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Desert pavements as indicators of soil erosion on aridic soils in north-east Patagonia (Argentina)

César M. Rostagno [a,*], Gabriela Degorgue [b]

[a] Unidad de Investigación Ecología Terrestre, CENPAT — CONICET, Boulevard Brown 2825, (CP 9120) Puerto Madryn, Chubut, Argentina
[b] Instituto de Cooperación Económica Internacional (ICEI), Viamonte 2795, Segundo Piso, Ciudad Autónoma de Buenos Aires, Argentina

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ABSTRACT

Desert pavements are prominent features of many geomorphic surfaces in arid and semiarid lands. In the semiarid soils of north-eastern Patagonia, gravel cover in the shrub interspace areas of shrub-dominated communities is generally high, and contrast with that of grass-dominated patches where gravel cover is either absent or negligible. In the present study we analyze the relationship between soil erosion and desert pavement formation, in three sites, the upper, middle and lower slope positions of a flank pediment where well-conserved soils served as reference areas. We used the gravel cover and mass, as well as the thickness of the remnant A horizon, as determined by the depth of the Bt horizon of a Xeric Calciargid, as measures of soil erosion. Surface gravel at four cardinal points in respect to mounds associated with shrub-clumps was collected and the depth to the Bt horizon was determined. The mean thickness of the A horizon in the well-conserved soils were 11.3, 10.0 and 13.5 cm for the upper, middle and lower slope positions, respectively. For the same positions, the mean coarse fragment contents (>2.0 mm) in the 0–10 cm depth of the A horizon in the well-conserved soils were 144, 92 and 119 g kg^{-1}, and the mean surface gravel mass in the eroded patches were 5.3, 3.1 and 4.7 kg m^{-2}. Surface gravel mass and depth of the remnant A horizon gave different estimates of the magnitude of soil erosion in the flank pediment. Thus, the mean/maximum soil loss, as determined by the mean gravel mass on the soil surface for the upper, middle and lower slope positions were, 28.3/68.2, 27.0/63.8 and 31.5/56.4 mm, respectively. These figures increased to a mean of 50.0, 52.5 and 82.0 mm for the same positions when soil loss was determined as the difference between the thickness of the A horizon of the well-conserved soil and that of the remaining A horizon in eroded patches. The loss of the A horizon by wind and water erosion seems to initiate the change from grass steppe to a stable shrub steppe characterized, in the shrub interspaces, by well-developed desert pavements. The strong correlation between surface gravel mass and the thickness of the remaining A horizon indicates that accelerated soil erosion has played an important role in the formation of desert pavements, and that desert pavements are good indicators of the extent and intensity of the erosion process in the Punta Ninfas area.

1. Introduction

Soil erosion is one of the most important environmental problems in the world and may irreversibly affect soil productivity. In arid and semiarid regions, soil erosion may have a high impact on soil quality, as soils are generally shallow. In these regions soil erosion has been considered to be a significant component of desertification processes (Schlesinger et al., 1990; Ravi et al., 2010). Erosion is, however, often difficult and sometimes very expensive to measure. Therefore, the use of soil erosion indicators can be an alternative tool to assess the extent of accelerated erosion and the basis to evaluate the impact of this process on soil quality and ecosystem health (Lal et al., 1999).

Desert pavements (the continuous soil cover of rounded or angular stones) are prominent features of many geomorphic surfaces in arid lands. The cover and size of the coarse fragments may affect the dynamics of various hydrological and soil degradation processes (Poesen et al., 1998; Cerda, 2001). Desert pavements have been described in soils of different landscapes (Cooke et al., 1993), although no single set of processes seem to be uniquely responsible for their formation. Cooke et al. (1993) described three groups of particle-concentration processes: 1) wind erosion, 2) surface runoff removal of fines, and 3) shrink-swell process of soils causing upward migration of coarse particles. In shrub dominated communities, rainsplash erosion can contribute to desert pavement formation (Parsons et al., 1992), although Wainwright et al. (1995) considered that raindrop erosion on its own cannot account for the development of pavements suggesting that other mechanisms leading to the surface concentration of coarse particles must also operate. Another upward transport process that can favor the concentration of coarse fragments on the soil surface is the excavating activity of fossorail fauna (organisms adapted for digging), mainly rodents (Johnson et al., 1987).

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* Corresponding author.
E-mail address: Rostagno@cenpat.edu.ar (C.M. Rostagno).

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An alternative explanation for the presence of coarse fragments on the soil surface suggests desert pavements are born at the land surface. This model of desert pavement formation considers clasts rise vertically on an accreting eolian mantle and the underlying vesicular horizon coevolves with pavement formation (McFadden et al., 1987; Anderson et al., 2002). Under this model of desert pavement formation, continued eolian accumulation and pedogenesis leads to cumulic soil development below accretionary desert pavements.

According to Dregne (1976), desert pavements are typically found in areas where plant cover is sparse and there is little impediment to wind and water erosion. They are also prominent in regions where erosion has been accelerated, as is the case of overgrazed rangelands in the west and south-west USA (Simanton et al., 1984), where some grasslands were transformed into shrublands. In some of these shrublands the A horizon between the shrubs has been eroded, leaving swales mantled by a gravel lag which forms a desert pavement (Abrahams et al., 1995).

In Patagonia, previous studies have suggested that desert pavement could indicate the extent to which wind and water erosion have removed fine particles (Castro, 1983; Rostagno and del Valle, 1988; Bouza and del Valle, 1997). However, none of these studies have attempted to establish the magnitude of the erosion process using the coarse particle concentration on the soil surface. In a recent study, Chartier et al. (2009) described incipient desert pavements associated with eroded patches where the presence of shrubs with exposed roots indicates the extent and intensity of the erosion process.

In soils containing rock fragments, desert pavement has been proposed as a visual criterion to identify areas affected either by water or wind erosion (FAO, 1979). Land degradation indicators may help to objectively assess the extent and rate of soil erosion problems in arid and semi-arid Patagonia, where almost 34% of land has been classified as severely desertified (del Valle et al., 1998), indicating that soil and vegetation have been severely degraded.

In this study we explore the relationship between soil erosion and desert pavement formation in an area where well conserved soils serve as reference areas. Specifically, the objective of this research was to determine the relationship between the surface gravel cover and mass and the thickness of the eroded layer in three topographic positions along a flank pediment in the semi-arid rangelands of NE Patagonia. The strong contrast between the A and Bt horizons allowed us to determine the thickness of the A horizon in well conserved and eroded patches, and indirectly, the eroded layer. We hypothesized that surface gravel cover or mass (desert pavement development) should increase as the thickness of the A horizon, a measure of soil erosion, decreases.

2. Materials and methods

2.1. Study area

The study was carried out in the Punta Ninfas area, 60 km east of Puerto Madryn City in an area centered at 42°59′33″S, 64°36′W, in the north-east of Patagonia, Argentina (Fig. 1). The study site is part of the 'Loma María' land system, mainly represented by an extensive pediment-like plateau with small closed basins. Beeskow et al. (1987) described the pediment-like plateau as erosional surfaces of low relief that locally are called 'mesetas' or plateau. Flank pediments (as described by Fidalgo and Riggi, 1970) are short slope transport surfaces, covered by a veneer of alluvium and generally developed between a plateau covered by a gravel mantle and a lower zone with a base level controlled by a playa lake.

The climate of the region is arid, temperate and windy. The mean annual precipitation (1995–2004) is 258 mm (Chartier and Rostagno, 2006) and the mean annual temperature is 12.5 °C (Barros, 1983). Most rains fall during the cold season, between April and October, although heavy rainfall events are more common during the warm season. Droughts are common in this area and can extend for several months with no rainfall or over consecutive years with below average rainfall. The highest mean wind velocity (~6 m s^{-1}) occurs during summer, when SW winds are dominant (data from the weather station located in Puerto Madryn, 50 km west of the study area) (CENPAT, 2005).

The study sites are located in a flank pediment, with a general slope of 2–3%, an SN aspect and an elevation between 75 and 85 m.a.s.l. (Fig. 1). The flank pediment gives way upslope to a short and convex slope that connects it to the regional pediment-like plateau and downslope, to several interconnected playa lakes. In the plateau, the Patagonian Gravel Formation (PGF; Haller, 1981) lies <1 m below the soil surface. The PGF is the source of the coarse fragments present in the soils. Coarse fragments are predominantly rounded to subrounded gravel (<76 mm) (Miller and Guthrie, 1984). In the flank pediment, a gravelly sandy alluvium 50–100 cm thick covers the Tertiary sediments and forms the soil parent material. The dominant soil was classified as a Xeric Calciargid. This soil is moderately deep with a loamy sand and weakly structured A horizon 10–20 cm, with variable gravel content, a sandy loam Bt horizon (10–15 cm thick) and a calcic, Btk and Bk, horizon 20–25 cm thick, with moderate to low permeability (Fig. 2). Classification of soils was according to the Soil Survey Staff (1999).

The dominant vegetation of the study area corresponds to a shrub or a shrub-grass steppe dominated by *Chuquiraga avellanedae* Lorentz, with patches of either grass or grass with scattered shrub steppes dominated by *Jarava tenuis* (Phil.) Barkworth. In the degraded patches, most shrubs of *C. avellanedae* are associated with small mounds, 10–20 cm high, and are distributed in a matrix of desert pavement. In the conserved patches, shrubs are distributed in a matrix of grasses. Sheep grazing for wool production is the main use of these rangelands, where continuous grazing has been extensively practiced for over 100 years at moderate to heavy intensity (0.3 sheep ha^{-1}) in paddocks commonly exceeding 2500 ha in size (Beeskow et al., 1995).

2.2. Sampling and analysis

In January 2005 we selected three study sites along the flank pediment, in the upper, middle and lower positions. The distance between the upper and lower sites was 500 m. In each site we randomly selected five clumps of *C. avellanedae* associated with mounds. We laid a 25 × 25-cm quadrat in each one of the four cardinal points of the selected plants, adjacent to the base of the mounds. In each of these quadrats gravel cover was estimated visually. For gravel mass determination, we collected all surface gravels (fraction > 2.0 mm) that laid either on the soil surface or were embedded in the soil by <50% of their volume. Gravels >5 mm were hand-harvested; the smaller ones were collected by means of a paintbrush and a spatula and passed through a 2.0-mm mesh. The A horizon thickness was determined as the depth to the Bt horizon in the center of each quadrat. We repeated this procedure along a transect between two contiguous shrub-mounds patches in each slope position. We also collected the 20 largest gravels in each site in a 50-m^2 quadrat (50 × 1 m). In each study site, soil samples (n = 5) from well conserved areas close to *C. avellanedae* plants were collected from the 0–10-cm soil depth with an 8.5-cm diameter auger. In one well conserved area per site, a 50-cm depth pit was opened for profile description and sampling. Samples were collected from each genetic horizon. Soil samples were sieved through a 2.0-mm mesh to separate coarse fragments.

2.3. Soil erosion assessment

Soil erosion was estimated considering the surface gravel mass and the thickness of the remnant A horizon (depth to Bt horizon).

1) Surface gravel mass. Once we obtained the mean gravel content (fragments > 2.0 mm) in the well conserved soil, we determined the gravel mass per unit area of land (i.e. kg m^{-2}) produced by the removal of a unit depth of soil (fractions < 2.0 mm). Then, soil erosion was estimated as the ratio between the surface gravel mass and the mean gravel mass present in a unit depth of the well conserved soil for the same position. The mean bulk density of the

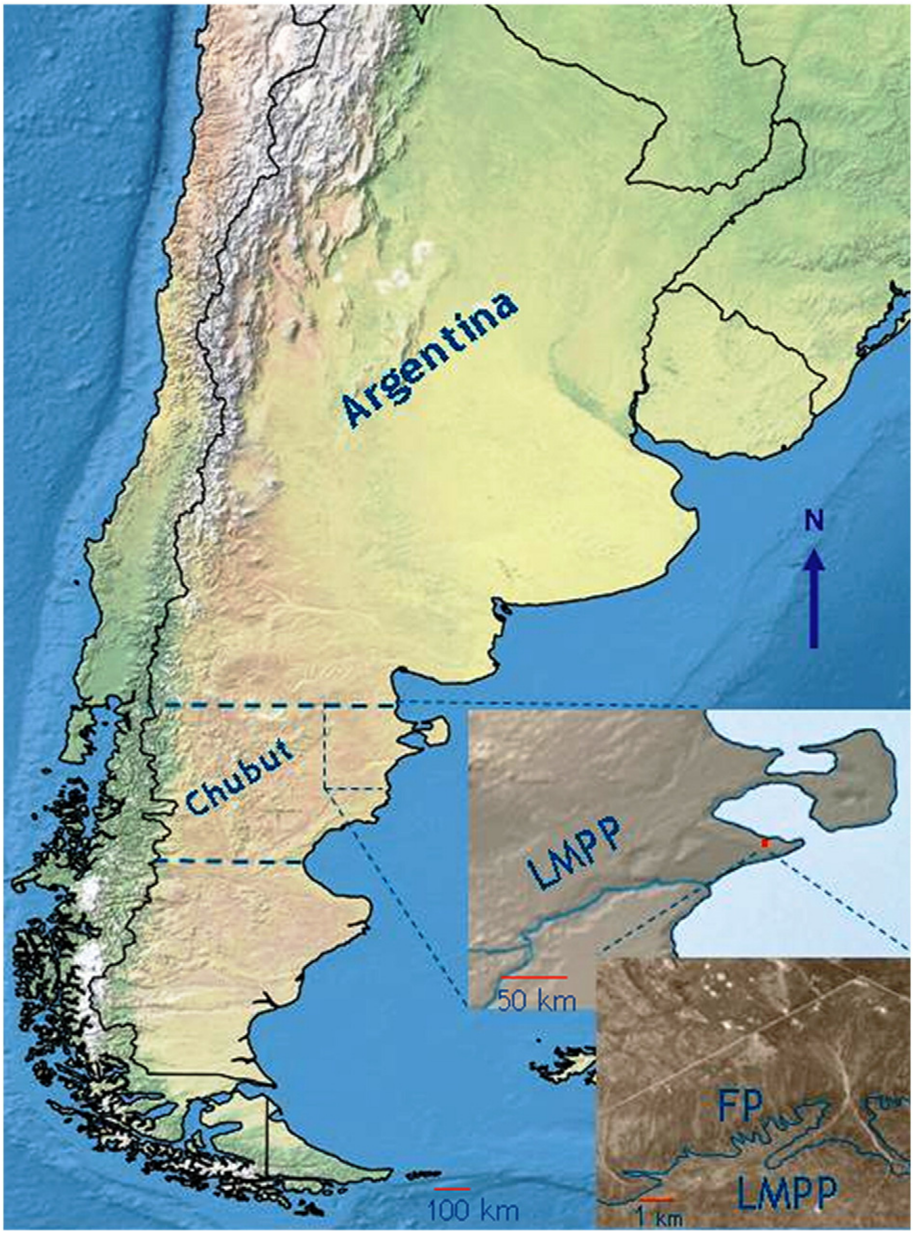


Fig. 1. Study area in the northeastern of the Chubut province, Argentina. LMPP: Loma María pediment plateau; FP: flank pediment.

A horizon was 1.30, 1.25 and 1.26 Mg m^{-3} for the upper, middle and low slope positions, respectively.

2) Thickness of the remnant A horizon. Soil erosion was determined as the difference between mean thickness of the A horizon of the well conserved soil and that of the remnant A horizon of the eroded soil as measured in each quadrat.

Regression analysis was used to examine the relationship between gravel cover and mass, and that between gravel mass and the depth to the Bt horizon (the A horizon thickness).

3. Results

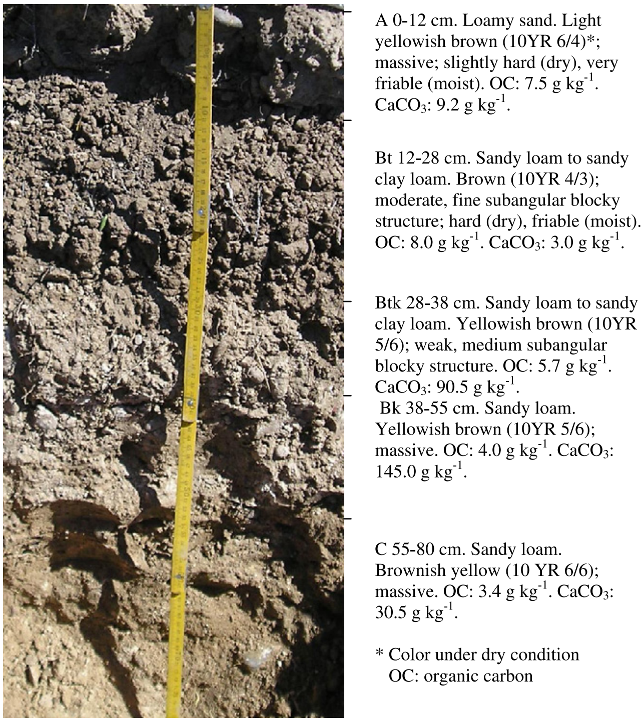
3.1. Gravel content in the well-conserved soils

Well-conserved soils at the three slope positions presented a similar profile development, with little differences in the thickness of genetic horizons. The gravel content throughout the soil profile decreased from between 10 and 15% in the A horizon to <5% in the Bt, Btk, and Bk horizons of the three study sites (Fig. 3).

The mean/standard deviation of the A horizon thickness in the well-conserved soils, adjacent to the eroded patches where gravel cover and thickness of the remaining A horizon were assessed, were 11.3/2.4, 10.0/2.1 and 13.5/5.0 cm for the upper, middle and lower slope positions. The concentration of gravels in the A horizon of the well-conserved soils varied between 4.5 and 25.3%, with a mean/standard deviation of 14.4/1.7%, 9.2/7.2%, and 11.9/1.8% for the upper, middle and lower slope positions, respectively. These contents were equivalent to 1.87, 1.15 and 1.5 kg m^{-2} cm^{-1}, respectively. In the A horizon, the size of the gravels, taken as its longer diameter, varied from ≤1 cm to ≤6 cm. In the Bt horizon they were smaller, with the major diameter of the largest gravels <3 cm.

3.2. Surface gravel characteristics and distribution

The largest gravels laying on the soil surface had major diameters between 3.3 and 15 cm (Fig. 4). Their median size decreased from



A 0-12 cm. Loamy sand. Light yellowish brown (10YR 6/4)*; massive; slightly hard (dry), very friable (moist). OC: 7.5 g kg^{-1}. $CaCO_3$: 9.2 g kg^{-1}.

Bt 12-28 cm. Sandy loam to sandy clay loam. Brown (10YR 4/3); moderate, fine subangular blocky structure; hard (dry), friable (moist). OC: 8.0 g kg^{-1}. $CaCO_3$: 3.0 g kg^{-1}.

Btk 28-38 cm. Sandy loam to sandy clay loam. Yellowish brown (10YR 5/6); weak, medium subangular blocky structure. OC: 5.7 g kg^{-1}. $CaCO_3$: 90.5 g kg^{-1}.

Bk 38-55 cm. Sandy loam. Yellowish brown (10YR 5/6); massive. OC: 4.0 g kg^{-1}. $CaCO_3$: 145.0 g kg^{-1}.

C 55-80 cm. Sandy loam. Brownish yellow (10 YR 6/6); massive. OC: 3.4 g kg^{-1}. $CaCO_3$: 30.5 g kg^{-1}.

* Color under dry condition
OC: organic carbon

Fig. 2. Main morphological characteristics and selected properties of the studied soil.

7 cm in the upper position to 6 cm and 5 cm for the middle and lower slope positions, respectively. The mean gravel cover and mass on the soil surface were 32.2%, 20.6% and 41.1% and 5.30, 3.10 and 4.72 kg m^{-2} for the upper, middle and lower slope positions, respectively. There was a close correlation between the gravel cover and mass, with the gravel cover accounting for 70% of the mass variation in the upper position, and 80% in the middle and lower positions, respectively (Fig. 5).

The surface gravels of the shrub interspaces were not homogeneously distributed around the shrub–mound systems, and presented a higher concentration in the northern position (Fig. 6). The surface gravel concentration between the shrubs was higher in the intermediate parts and declined in the areas adjacent to the shrubs. The thickness of the remaining A horizon was maximum in the west extreme of the intershrub transect and decreased towards the east (Fig. 7).

3.3. Soil erosion and desert pavement formation

There was a strong correlation between the surface gravel mass adjacent to the shrub–mound systems and the thickness of the remaining A horizon. Regression analysis indicated that depth to the Bt horizon explained 54%, 84% and 63% of the variability in coarse fragments concentration on the soil surface for the upper, middle and lower slope positions, respectively (Fig. 8). The mean and range of soil erosion for the upper, middle and lower slope positions, as determined by the surface gravel mass, were 28.3 (0–68.2), 27.0 (0–63.8) and 33.1 mm (1.5–56.4 mm), respectively. However, the mean soil loss for each of these positions, as determined by the difference between the intact and the remaining A horizon of the eroded areas, were 50.0, 52.5 and 82.0 mm, respectively. Where most of the A horizon was removed, the Bt was exhumed and a very pale brown (10 YR 7/3), vesicular (Av) horizon develops on top of it, showing a strong color and structural contrast with the very dark grayish brown (10 YR 4/2) Bt horizon with a granular structure.

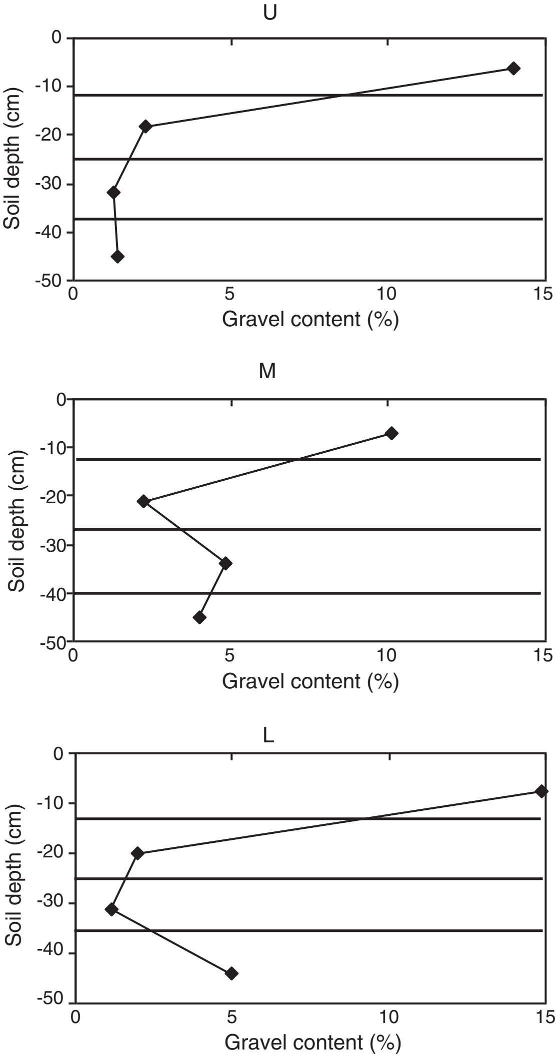


Fig. 3. Coarse fragments content as a function of soil depth in the soils of the upper (U), middle (M) and lower (L) slope positions.

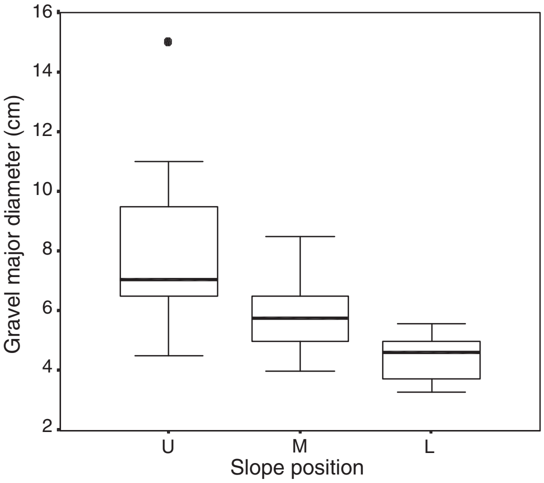


Fig. 4. Box-and-whiskers plot showing the major diameter of the coarse fragments laying on the soil surface of the eroded patches in the upper (U) middle (M) and lower (L) slope positions (n = 20).

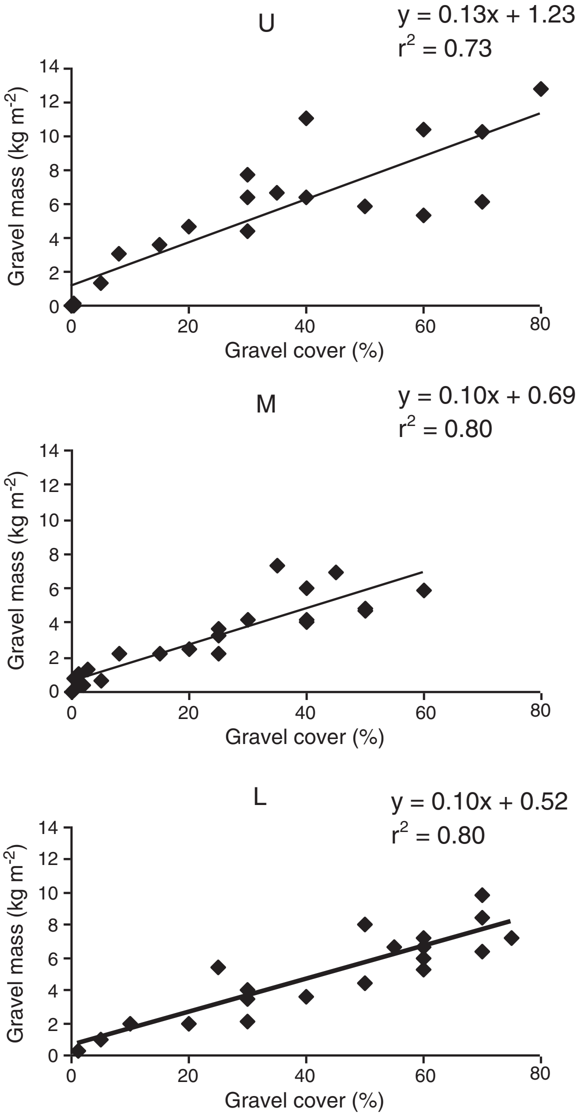


Fig. 5. Gravel cover and gravel mass relationship of the eroded patches adjacent to 5 *C. avellanedae* plants in the upper (U), middle (M) and lower (L) slope positions (n = 20).

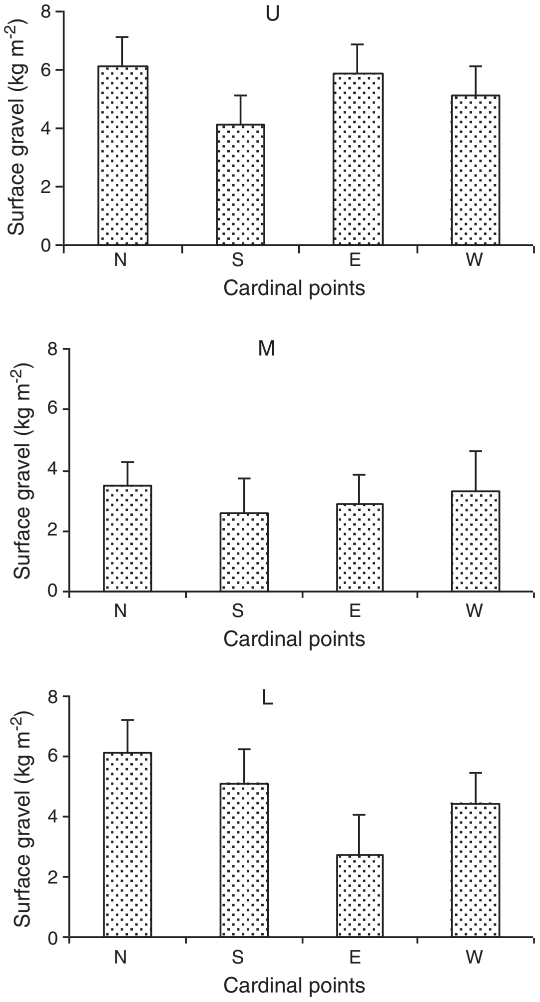


Fig. 6. Surface gravel distribution in the four cardinal points of selected shrub–mounds of the upper (U), middle (M) and lower (L) slope positions. Error bars represent standard error of the mean (n = 5).

4. Discussion

4.1. Surface gravel distribution

There was a continuous decline in the maximum and median sizes of the gravels present at the soil surface from the upper to the lower slope position, along the 500-m transect (Fig. 4). This trend in the gravel size would be the result of sorting during the downslope transport of the gravels that covers the plateau-like pediment (Fidalgo and Riggi, 1970). The general decrease in gravel size from the upper to the lower slope position partly explains the higher gravel mass per unit cover in the upper position (Fig. 5).

In the study area, the spatial variation of coarse fragment cover probably reflects spatial variations in soil erosion. The high cover of desert pavement in the shrub interspaces would indicate that these areas have been submitted to intense wind and water erosion processes (Fig. 9), contrasting with the shrub underneath area where deposition of part of the eroded material has predominated. However, for shrubs recently established in eroded areas no sediment has yet accumulated and a continuous cover of desert pavement persists (Fig. 10).

The most intense eroded areas, as indicated by the thickness of the remaining A horizon as well as the gravel cover, were the intermediate points between the shrub–mound systems (Fig. 7). Wind, splash and runoff erosion are influenced by surface cover characteristics. In shrub dominated areas, shrub clumps and gravel cover in the shrub interspaces affect the detachment, transport, sorting and deposition of soil particles (Rostagno, 1989; Parsons et al., 1992; Poesen et al., 1994; Abrahams et al., 1995). Thus, sediment detachment by wind may have more intensively affected areas north and south of shrub clumps, as westerly winds prevail. According to Ash and Wasson (1983), wind velocities may increase up to 120% on the flank side of shrubs and decrease from 20 to 50% of the upwind velocity in the lee side. The change in velocity and the physical obstruction favor the deposition of wind entrained particles within shrubs, giving rise to the mounds associated with shrubs of *C. avellanedae* (Fig. 9). On the contrary, surface runoff must have eroded more intensively either the east or the west side of the shrub–mound system, since the main slope runs in a south north direction. Overland flow in the areas between the shrub–mound patches concentrate in flow paths that diverge and converge around the shrubs (Howes and Abrahams, 2003). However, the data provide little evidence to conclude on the dominance of either process.

4.2. Soil erosion and desert pavement formation

In the most degraded sites of the Punta Ninfas area, the desert pavement occurs on top of the B_t horizon. This horizon, as well as the underlying soil horizons up to 50-cm depth, presents a low gravel

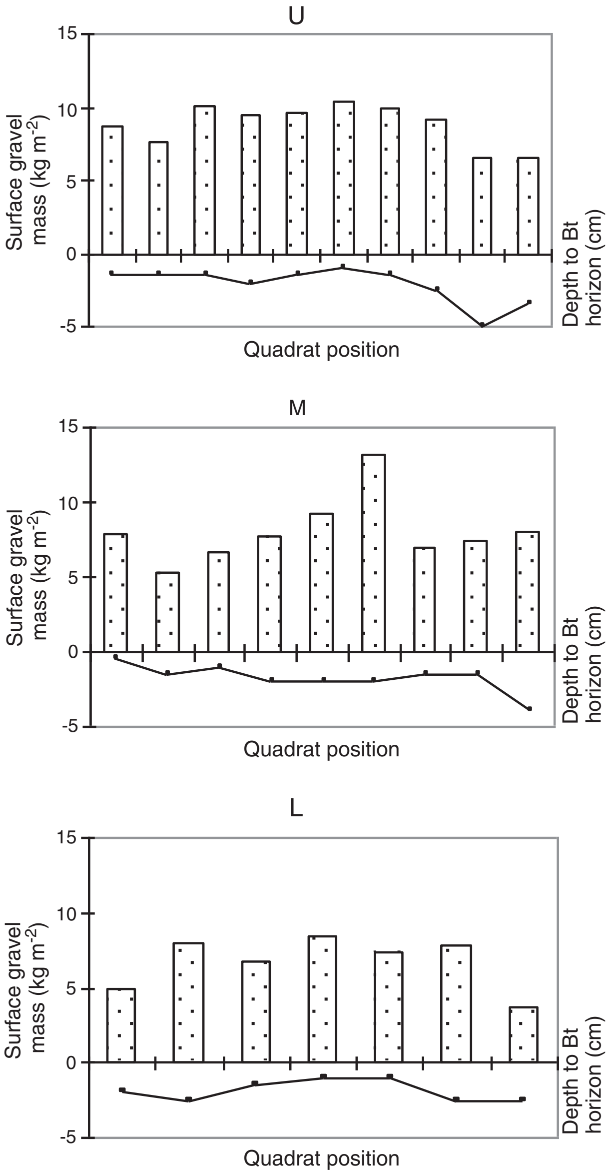


Fig. 7. Surface gravel mass distribution and thickness of the remaining A horizon along an east (left) to west (right) transect between two contiguous shrub–mounds in the upper (U), middle (M) and lower (L) slope positions.

content (Fig. 3) and gravels that are generally smaller than those forming the desert pavement. In other soils of Patagonia (Bouza et al., 2005) as well as in soils of other regions (Mabbutt, 1979; Nettleton et al., 1989), researchers have found that almost stone-free horizons may underlay desert pavements. The low gravel content in the soil horizons beneath desert pavements has been considered a strong evidence supporting the view that coarse fragments have concentrated on the soil surface by upward migration (Cooke et al., 1993) or because desert pavements were born at the land surface, that is, coarse fragments rose vertically on an accreting eolian mantle (McFadden et al., 1987).

Our data, however, support the view that the desert pavements in Punta Ninfas are erosional features indicating that finer soil particles have been selectively removed by erosion. The presence of grass-covered patches with soils that conserve an intact A horizon with variable amount of coarse fragments, adjacent to the desert pavements present in the shrub interspaces, as well as mounds associated with shrub-clumps representing part of the eroded sediments, indicate that soil erosion played an important role in their origin.

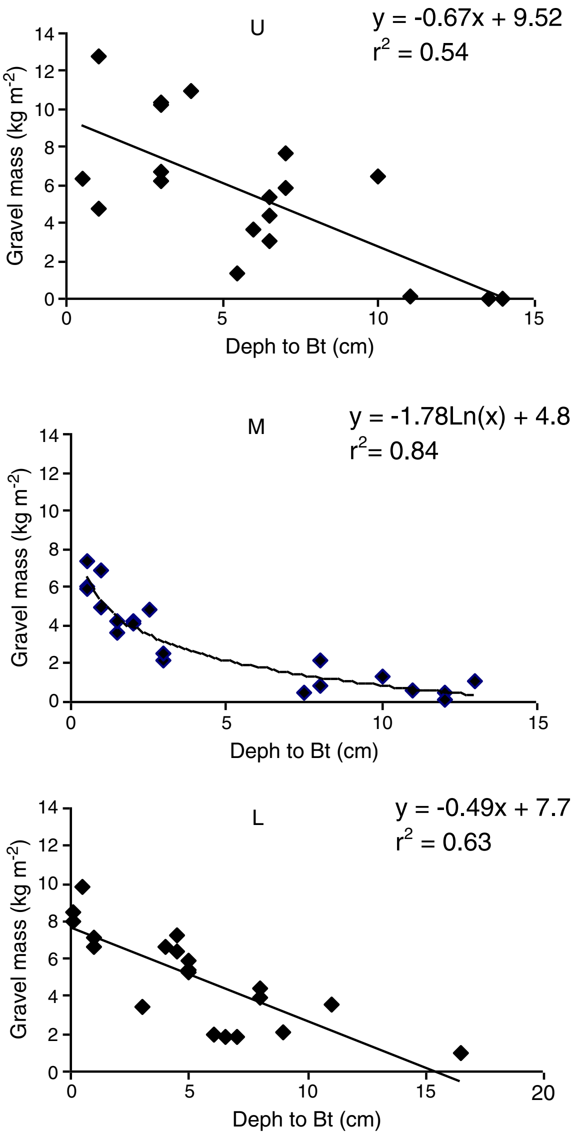


Fig. 8. Functional relationship between the surface gravel mass and the thickness of the remaining A horizon (depth to Bt) in the upper (U), middle (M) and lower (L) slope positions (n = 20).

4.3. Vegetation changes and soil erosion

Shrub encroachment and soil erosion have been recognized as major land degradation problems in semiarid perennial grasslands (Schlesinger et al., 1990). Both processes are intimately related as shrub encroachment generally induces changes in surface processes, notably increased runoff and water erosion (Abrahams et al., 1995; Turnbull et al., 2008) and wind erosion (Hennessy et al., 1986). In Punta Ninfas, shrub encroachment has been associated with areas highly impacted by sheep grazing (Beeskow et al., 1995). In this area the grass steppe or the grass steppe with scattered shrubs represents the most conserved areas and alternates with patches of shrub steppes where desert pavements are prominent features occupying shrub interspaces.

The stability of perennial grass steppes in Punta Ninfas is closely related to the ability of grasses to stabilize soils (Ocariz et al., 2004). This function of perennial grasses has been recognized as a key component of the resistance to shrub encroachment (Okin et al., 2009). The removal of the highly erodible A horizon in the shrub interspaces following a decrease in perennial grass cover, changes the physical properties of the

Fig. 9. Photograph showing the desert pavement in the shrub interspaces of the *Chuquiraga avellanedae* shrub steppe in the flank pediment of the Punta Ninfas rangelands, in northeastern Patagonia. The rod stretches between two mounds; the pen is 14.5 cm.

remaining soil, preventing the re-establishment of grasses, as found in other areas (Rostagno, 1989; Parizek et al., 2002).

In the degraded patches characterized by well developed desert pavements, infiltration rates are generally reduced, thus increasing runoff rates (Chartier and Rostagno, 2006). The redistribution of water by runoff increases the heterogeneity in the spatial distribution of soil moisture. Schlesinger et al. (1990) suggested that shrubs cover increases as a direct result of nonuniform distributions of water in space and time. Thus, the exhumation of the Bt horizon with a low permeability pose a double threat, as it increases the potential for runoff and erosion and by limiting plant establishment. Similar findings were reported by Abrahams et al. (1995) for southern Arizona soils where the conversion of grasslands to shrublands have been accompanied by the loss of A horizons, the formation of desert pavement and the development of rills.

4.4. Desert pavement as indicator of soil erosion

The high correlation between gravel cover and the thickness of the remaining A horizon, determined by the depth to the Bt horizon (Fig. 8), as well as the wide range in gravel cover (Fig. 5) highlights the importance of desert pavements as indicators of soil erosion. Desert pavements indicate the total erosion with respect to the soil of the well conserved patches of grass steppe, considered a local reference. The underlying assumption in this study is that the erosion process in Punta Ninfas, as well as in most of arid and semiarid Patagonia, accelerated after sheep grazing was introduced at the end of the 19th Century (Soriano et al., 1983; Ares et al., 1990). The stability of the arid and semiarid rangeland systems has been defined as their capability to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water (Schlesinger et al., 1990; Ritchie et al., 2003). In the Punta Ninfas rangelands, grass cover above a certain threshold seems to play an important role in controlling soil erosion (Chartier and Rostagno, 2006). However, in areas where grazing has reduced grass cover, erosion has been intensified. In those soils containing coarse fragments the erosion process generated, among others erosional features, desert pavements. Thus, the desert pavements indicate the extension and, in those areas where a conserved soil can be used as reference, the severity (i.e. the thickness of the eroded layer) of the erosional process, being this process natural or anthropogenically accelerated. One limitation of desert pavements as an indicator of soil erosion in the context of this study is that they cannot be used to determine the rate of the process. Erosion rates can vary greatly among different soils as well as among patches. Chartier et al. (2009) using a dendrochronological analysis of the exposed roots of a dwarf shrub found an erosion rate for the flank pediment of 3.1 mm yr^{-1} for a period of approximately 10 years. The mean eroded layer in this period was 26.4 mm, a figure close to the 28.3, 27.0 and 33.1 mm determined by the surface gravel mass for the upper, middle and lower slope positions, respectively.

Fig. 10. Photograph showing a young *Chuquiraga avellanedae* plant established in a desert pavement patch.

5. Conclusions

Most studies on desert pavement formation have generally been conducted in arid environments where vegetation cover is either scant or absent. The semiarid regions where grass or grass with scattered shrubs steppes are being transformed into shrub steppes coincide with an intensification of geomorphic processes, mainly soil erosion.

In the Punta Ninfas area, the dominant soil is very erodible due to relatively low clay and organic matter contents. Accelerated soil erosion has created a mosaic of different vegetation types, and each of them associates with a particular soil surface condition. Large tracts of the once dominant grass with scattered shrubs steppe were transformed into *Chuquiraga avellanedae* dominated shrub steppes, characterized by patchy, discontinuous cover of desert pavements. The presence of soils with intact A horizons with high coarse fragment contents in areas where grass cover dominates, and the high correlation between surface gravel mass and the thickness of the remaining A horizon indicates that: 1) accelerated soil erosion had played an important role in the formation of desert pavements, and 2) desert pavements are good indicators of the extent and intensity of the erosion process in the Punta Ninfas area.

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