance was assessed by estimating the fraction of the peatland area that was altered. Disturbance to vegetation was assessed in terms of the fraction of bare soil, the presence of invasive or non-wetland plant species, and the intensity of grazing (as indicated by the types and number of livestock if present, and the frequency of cropped plants). Soil disturbance was assessed as the fraction of peatland with bare soil, mineral material overlying peat soil, or undergoing erosion.

RESULTS

Physical, chemical and vegetation characteristics

Basic data for the 24 peatlands selected for study are presented in Table 1. The average altitude of these peatlands was 4302 m a.s.l., and 96 % of them lay above 4000 m a.s.l. The two main types identified were basin and slope peatlands, but 83 % of the

Table 1. Peatland locations, types, main dominant vegetation and some physicochemical characteristics of peats in the Peruvian Puna ecoregion. JNR: Junin National Reserve, HMS: Huaron Mining Site, SABNR: Salinas y Aguada Blanca National Reserve. Ar: acaulescent rosette, Cu: cushion, Tu: tussock. DM: *Distichia muscoides*, FS: *Festuca* sp., PR: *Plantago rigida*, PT: *Plantago tubulosa*, OA: *Oxychloe andina*.

Ownership	Co-ordinates (UTM)			Altitude (m)	Type	Peat depth (cm)	Degree of humification (von Post H scale)	Percentage of organic matter (average) 25–50 cm	Main dominant plant growth-form(s)	Main peat forming plant(s)
	Zone	Northing	Easting							
JNR	*18L*	*3770*	*8772*	4116	basin	>140	3	---	Cu, Ar	DM, PT
		3739	*8777*	4110	basin	>85	5	---	Tu, Ar	FS, PT
		3889	*8796*	4325	basin	>175	5	---	Cu	DM
		3901	*8777*	4118	basin	25	6	67	Cu, Ar	DM, PT
		3856	*8789*	4113	basin	170	5–6	---	Ar	PT
		3864	*8787*	4106	basin	50	---	---	Cu, Ar	DM, PT
		3887	*8795*	4335	slope	130	5–8	87	Cu, Ar	DM, PT
		3891	*8765*	4115	basin	250	2–9	---	Cu, Ar	DM, PT
		3836	*8767*	4119	basin	165	4–5	---	Cu, Ar	DM, PT
		3936	*8799*	4361	basin	>250	2–9	---	Cu	DM
HMS	*18L*	*3471*	*8782*	4468	basin	180	5–7	87	Cu, Ar	DM, PT
		3468	*8783*	4478	slope	160	7–8	85	Cu, Ar	DM, PT
		3490	*8783*	4395	basin	100	5–9	69	Cu, Ar	DM, PT
		3428	*8782*	4610	basin	50	---	21	Cu	PR
		3432	*8782*	4619	basin	120	---	55	Cu	DM
		3463	*8782*	4482	basin	>200	5–8	63	Ar	PT
		3516	*8784*	4234	basin	200	4–5	66	Cu	DM
SABNR	*19L*	*2657*	*8240*	4408	basin	145	3–4	---	Cu	DM
		2434	*8224*	3975	basin	36	4–5	28	Cu, Ar	DM, PT
		2714	*8194*	4400	basin	45	3–4	56	Cu	DM
		2715	*8199*	4381	basin	70	3	---	Cu	OA, DM
		2705	*8193*	4330	basin	120	5–6	44	Cu, Ar	DM
		2643	*8205*	4495	slope	190	2–6	---	Cu	DM, OA
		2572	*8191*	4151	slope	104	2–6	78	Cu	OA

peatlands we visited had formed in basins or depressions (i.e. they were basin peatlands). All of the peatlands we surveyed were fed by groundwater, mostly derived from springs, but they also received superficial water from external sources such as streams, rivers and lakes. Peatlands located near 4500 m a.s.l. received additional water from snowmelt.

In terms of growth forms, 46 % of the surveyed peatlands were dominated exclusively by cushions (Figure 1), 8 % by acaulescent rosettes, and 42 % by a mixture of cushions and acaulescent rosettes. The least common life form category was a mixture of tussocks and acaulescent rosettes (4 %). In terms of the main dominant peat forming plants, 42 % of the peatlands were dominated by a mixture of *Distichia* and *Plantago tubulosa*, 29 % by *Distichia* alone and 8 % by *Plantago tubulosa*. Tussock vegetation (i.e. *Festuca* sp.) was also occasionally present.

The 24 peatland sites (Table 1) showed a relatively wide range of peat characteristics. Peat thickness ranged from 0.36 to > 2.5 m, and degree of humification from H2 to H9. The mean organic matter content of the peat was 58 ± 21 % and, from 13 of the peatlands, we associated a wide range of soil organic matter contents with the main dominant peatland plant(s). In peatlands dominated by cushions of *Distichia* only (Figure 1a), organic matter content was 69 ± 14 %, while in peatlands dominated by *Distichia* and *Plantago tubulosa* it was 56 ± 26 %. In the less common sites dominated by acaulescent rosettes of *Plantago tubulosa* (Figure 1b) and cushions of *Plantago rigida* (Figure 1c), the organic matter contents were 63 % and 21 %, respectively. Samples taken from cushions of *Oxychloe* (Figure 1d) contained 78 % organic matter. At Junín peatlands (Central Andes), below the vegetated peatland surface and the organic layer, we found a clay or clay-silt layer and then the water layer. At the Arequipa peatlands

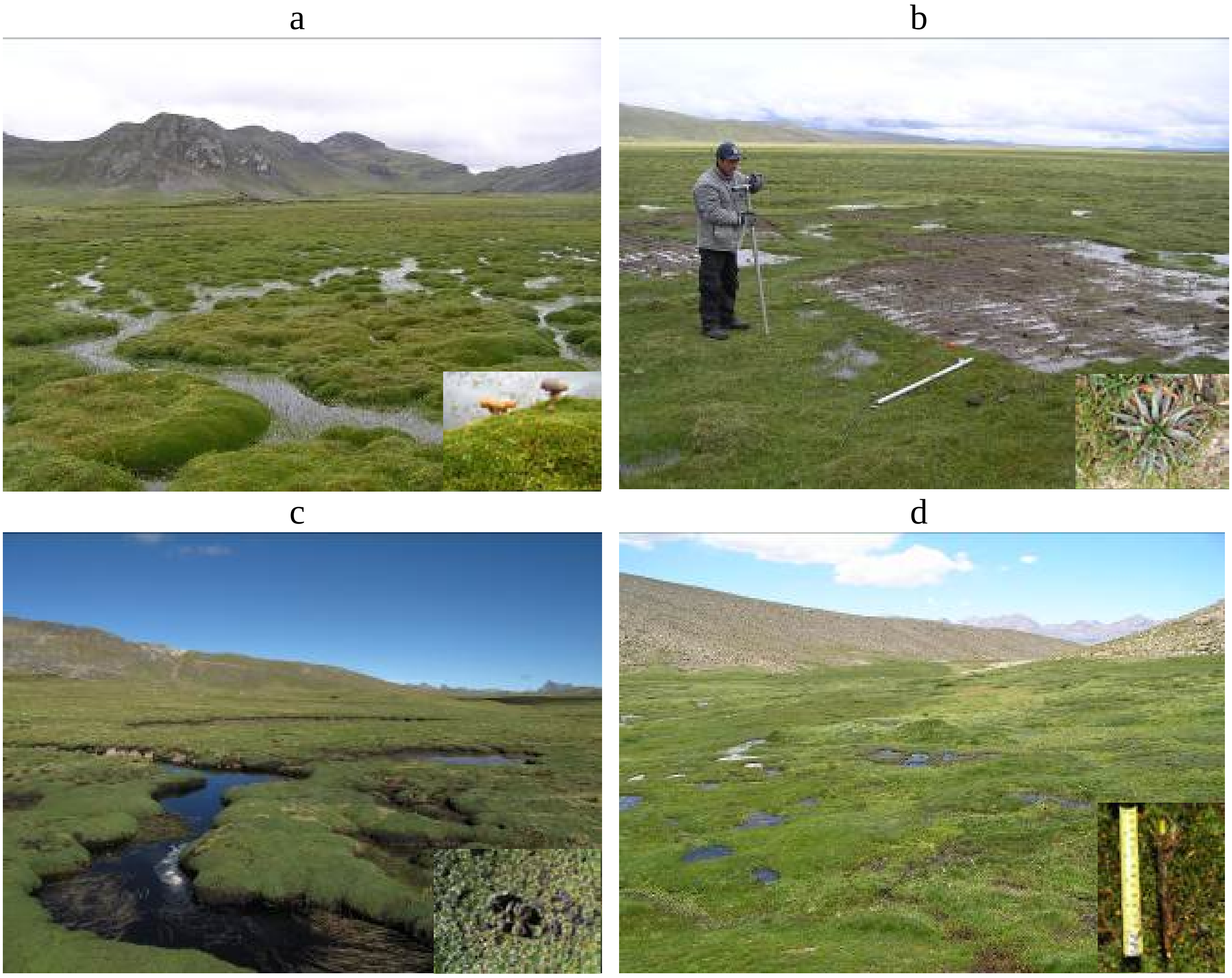

Figure 1. (a) Cushions of *Distichia muscoidis* (Shalipaico, JNR, 4361 m); (b) Acaulescent rosettes of *Plantago tubulosa* (JNR, Sasicucho, Junín, 4119 m); (c) Cushions of *Plantago rigida* (HMS, Junín, 4619 m); (d) Cushions of *Oxychloe andina* (SABNR, Turca, Arequipa, 4400 m).

(Southern Andes), we found, mainly, a sand layer and a clay-sand layer below the superficial layer of organic matter.

The pH of surface water samples collected from 17 peatland sites ranged from 4.5 to 7.9 (mean value 6.5 ± 0.8) and their corrected electrical conductivity (*K* corr.) ranged from 137 to 3176 µS cm^{-1} (mean value 766 ± 701 µS cm^{-1}). The values from 12 sites that were associated with the main peat forming plants also varied widely (Table 2). Surface water from peatlands dominated by *Distichia* and a mixture of *Distichia* and *Plantago tubulosa* had pH > 6. However, *Distichia* and *Plantago tubulosa* also occurred in association with acidic water (pH 4.5). The values of *K* corr. for *Distichia* peatlands varied over a wide range (137–2092 µS cm^{-1}) and included the highest values (> 650) observed. Water from peatlands dominated by *Distichia* had the highest contents of the majority of exchangeable cations (i.e. K^+, Mg^{2+} and Na^+) (Table 2). We also observed that surface water in peatlands characterised by *Distichia* and *Plantago tubulosa* were richest in Ca^{2+}, although the concentrations measured were highly variable.

Disturbance

The majority of the surveyed peatlands were highly disturbed (Table 3, Figure 2). The commonest sources of disturbance overall were grazing (71 %), roads (58 %) and peat extraction (46 %) with mean severity levels of, respectively, 3.4, 3.6 and 3.5 (on a scale of 1 to 4). The natural reserves were most affected by grazing and peat extraction, and the mining sites were most impacted by roads.

Table 2. Chemical properties of surface water associated with the main peat forming plants. Units: electrical conductivity (*K* corr.) in µS cm^{-1}, ion concentrations in mg L^{-1}. DM: *Distichia muscoides*; PT: *Plantago tubulosa.* Mean (±SD: Standard deviation) and range are shown for each chemical property. n: number of peatland sites.

Chemical property		Main peat forming plants	
		DM, PT	DM
pH	mean (SD)	6.3 (±0.9)	6.5 (±0.8)
	min-max	4.5–7.8	5.3–7.9
	n	10	7
K corr.	mean (SD)	761 (±433)	659 (±698)
	min-max	300–1814	137–2092
	n	10	7
K^+	mean (SD)	2.1 (±3.3)	22.4 (±34.3)
	min-max	0.03–8.6	0.5–82
	n	6	5
Mg^{2+}	mean (SD)	9.6 (±5.2)	17.4 (±13)
	min-max	2.9–19	6.9–38
	n	6	5
Na^+	mean (SD)	8.2 (±14.7)	94 (±159)
	min-max	0.1–38	0.4–374
	n	6	5
Ca^{2+}	mean (SD)	48 (±25)	35.3 (±15)
	min-max	25–82	14.6–49
	n	6	5
Fe^{3+}	mean (SD)	0.03 (±0.01)	0.22 (±0.3)
	min-max	0.03–0.11	0.03–0.7
	n	6	5

Table 3. Disturbance categories, number of times disturbance was encountered during the field surveys of 24 peatlands, and average severity level of disturbance (1 = lowest severity and 4 = most severe impact). Categories ranked by average severity. Numbers are based on stand level data and each site can be subject to more than one type of disturbance.

Disturbance	Number of occurrences	Average severity
drainage	4	3.8
roads	14	3.6
peat extraction	11	3.5
grazing	17	3.4
erosion	9	2.1
other	13	3.1

other=trails, subterranean cables, ditches, deposition, flooding, power lines

Disturbance arising from mining activities (including drainage, deposition, erosion, power lines and flooding) scored highest for (average) severity at 3.5–3.8. Erosion causing moderate disturbance (average severity 2.1) was found at 38 % of the surveyed peatlands. None of the 24 peatlands was placed in the 'low severity' category. Vegetation was most affected by heavy (cattle) grazing pressure. Damage to vegetation and soils was most evident in peatlands whose hydrological functioning had been altered (Table 3, Figures 2c and 2e).

DISCUSSION

Peruvian Puna peatlands: general characteristics

Peat thickness at our study sites ranged from 0.3 m to more than 2.5 m. These results are consistent with those from other studies on Puna peatlands, which variously report peat deposits of some decimetres to 1 m (Olivares 1988), mostly more than 1 m (Troncoso 1982, Prieto *et al*. 2003) and 3.6 m (Earle *et al*. 2003). Thick and rapidly growing peat bodies have been identified in the Chilean Andes (Earle *et al*. 2003), where peat accumulated at a rate of approximately 2 m per 1000 years, which is 2–10 times the accumulation rates found in boreal and mountain peatlands in the northern hemisphere (Chimner *et al*. 2002). This rapid peat accumulation rate could arise from the 12-month growing season and the very dense carbon-rich peat formed by cushion plants, *Carex* spp. and bryophytes (Cooper *et al*. 2010).

In general, degree of humification was higher in the Puna peatlands we sampled than in the *Sphagnum* peatlands of the northern hemisphere. Our values of organic matter content (20–87 %) and mean soil organic matter content for the uppermost 50 cm of peat (60 %) are similar to those reported from the San Juan Mountains (USA) by Chimner *et al*. (2010). Peatland dominated by cushion plants had the highest organic matter content. This is in line with the results of Cooper *et al*. (2010) from peatlands in northern Peru. Our results are also within the range for cushion peatlands indicated by La Fuente *et al*. (1988) and Caro (2010), who reported an average organic matter content of 38 % and a range of 50 % to 64 %, respectively. Nevertheless, we found that organic matter content was only 21 % in peatlands dominated by cushion plants like *Plantago rigida*. This could be attributed to the fact that we sampled in a peatland that was drained, where we observed dried-out cushions and physical evidence of peat erosion (Figure 2e), suggesting that carbon loss was in progress. Our results differ from those of Sotomayor *et al*. (1990), who described Bolivian peatlands with 0.9–5.8 % organic matter content. This could be attributed to the continual downward movement of mineral matter (mainly volcanic parent material). Segnini *et al*. (2010) located large organic carbon stocks (23.03–30.62 kg m^{-2}) in the uppermost 30 cm of Peruvian Puna peatlands, suggesting that they offer substantial C sequestration potential.

When compared to North American geochemical peatland classifications based on pH, calcium, magnesium and electrical conductivity of surface water, the Peruvian Puna peatlands we surveyed can be classified as poor, moderately rich and extremely rich peatlands (Vitt & Chee 1990, Vitt 2006). The majority of the sites we studied featured rather alkaline surface water, and only a few of them presented acidic water. Similar results were found by Prieto *et al*. (2003) and Squeo *et al*. (2006) in the Puna of Bolivia and Chile (Table 4). Data from Colombian Páramos have demonstrated that

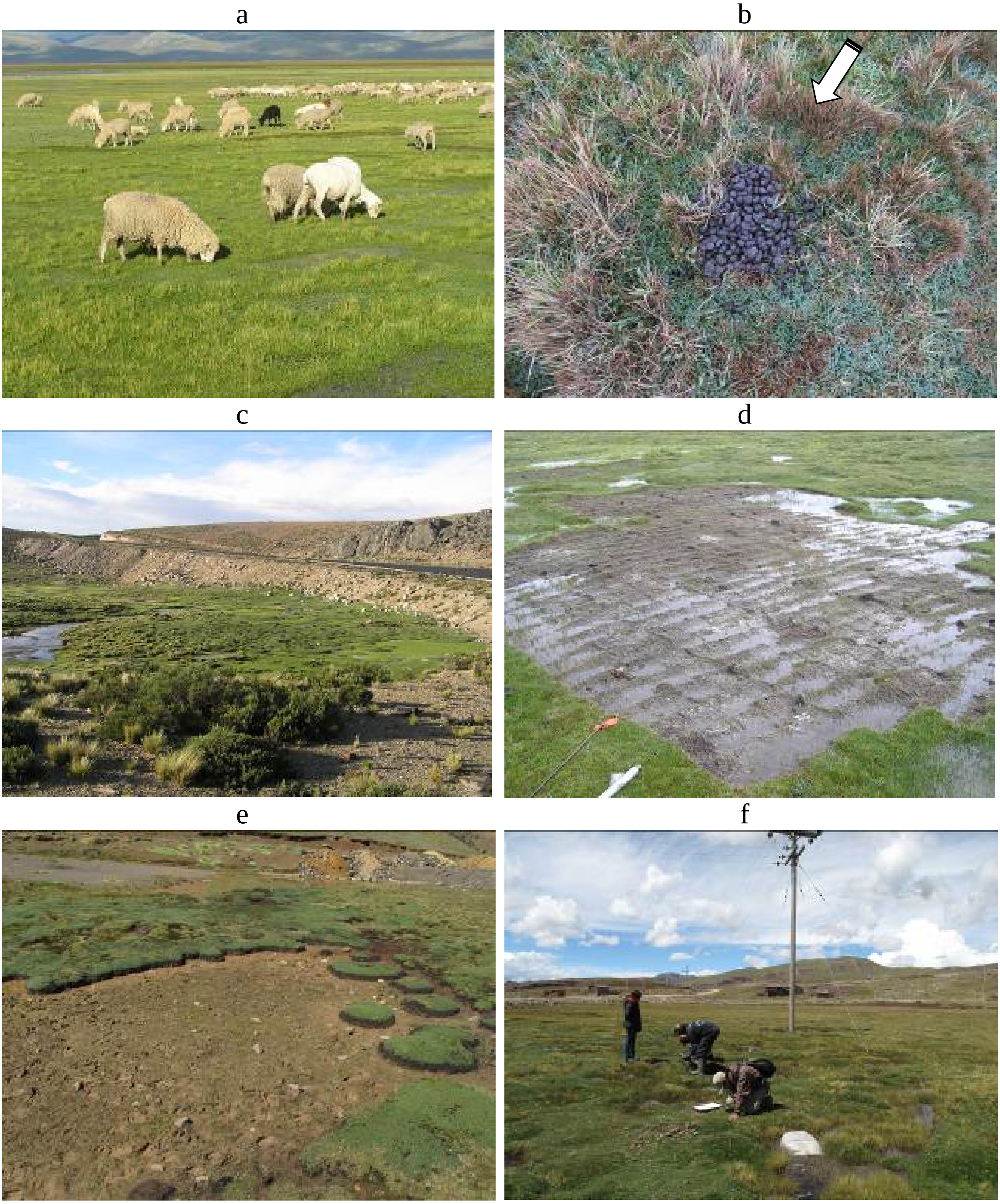

Figure 2. (a) Ovine grazing (Sasicucho, JNR, Junín, 4119 m a.s.l.); (b) Alpaca faecal matter. Arrow indicates cropping of the grass *Calamagrostis rigescens* (HMS, Junín, 4478 m a.s.l.); (c) Roads (SABNR, Salcoyo, Arequipa, 4408 m a.s.l.); (d) Peat extraction (RNJ, Sasicucho, JNR, Junín, 4119 m a.s.l.); (e) Drainage (HMS, Junin, 4610 m a.s.l.) and (f) Power lines (HMS, Junin, 4619 m a.s.l.).

Table 4. Comparison of pH and EC (µS cm^{-1}) values obtained for surface water on some peatlands in the Puna region. Mean values and ranges are also presented. PT: *Plantago tubulosa*; PR: *Plantago rigida*; DM: *Distichia muscoides*; OA: *Oxychloe andina*. n.d.: not determined.

pH	EC	Main dominant plant	Location	n	Source
6.3	761*	DM, PT	Peru	10	this study
7.2	697*	PT	Peru	2	"
6	145*	PR	Peru	1	"
6.5	659*	DM	Peru	7	"
7–8	19–713		Chile	n.d.	Squeo *et al*. (2006)
7	3176	OA	Peru	1	this study
7–8	22–2620		Chile	n.d.	Squeo *et al*. (2006)
3	361	DM, OA	Peru	2	this study
5.1–7.2	---	PT, DM, OA	Bolivia	31	Prieto *et al*. (2003)

*Corrected electrical conductivity (*K* corr.).

cushions of *Distichia* and *Plantago rigida* can also grow in acidic waters with pH 5.1–6.3 for *Distichia* and 5.1–5.8 for *Plantago rigida*, respectively (Cleef 1981). Exchangeable cations (i.e. K^+, Mg^{2+}, Na^+) were more abundant in *Distichia* cushion peatlands than in mixed *Distichia* and *Plantago tubulosa* peatlands, while Ca^{2+} concentrations increased in mixed *Distichia* and *Plantago tubulosa* peatlands. The presence of *Distichia* cushions could indicate environments with different levels of mineralisation (Squeo *et al*. 2006). This was recently demonstrated in an analysis of the ecological conditions of cushion plant peatlands in the high Andes of Bolivia (3800–4800 m) by Ruthsatz (2012). The electrical conductivity of water associated with *Distichia* cushions ranges from 19 to 713 µS cm^{-1} and is related to streams and springs that do not accumulate salts during the dry season (Squeo *et al*. 2006). Cushions of *Oxychloe andina* are usually associated with (saline water) conductivity values of 2,620 µS cm^{-1} (Squeo *et al*. 2006) up to 3,176 µS cm^{-1} as was demonstrated in this study. Ruthsatz (2012) suggests that height above sea level and salt content of the water are the most important factors affecting the distribution of cushion peatland species in Bolivia. These results could be tested in the Peruvian high mountains by sampling peatlands along the gradient of humidity and salinity which runs from the humid north-east to the arid south-west where saline soils and salt lakes are very common.

In the Puna context, we propose that all of the surveyed peatlands should be classified as fens, on the basis of origin of the water feeding them (Bedford & Godwin 2003, Squeo *et al*. 2006). Puna peatlands exist because they are fed by groundwater discharging from local or regional flow systems linked to springs, feeder streams or river influence and with some inputs directly from snowmelt (Squeo *et al*. 2006). Thus, we surveyed not only soligenous peatlands but also topogenous peatlands that had formed in basins (Prieto *et al*. 2003, Squeo *et al*. 2006, Cooper *et al*. 2010). The premise that bogs or ombrogenous (exclusively rain-fed) peatlands (Rydin & Jeglum 2006) are not present in this area is corroborated by other studies carried out in mountains (Prieto *et al*. 2003, Chimner *et al*. 2010, Cooper *et al*. 2010). Consequently, the peatlands of the Puna region should be termed fens or minerotrophic peatlands with highly variable degree of mineralisation, as was found also by Navarro & Maldonado (2002).

Finally, other rosette and peat forming cushion plants have been described in the Peruvian Puna ecoregion (Gutte 1980, Salvador 2008) and in the Páramo ecoregion (Cleef 1981). Rosettes of *Isoëtes andicola* and cushions of *Oreobolus* sp. have been reported as the dominant peatland plant species at two locations in Huánuco and Junín Departments (Gutte 1980, Salvador 2008). The problem is that these species are overlooked because they are typically confused with *Distichia muscoides*. We certainly believe that more surveys and monitoring should be undertaken to increase our knowledge about the distribution and ecology of the Puna peatlands, as their time is running out in the face of increasing human impacts and climate change.

Disturbance

Most of the surveyed peatlands were, or are still being, grazed. The primary indicators of disturbance were the presence of different kinds of livestock and the occurrence of indicator plants for grazing. At present, Puna peatlands show patterns of excessive stocking and consequent overgrazing especially due to the high density of alpaca and sheep (Lara 2003). We also associated more severe disturbance with non-native animals such as cattle, pigs and horses; these non-native animals cause erosion which is maintained to a lesser extent by the Andean Goose (*Chloephaga melanoptera* Eyton). Although we found that the presence of cropped plants of species such as *Calamagrostis rigescens* (J. Presl) Scribn. and *Eleocharis albibracteata* Nees & Meyen ex Kunth and the abundance of the graminoid *Aciachne pulvinata* Benth. were easy to recognise in the field as indicators of overgrazing, published studies quantifying the effects of grazing on Peruvian peatlands are still scarce. Nonetheless, some direct and indirect management measures, based on field intuition, had been taken to reduce grazing on the peatlands we surveyed in nature reserves. For example, in the JNR, livestock have been excluded from some peatland areas in order to estimate and control overgrazing. Also, grazing has already been excluded for more than 50 years on peatlands located on HMS at around 4500 m a.s.l.

Roads were the second most important source of disturbance that we observed. Roads affect peatlands by bisecting them, by intercepting their water supplies, and by introducing mineral sediment that can bury organic soils (Chimner *et al*. 2010). Thus, peatlands are more vulnerable to drying out, erosion and sediment input when roads are present. In peatlands located near mining sites, we observed that the impacts of some roads were exacerbated when their purpose was to support activities like the installation of power lines or subterranean cables, which caused channelisation, sedimentation and erosion.

The third most important source of disturbance is the cutting of peat for use as a fuel for cooking. Indeed, cushion and acaulescent rosette plants are collected by local people for this purpose. *Distichia* and *Plantago rigida* are two peatland species that are commonly used as energy sources because of their high productivity and forage biomass (Gutte 1980, Prieto *et al*. 2003). There have been many studies of peat extraction and its impact on peatland structure and functioning in the Northern Hemisphere (Poulin *et al*. 1999, Strack *et al*. 2008); however, counterparts for Peruvian Puna peatlands are rare. It is of paramount importance to acquire greater knowledge about these effects in the near future, to enable stakeholders to responsibly manage high Andean peatlands under increasing anthropic pressure (Millenium Ecosystem Assessment 2005) as they become dryer and more vulnerable due to climate change (IPCC 2007).

Amongst the sources of disturbance we recorded for Puna peatlands, mining activities (tailing ponds, dewatering, subterranean cables, power lines, sedimentation) were ranked fourth in terms of extent, but the impacts were of high intensity. In addition to their direct physical effects, roads can disrupt the flow of both surface water and groundwater and alter the chemical and sediment dynamics of Puna peatlands. It is well known from the literature that hydrological changes can affect peat and vegetation (Wheeler & Shaw 1995). Among mining operations, flooding to create tailing ponds affected limited areas but was logged as very high impact because it completely eliminated the peatland habitat. Soil extraction, the burying of subterranean cables and the installation of power lines were similarly destructive activities. In the most extreme cases of mining impacts, de-watering a peatland was judged to be a severe disturbance because it lowers the peatland water table allowing peat to oxidise and the peat surface to subside due to increased decomposition (Chimner *et al*. 2010). De-watering can also cause large changes in vegetation communities (Heikkilä & Lindholm 1995).

Finally, ditches and trails were judged to be minor sources of disturbance to peatlands. Local people dig ditches as a measure to extend peatlands rather than to drain them. Trails were present on dry and disturbed portions of a few peatlands.

All of the disturbed areas we observed in Puna peatlands could potentially emit as much greenhouse gas as an area of *Sphagnum* dominated peatland 10–100 times larger (Earle *et al*. 2003). On the other hand, with judicious management, Puna peatlands could perform a useful carbon sequestration function. The same authors report RERCA (Recent minimum rates of carbon accumulation) values per unit area of cushion peatland that are at least an order of magnitude higher than the values reported for Northern Hemisphere *Sphagnum* peatlands. This means that, for example, 1 m^2 of cushion (i.e. *Oxychloe*) peatland sequesters the same amount of atmospheric carbon in one year as at least 10 m^2 of *Sphagnum* peatland.

CONCLUSIONS

From our surveys we have shown that peat thickness, organic matter content and degree of humification are good indicators for identifying peatlands in the Puna region. The cushion and acaulescent rosette vascular plants *Distichia* and *Plantago tubulosa* are the main components of Puna peatland vegetation and the plant material contributing to peat accumulation. Peatlands in the Puna region of Peru are minerotrophic in nature. *D. muscoides* cushions were found across a wide range of surface water pH, electrical conductivity and exchangeable cation values.

The main sources of disturbance we encountered in Puna peatlands were grazing (most extensive), peat extraction and roads (least extensive). However, the most severe disturbance (drainage, erosion, flooding, deposition of mineral sediments) was found in mining sites, where peatlands are especially vulnerable because they are not under legal protection.

Because Peruvian Puna peatlands are a key source of resources (i.e. water, fodder and fuel) for the local economy, their wise management is an enormous responsibility for government. This responsibility might be shouldered by pursuing research or advice on the impacts of grazing, peat cutting, etc., and how to conduct such activities sustainably. Moreover, national and international mining companies should be encouraged by the appropriate governments to undertake relevant research and development (R&D) programmes. With regard to the management of disturbed peatlands in mining areas, a reference ecosystem is recommended to define restoration goals, determine the restoration potential of disturbed sites, and evaluate the success of restoration efforts (White & Walker 1997, SER 2004). There is an enormous need for a reference database of Peruvian Puna peatlands that, to encompass ecosystem variability, should be built from multiple types of data collected from a variety of reference sites (White & Walker 1997). All of these measures are crucial for the long term management of these fragile ecosystems in a future scenario of decreasing precipitation and increasing demands for water from the mining sector.

ACKNOWLEDGEMENTS

This research was supported by a grant from the Centre d'études Nordiques (CEN). The fieldwork was carried out in the Junin and Salinas y Aguada Blanca National Reserves and the Huaron mine, Peru, with the permission and logistical support of SERNANP and the Pan American Silver Corporation. Special thanks are due to Rosario Araoz, Arturo Cornejo and Wade Strogan who arranged the support that made the fieldwork possible, and to Asuncion Cano from the Museo de Historia Natural of Lima for general help. We also thank Eduardo Navarro for assistance with the fieldwork, and Claire Boismenu for invaluable help with editing of the manuscript.

REFERENCES

Anderson, E.P., Marengo, J., Villalba, R., Halloy, S., Young, B., Cordero, D., Gast, F., Jaimes, E. & Ruiz, D. (2011) Consequences of climate change for ecosystems and ecosystem services in the Tropical Andes. In: Herzog, S.K., Martínez, R., Jørgensen, P.M. & Tiessen, H. (eds.) *Climate Change and Biodiversity in the Tropical Andes*, Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE), São José dos Campos, Brazil, 1–18.

APHA (2005) *Standard Methods for the Examination of Water and Wastewater*. 21st edition, American Public Health Association (APHA), Washington DC, USA, 1268 pp.

ASTM (1993) Standard test methods for moisture, ash, and organic matter of peat and other organic soils. In: *Annual Book of ASTM Standards*, Vol. 04.08, Section 4, American Society for Testing Materials (ASTM), Philadelphia, Pennsylvania, USA, 400–402.

Baied, C. & Wheeler, J. (1993) Evolution of high Andean Puna ecosystems: environment, climate, and culture change over the last 12,000 years in the Central Andes. *Mountain Research and Development*, 13, 145–156.

Bedford, B.L. & Godwin, K.S. (2003) Fens of the United States: distribution, characteristics, and scientific connection versus legal isolation. *Wetlands*, 23, 608–629.

Blench, R. (2001) '*You Can't Go Home Again': Pastoralism in the New Millennium*. Overseas Development Institute, London, UK, 104 pp.

Brinson, M.M. (1993) *A Hydrogeomorphic Classification for Wetlands*. Wetlands Research Program Technical Report WRP-DE-4, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, USA, 102 pp.

Caro, C. (2010) *Extracción de Pastos por Actividad de "Champeo" en la Reserva Nacional de Junín Durante el Año 2004–2005. Una Perspectiva desde la Teoría de la Sucesión: Estudio de Caso en la Comunidad Campesina de Villa Junín* (*Removing Grazing by Activity "Champeo" in Junín National Reserve During the Year 2004–2005. A Perspective from the Theory of Succession: a Case Study in the Rural Community of Junín Village*). M.Sc. thesis, University of Agraria La Molina, Lima, Peru, 168 pp. (in Spanish).

Chimner, R.A., Cooper, D.J. & Parton, W.J. (2002) Modeling carbon accumulation in Rocky Mountain fens. *Wetlands*, 22, 100–110.

Chimner, R.A. & Karberg, J.M. (2008) Long-term carbon accumulation in two tropical mountain peatlands, Andes Mountains, Ecuador. *Mires and Peat*, 3(04), 1–10.

Chimner, R.A., Lemly, J.M. & Cooper, D.J. (2010) Mountain fen distribution, types and restoration priorities, San Juan Mountains, Colorado, USA. *Wetlands*, 30, 763–771.

Cleef, A.M. (1981) *The Vegetation of the Páramos of the Colombian Cordillera Oriental*. Dissertationes Botanicae Series, Volume 61, J. Cramer, Vaduz, Liechtenstein, 320 pp.

Cooper, D.J., Wolf, E.C., Colson, C., Vering, W., Granda, A. & Meyer, M. (2010) Alpine Peatlands of the Andes, Cajamarca, Peru. *Artic, Antarctic, and Alpine Research*, 42(1), 19–33.

Earle, L., Warner, B.G. & Aravena, R. (2003) Rapid development of an unusual peat accumulating ecosystem in the Chilean Altiplano. *Quaternary Research*, 59, 2–11.

Gutte, P. (1980) Beitrag zur Kenntnis zentralperuanischer Pflanzengesellschaften II. Die hochandinen Moore und ihre Kontaktgesellschaften (A contribution on the plant communities of Central Peru II. The High Andes peatlands and adjacent communities). *Feddes Repertorium*, 91(5–6), 327–336 (in German).

Heikkilä, H. & Lindholm, T. (1995) The effects of mire drainage and the initial phases of mire restoration on the vegetation in the Seitseminen National Park, western Finland. *Gunneria*, 70, 221–236.

Holmgren, C.A., Betancourt, J.L., Rylander, K.A., Roque, J., Tovar, O., Zeballos, H., Linares, E. & Quade, J. (2001) Holocene vegetation history from fossil rodent middens near Arequipa, Peru. *Quaternary Research*, 56, 242–251.

INEI (2005) Censo Nacional: X de Población y V de Vivienda (National Census: X Population and V Housing). Instituto Nacional de Estadística e Informática (INEI; National Institute of Statistics and Informatics), Lima, Peru. Online at: http://censos.inei.gob.pe/Censos2005/redatam/#, accessed 20 February 2014 (in Spanish).

INRENA (2007) *Plan Maestro de la Reserva Nacional de Salinas y Aguada Blanca 2006–2011* (*Master Plan 2006–2011 for Salinas y Aguada Blanca National Reserve*). Instituto Nacional de Recursos Naturales (INRENA; National Institute of Natural Resources), Lima, Peru, 222 pp. (in Spanish).

INRENA (2008) *Plan de Manejo Reserva Nacional de Junín 2008–2012* (*Management Plan for the Junín National Reserve 2008–2012*). Instituto Nacional de Recursos Naturales (INRENA; National Institute of Natural Resources), Lima, Peru, 271 pp. (in Spanish).

IPCC (2007) *Climate Change 2007: Synthesis Report.* Core Writing Team, Pachauri, R.K. & Reisinger, A. (eds.) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland, 104 pp.

Izurieta, X. (2007) Estrategia de humedales altoandinos (Andean wetlands strategy). In: Castro, M. & Fernández, L. (eds.) *Gestión Sostenible de Humedales* (*Sustainable Management of Wetlands*), Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (Latin American Science and Technology Development Program), University of Chile, Santiago, 173–183 (in Spanish).

Joosten, H. & Clarke, D. (2002) *Wise Use of Mires and Peatlands - Background and Principles Including a Framework for Decision-making*. International Mire Conservation Group and International Peat Society, Saarijärvi, Finland, 304 pp.

La Fuente, A., Velasco, A. & Alzérreca, H. (1988) Evaluación de la productividad de campos nativos de pastoreo en Ulla Ulla (Evaluation of the productivity of native pastures in Ulla Ulla). In: Alzérreca, H. (ed.) *Primera Reunión Nacional en Praderas Nativas de Bolivia, del 26 al 29 de Agosto de 1987, Oruro* (*First National Meeting on Native Grasslands of Bolivia, 26–29 August 1987, Oruro*), Programa de Autodesarrolo Campesino, Corporación Desarrollo de Oruro (PAC, CORDEOR; Programme for Peasant Self-development, Oruro Development Corporation), La Paz, Bolivia, 56–64 (in Spanish).

Lara, R. (2003) Factores de degradación en bofedales y vegas (Factors in degradation of bofedales and vegas). In: Rocha, O.O. & Sáez, C. (eds.) *Uso Pastoril en Humedales Altoandinos. Talleres de Capacitación para el Manejo Integrado de los Humedales Altoandinos de Argentina, Bolivia, Chile y Perú : Sitio Ramsar, Lago Titicaca (Sector Boliviano), Huarina, 28 de Octubre al 2 de Noviembre de 2002.* (*Pastoral Use of High Andean Wetlands. Training Workshops for Integrated Management of the High Andean Wetlands of Argentina, Bolivia, Chile and Peru : Ramsar Site Lake Titicaca (Bolivian Sector), Huriana, 28 October to 2 November 2002*), Convención Ramsar (Ramsar

Convention), WCS/Bolivia, La Paz, Bolivia, 77–80 (in Spanish).

León, B. (1993) Catálogo anotado de las fanerógamas acuáticas del Perú (Annotated catalogue of the aquatic flowering plants of Peru). In: Kahn, F., León, B. & Young, K.R. (eds.) *Las Plantas Vasculares en las Aguas Continentales del Perú* (*Vascular Plants of the Inland Waters of Peru*). Instituto Francés de Estudios Andinos (IFEA; French Institute of Andean Studies), ORSTOM, Lima, Peru, 11–128 (in Spanish).

Maldonado, M., Maldonado-Ocampo, J.A., Ortega, H., Encalada, A.C., Carvajal-Vallejos, F.M., Rivadeneira, J.F., Acosta, F., Jacobsen, D., Crespo, A. & Rivera-Rondón, C.A. (2011) Biodiversity in aquatic systems of the Tropical Andes. In: Herzog, S.K., Martínez, R., Jørgensen, P.M. & Tiessen, H. (eds.) *Climate Change and Biodiversity in the Tropical Andes*, Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE), São José dos Campos, Brazil, 276–294.

Martínez R., Ruiz D., Andrade M., Blacutt L., Pabón D., Jaimes E., León G., Villacís M., Quintana J., Montealegre E., & Euscátegui C. (2011) Synthesis of the Climate of the Tropical Andes. In: Herzog, S.K., Martínez, R., Jørgensen, P.M. & Tiessen, H. (eds.) *Climate Change and Biodiversity in the Tropical Andes*. Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE), São José dos Campos, Brazil, 276–294.

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis.* Island Press, Washington, DC, USA, 155 pp.

Morlon, P., Orlove, B. & Hibon, A. (1982) *Tecnologías Agrícolas Tradicionales en los Andes Centrales: Perspectivas para el Desarrollo* (*Traditional Agricultural Technology in the Central Andes: Prospects for Development*). UNESCO and Corporación Financiera de Desarroll (Financial Corporation of Development), Lima, Peru, 104 pp. (in Spanish).

Mueller-Dombois, D. & Ellenberg, H. (1974) *Aims and Methods of Vegetation Ecology*. Wiley, New York, 547 pp.

Navarro, G. & Maldonado, M. (2002) *Geografía Ecológica de Bolivia: Vegetación y Ambientes Acuáticos* (*Ecological Geography of Bolivia: Vegetation and Aquatic Environments*). Cochabamba, Bolivia, 719 pp. (in Spanish).

Olivares, A. (1988) Experiencias de investigaciones en pradera nativa en un ecosistema frágil (Review of research on a native grassland in a fragile ecosystem). In: *Primera Reunión Nacional en Praderas Nativas de Bolivia* (*First National Meeting on the Native Grasslands of Bolivia*), Programa de Autodesarrolo Campesino, Corporación Desarrollo de Oruro (PAC, CORDEOR; Programme for Peasant Self-development, Oruro Development Corporation), Oruro, Bolivia, 265–291 (in Spanish).

Poulin, M., Rochefort, L. & Desrochers, A. (1999) Conservation of bog plant species assemblages: Assessing the role of natural remnants in mined sites. *Applied Vegetation Science*, 2, 169–180.

Prieto, G., Alzérreca, H., Laura, J., Luna, D. & Laguna, S. (2003) Características y distribución de los bofedales en el ámbito boliviano del sistema T.D.P.S. (Characteristics and distribution of bofedales in the Bolivian context of the T.D.P.S. system). In: Rocha, O. & Sáez, C. (eds.) *Uso Pastoril en Humedales Altoandinos. Talleres de Capacitación para el Manejo Integrado de los Humedales Altoandinos de Argentina, Bolivia, Chile y Perú : Sitio Ramsar, Lago Titicaca (Sector Boliviano), Huarina, 28 de Octubre al 2 de Noviembre de 2002.* (*Pastoral Use of High Andean Wetlands. Training Workshops for Integrated Management of the High Andean Wetlands of Argentina, Bolivia, Chile and Peru : Ramsar Site Lake Titicaca (Bolivian Sector), Huriana, 28 October to 2 November 2002*), Convención Ramsar (Ramsar Convention), WCS/Bolivia, La Paz, Bolivia, 13–40 (in Spanish).

Renaudeau d'Arc, N., Cassini, M.H. & Vilá, B.L. (2000) Habitat use by vicuñas *Vicugna vicugna* in the Laguna Blanca Reserve (Catamarca, Argentina). *Journal of Arid Environments*, 46, 107–115.

Ruthsatz, B. (2012) Vegetación y ecología de los bofedales altoandinos de Bolivia (Vegetation and ecology of the high Andean peatlands of Bolivia). *Phytocoenologia*, 42(3–4), 133–179 (in Spanish).

Rydin, H. & Jeglum, J.K. (2006) *The Biology of Peatlands*. Oxford University Press, Oxford, United Kingdom, 354 pp.

Salvador, F. (2008) *Paisaje Vegetal de los Humedales de una Cuenca Altoandina: Subcuenca del Rio Lauricocha, Huánuco, Andes Centrales, Perú* (*The Wetland Plant Landscape of a High Andean Catchment: Lauricocha River Basin, Huánuco, Central Andes, Peru*). Doctoral thesis, University of Alicante, 522 pp. (in Spanish).

Salvador, F., Alonso, M.A. & Ríos, S. (2006)

Adiciones a la flora andina peruana del departamento de Huánuco I, Perú (Additions to the Peruvian Andean flora of the Department of Huánuco I, Peru). *Candollea*, 96(2), 279–291 (in Spanish).

Salvador, F., Alonso, M.A. & Ríos, S. (2009) Tres nuevos registros del genero *Carex* (*Cyperaceae*) para el Perú y adiciones a la flora andina del departamento de Huánuco (Three new records of the genus *Carex* (*Cyperaceae*) for Peru and additions to the flora of the Andean Department of Huánuco). *Revista Peruana de Biología*, 15(2), 83–92 (in Spanish).

Salvador, F. & Cano, A. (2002) *Lagunas y Oconales: los Humedales del Trópico Andino* (*Lakes and Oconales: the Wetlands of the Tropical Andes*). Cuadernos de Biodiversidad 11, Centro Iberoamericano de la Biodiversidad (CIBIO) (Books of Biodiversity 11, Latin American Centre for Biodiversity (CIBIO)), University of Alicante, Alicante, Spain, 4–9 (in Spanish).

Salvador, F., Monerris, J. & Rochefort, L. (2010) Peruvian peatlands (bofedales): from Andean traditional management to modern environmental impacts. *Peatlands International*, 2010/2, 42–48.

Segnini, A., Posadas, A., Quiroz, R., Milori, D.M.B.P, Saab, S.C., Martin Neto, L. & Vaz, C.M.P. (2010) Spectroscopic assessment of soil organic matter in wetlands from the High Andes. *Soil Science Society of America Journal*, 74, 2246–2253.

SER (2004) *The SER International Primer on Ecological Restoration*. Version 2, Society for Ecological Restoration (SER) International Science and Policy Working Group. Online at: http://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration, accessed 20 February 2014.

Sierra, R. (2006) A transnational perspective on national protected areas and ecoregions in the tropical Andean countries. In: Zimmerer, K.S. (ed.) *Globalization and New Geographies of Conservation*, University of Chicago Press, Chicago, 212–228.

Soruco, A., Vincent, C., Francou, B. & Gonzalez, J.F. (2009) Glacier decline between 1963 and 2006 in the Cordillera Real, Bolivia. *Geophysical Research Letters*, 36, L03502, doi: 10.1029/2008GL036238, 1–6.

Sotomayor, M., Canahua, F. & Vargas, B. (1990) V*alidación de Cercados y Mejoramiento de Bofedales en Puna Seca - (Ahijaderos). Avances.* (*Validation and Improvement of Wetlands Surrounded by Dry Puna - (Ahijaderos). Progress*). Serie Pastos: Informe Técnico - Proyecto Alpacas (Peru), No. 34, Puno (Peru) (Grazing Series: Technical Report - Alpacas Project (Peru), No. 34, Puno (Peru), 28 pp. (in Spanish).

Squeo, F.A., Warner, B.G., Aravena, R. & Espinosa, D. (2006) Bofedales: High altitude peatlands of the central Andes. *Revista Chilena de Historia Natural*, 79, 245–255.

Strack, M., Waddington, J.M., Turetsky, M., Roulet, N.T. & Byrne, K.A. (2008) Northern peatlands, greenhouse gas exchange and climate change. In: Strack, M. (ed.) *Peatlands and Climate Change*, International Peat Society, Jyväskylä, Finland, 44–69.

Thomas, R. & Winterhalder, B.P. (1976) Physiological and biotic environment of southern highland Peru. In: Baker, P.T. & and Little, M.A. (eds.) *Man in the Andes: a Multidisciplinary Study of High Altitude Quechua*. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania, USA, 482 pp.

Tosi, J.A. (1960) *Zonas de Vida Natural en el Perú* (*The Natural Areas of Peru*). Technical Bulletin No. 5, Instituto Interamericano de Ciencias Agrícolas, Zona Andina (Inter-American Institute of Agricultural Sciences, Andes area, Lima, Peru, 271 pp. (in Spanish).

Troll, C. (1968) The cordilleras of the tropical Americas. In: Troll, C. (ed.) *Geo-ecology of the Mountainous Regions of the Tropical Andes*. Colloquium Geographicum 9, Geographisches Institut der Universität Bonn, Germany, 15–55.

Troncoso, R. (1982) *Caracterización Ambiental de Ecosistema Bofedal de Parinacota y su Relación con la Vegetación* (*Environmental Characterisation of the Parinacota Wetland Ecosystem and its Relationship to Vegetation*). Thesis in Agricultural Engineering, University of Chile, Santiago, Chile, 252 pp. (in Spanish).

Villagrán, C. & Castro, V. (1997) Etnobotánica y manejo ganadero de las vegas, bofedales y quebradas en el Loa superior, Andes de Antofagasta, Segunda Región, Chile (Ethnobotany and livestock management of vegas, wetlands and streams in the Upper Loa, Andes of Antofagasta, II Region, Chile). *Chungará*, 29, 275–304.

Vitt, D.H. (2006) Functional characteristics and indicators of boreal peatlands. In: Wieder, R.K. & Vitt, D.H. (eds.) *Boreal Peatland Ecosystems*. Ecological Studies 188, Springer-Verlag, Berlin, Germany, 9–24.

Vitt, D.H. & Chee, W.L. (1990) The relationships of vegetation to surface-water chemistry and peat chemistry in fens of Alberta, Canada. *Vegetation*, 89, 87–106.

Vuille, M. & Bradley, R. (2000) Mean annual temperature trends and their vertical structure in the tropical Andes. *Geophysical Research Letters*, 27, 3885–3888.

Weberbauer, A. (1945) *El Mundo Vegetal de los Andes Peruanos* (*The Plant World of the Peruvian Andes*). Ministerio de Agricultura (Department of Agriculture), Lima, Peru, 776 pp. (in Spanish).

Wheeler, B.D. & Shaw, S.C. (1995) *Restoration of Damaged Peatlands*. HMSO, London, 211 pp.

White, P.S. & Walker, J.L. (1997) Approximating nature's variation: selecting and using reference sites and reference information in restoration ecology. *Restoration Ecology*, 5, 338–349.

Young, K.R., Leon B., Cano A. & Herrera-MacBryde O. (1997) Peruvian Puna Peru. In: Davis, S.D., Heywood, V.H., Herrera-MacBryde, O., Villa-Lobos, J. & Hamilton, A.C. (eds.) *Centres of Plant Diversity: A Guide and Strategy for their Conservation, Volume 3, The Americas*, IUCN, WWF, Oxford, UK, 470–476.

Young, B.C., Young, K.R. & Josse, C. (2011) Vulnerability of Tropical Andean Ecosystems to Climate Change. In: Herzog, S.K., Martínez, R., Jørgensen, P.M. & Tiessen, H. (eds.) *Climate Change and Biodiversity in the Tropical Andes*, Inter-American Institute for Global Change Research (IAI) and Scientific Committee on Problems of the Environment (SCOPE), São José dos Campos, Brazil, 170–181.

Submitted 22 Jly 2013, revision 13 Feb 2014
Editor: Olivia Bragg

Author for correspondence:
Dr Line Rochefort, Département de phytologie and Centre d'études nordiques, Université Laval, 2425 rue de l'Agriculture, Québec, G1V 0A6, Canada.
Tel: 1-418-656-2131 ext. 2583; Fax: 1-418-656-7856; Email: Line.Rochefort@fsaa.ulaval.ca

Appendix 1. List of plant taxa found in stands of Peruvian Puna peatlands. The geographical range of each taxon is also shown.

Group	Family	Species	Distribution
Vascular plant taxa			
	APIACEAE	*Lilaeopsis macloviana* (Gand.) A.W. Hill	Andes: Colombia to Argentina
		Oreomyrrhis andicola (Kunth) Endl. ex Hook. f.	Andes: Colombia to Argentina
	ASTERACEAE	*Cotula mexicana* (DC.) Cabrera	Central America and Andes (Ecuador to Argentina)
		Cuatrecasasiella isernii (Cuatrec.) H. Rob.	Andes: Ecuador and Peru
		Hypochaeris taraxacoides (Meyen & Walp.) Ball	Andes: Ecuador to Argentina
		Lucilia kunthiana (DC.) Zardini	Andes: Ecuador, Peru and Bolivia
		Oritrophium limnophyllum (Sch. Bip.) Cuatrec.	Andes: Venezuela to Bolivia
		Senecio spp.	
		Werneria nubigena Kunth	Central America and Andes (Ecuador to Bolivia)
		Werneria pygmaea Gillies ex Hook.& Arn.	Andes: Venezuela to Argentina
	CAMPANULACEAE	*Hypsela reniformis* (Kunth) C. Presl	Andes: Ecuador to Argentina
	CYPERACEAE	*Carex humahuacahensis* G. A. Wheeler	Andes: Peru and Argentina
		Carex (spp.)	
		Eleocharis albibracteata Nees & Meyen ex Kunth	Andes: Ecuador to Argentina
		Phylloscirpus acaulis (Phil.) Dhooge & Goetgh. subsp. pachycaulis Dhooge & Goetgh.	Andes: Ecuador and Peru
		Phylloscirpus boliviensis (Barros) Dhooge & Goetgh.	Andes: Colombia to Bolivia
		Phylloscirpus deserticola (Phil.) Dhooge & Goetgh.	Andes: Ecuador to Argentina
		Zameioscirpus muticus Dhooge & Goetgh.	Andes: Peru to Argentina
	ELATINACEAE	*Elatine peruviana Baehni & J. F. Macbr.*	Andes: Peru and Bolivia
	ERICACEAE	*Pernettya prostrata* (Cav.) DC.	Central America, S. South America and Andes
	FABACEAE	*Trifolium amabile* Kunth	Central America and Andes (Ecuador to Argentina)
	GENTIANACEAE	*Gentiana sedifolia* Kunth	Central America and Andes (Venezuela to Argentina)
		Gentianella sp.	
		Halenia umbellata (Ruiz & Pav.) Gilg	Andes: Ecuador, Peru and Bolivia
	ISOETACEAE	*Isoëtes andicola* (Amstutz) L.D. Gómez	Andes: Peru and Bolivia
	JUNCACEAE	*Distichia muscoides* Nees & Meyen	Andes: Colombia to Argentina
		Oxychloe andina	Andes: Peru to Argentina
		Juncus ebracteatus E. Mey.	Central America and Andes (Peru and Bolivia)
		Juncus sp.	
		Luzula vulcanica Liebm.	Andes: Venezuela to Peru
	JUNCAGINACEAE	*Lilaea scilloides* (Poir.) Hauman	America
	ORCHIDACEAE	*Myrosmodes paludosa* (Rchb. f.) C. Vargas (species complex, under discussion)	Andes: Venezuela to Bolivia
	OROBANCHACEAE	*Bartsia patens* Benth.	Andes: Ecuador, Peru and Bolivia
		Bartsia pedicularoides Benth.	Andes: Venezuela to Bolivia
		Castilleja pumila (Benth.) Wedd.	Andes: Colombia to Argentina
	PHRYMACEAE	*Mimulus glabratus* Kunth	America
	PLANTAGINACEAE	*Ourisia muscosa* Benth.	Andes: Ecuador to Argentina
		Plantago rigida Kunth	Andes: Venezuela to Bolivia
		Plantago tubulosa Decne.	Central America and Andes (Ecuador to Argentina)
	POACEAE	*Aciachne acicularis* Lægaard	Andes: Venezuela to Bolivia
		Aciachne pulvinata Benth.	Andes: Venezuela to Bolivia
		Agrostis breviculmis Hitchc.	Andes: Venezuela to Argentina
		Agrostis gelida Trin.	Andes: Ecuador, Bolivia and Peru
		Calamagrostis chrysantha (J. Presl) Steud.	Andes: Peru to Argentina
		Calamagrostis curvula (Wedd.) Pilg.	Andes: Peru to Argentina
		Calamagrostis jamesonii Steud.	Andes: Venezuela to Bolivia
		Calamagrostis rigescens (J. S. Presl) Scribn.	Andes: Central America and Andes (Ecuador to Argentina)
		Festuca sp.	
		Muhlenbergia ligularis (Hack.) Hitchc.	Central America and Andes (Venezuela to Argentina)
	POLYGONACEAE	*Muehlenbeckia volcanica* (Benth.) Endl.	Central America and South America (Brasil and Andes from Colombia to Bolivia)
	POTAMOGETONACEAE	*Potamogeton filiformis* Pers.	America and Asia
	RANUNCULACEAE	*Ranunculus limoselloides* Turcz.	Andes: Colombia to Bolivia
	ROSACEAE	*Alchemilla diplophylla* Diels	Andes: Peru to Argentina
		Alchemilla orbiculata Kunth	Central America and Andes (Colombia to Bolivia)
		Alchemilla pinnata Ruiz & Pav.	Central America and Andes (Ecuador to Argentina)
	SCROPHULARIACEAE	*Limosella subulata E. Ives*	North America and Andes (Venezuela, Ecuador, Peru and Bolivia)
Bryophytes taxa	AMBLYSTEGIACEAE	*Cratoneuron* sp.	
		Amblystegiaceae (spp.)	
	DICRANACEAE	*Campylopus heterostachys* (Hampe) A. Jaeger	Central America and South America
		Dicranaceae (spp.)	
	FISSIDENTACEAE	*Fissidens rigidulus* Hook. f. & Wilson	S. Australia/New Zealand, Central America, Brasil and Andes
	POTTIACEAE	*Leptodontium* sp.	
	MARCHANTIACEAE	*Marchantia* sp.	
	BRYACEAE	*Bryum argenteum* Hedw.	Cosmopolitan
		Anomobryum sp.	
Algae taxa	NOSTOCACEAE	*Nostoc* sp.	

Appendix 2. The peatland survey form used in this study.

PEATLAND SURVEY FORM	***Program for management and conservation of peatlands of the High Andes of Peru***		
GENERAL INFORMATION			**Updated: March 2010**
Wetland name:			
Peatland name:		**Date:**	
Location:		**Surveyors:**	
District:		**Peatland?:**	
Province:		**Size of Peatland:**	
Department:		**Surveyed Area Size:**	
Elevation (m):		**GPS Coordinates:** E	N **UTM Zone:**
Ownership:			

Peatland Overview Pictures

Photo Number	**View***	**Description:**

***View: landscape viewed from N/S/E/W, etc.**

CHARACTERISTICS OF THE WHOLE AREA

Peatland land form:		**Slope:**	**Orientation:**
Basin			
Slope			
Flat			
Other: specify			
Channels through site: Y/N			
Ponds in site: Y/N			

Vegetation type:	Main species composition
Cushion plants	
Forb plants	
Sedges	
Grass	
Floating mats	
Bulrush	
Bryophyte	
Aquatic plants	
Other -specify:	
Amphibian observed:	
Camelids observed (or faeces):	
Other observed fauna	

Components	**DISTURBANCES/CONDITIONS**				
	Disturbances	**Source (if known)**	**Altered area (%)**	**Severity**	**Specific comments (stand #)**
HYDROLOGIC					
VEGETATION					
SOILS					
Overall Impact Remarks:					

Disturbances: 1 grazing (specify type of livestock, camelids, ovines, cows, pigs, other; presence of cliping plants), 2 tracks, 3 trails, 4 roads (constructed), 5 ditches, 6 de-watering, 7 flooding, 8 drainage from above, 9 exotic plants 10 soil removal (peat mining), 11 erosion, 12 deposition (sedimentation), 13 power lines, 14 ground disturbances (general), 15 others (describe)

Severity: none (0),<1% of the peatland (1), 1–5% (2), 5–15% (3), >15% (4)

Peatland Impact Pictures

Photo number	**Stand #**	**Description**