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FOUR-YEAR SOIL EROSION RATES IN A RUNNING-MOUNTAIN TRAIL IN EASTERN IBERIAN PENINSULA

D. SALESA*, A. CERDÀ

Soil Erosion and Degradation Research Group. Department of Geography,Valencia University, Blasco Ibàñez, 28, 46010 Valencia, Spain.

ABSTRACT. *During the last decades, the use of mountain trails for running is more and more popular. New trails are opened to allow the runners to practice and compete. This form of human impact on the landscape is new as the new trails do not follow the conservation strategies in design and maintenance as traditional mountain trails constructed by farmers, shepherds and muleteers do. This impact of sport events in nature is not measured and we know little about this impact on vegetation, fauna and soils. We surveyed in September 2018 a trail that was opened in September 2014 and was used for four official mountain trail races, and for training by local runners. Our interviews with organizers and users show that 1054 runners passed during the competition days (4 races in 4 years) and over the 4-year period the trail was used approximately 43,800 times by a runner. We measured the current topography and calculated the soil lost. The results show extremely high erosion rates in the sloping terrain, with the highest rates in the north-facing slope, reaching up to 180.29 Mg ha*$^{-1}$ *y*$^{-1}$*, while in the flat section of the trail soil erosion rates are 107.56 Mg ha*$^{-1}$ *y*$^{-1}$ *and in the south-facing slope trail 128.93 Mg ha*$^{-1}$ *y*$^{-1}$*. Our study demonstrates that (i) soil erosion rates on trails can be easily estimated by measuring the deepest trail position enabling fast and cheap surveys; and (ii) that there is a need to establish conservation strategies on new trails to avoid non-sustainable soil losses in the Mediterranean mountains due to the sport activities such as the mountain trail races.*

Cuatro años de tasas de erosión de suelo en una senda para carreras de montaña en el Este de la Península Ibérica

RESUMEN. *Desde hace unas décadas, el uso de sendas de montaña para carreras es cada vez más habitual, de manera que se abren nuevas sendas para poder practicar y competir. Esta forma de impacto humano en el paisaje es nueva ya que el diseño y mantenimiento de estas nuevas sendas no siguen las estrategias de conservación de las sendas tradicionales de los agricultores, pastores y muleros. El impacto de los eventos deportivos en la naturaleza no ha sido evaluado y se sabe muy poco sobre este impacto sobre la vegetación, fauna y suelos. En septiembre de 2018 se monitorizó una senda de montaña que había sido creada en septiembre* *de 2014 y había sido utilizada para cuatro carreras de montaña oficiales y para el entrenamiento de corredores locales. Las entrevistas a organizadores y usuarios muestran que 1054 corredores pasaron durante los días de competición (4 carreras en 4 años) y que durante los 4 años la senda había sido utilizada aproximadamente 43.800 veces por corredores. Se midió la topografía actual y se calculó la pérdida de suelo. Los resultados muestran tasas de erosión extremas en las laderas en pendiente, con valores máximos en la ladera umbría, alcanzando hasta 180.29 Mg ha^{-1} a^{-1}, mientras que en las secciones llanas las tasas fueron de 107.56 Mg ha^{-1} a^{-1} y en la ladera solana de 128.93 Mg ha^{-1} a^{-1}. El estudio demuestra que (i) las tasas de erosión en sendas de montaña pueden ser fácilmente estimadas midiendo la posición más profunda de la senda, lo cual permite medidas rápidas y a bajo coste; y (ii) se necesitan establecer estrategias de conservación en las nuevas sendas para evitar pérdidas de suelo no sostenibles en las montañas mediterráneas debido a actividades deportivas como son las carreras de montaña.*

Key words: soil erosion, mountain trails, sustainability, mountain sports, running races.

Palabras clave: erosión del suelo, senda de montaña, sostenibilidad, deportes de montaña; carreras.

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*Corresponding author: David Salesa, Soil Erosion and Degradation Research Group. Department of Geography, Valencia University, Blasco Ibàñez, 28, 46010 Valencia, Spain. E-mail address: david.salesa@uv.es

1. Introduction

Running and biking are popular sports that are growing in participants and social acceptance (Hoffman *et al.*, 2010; Borgers *et al.*, 2015; Knechtle *et al.*, 2015). The use of mountain areas for sport activities is not new (White and Schreyer, 1981), but during the last decade it has grown in the number of participants, and therefore the social, economic and environmental impacts have increased also (Nepal and Way, 2007). The scientific community is researching the economic and social impact of the use of trails as a leisure activity (Fix and Loomis, 1997; Bowker *et al.*, 2007; Duglio and Beltramo, 2017) but much less is known about the biophysical impact of these activities on the environment. Within the research studies developed in the last decades, the environmental impact of trails has been assessed in only few regions (Nepal, 2003; Nepal and Nepal, 2004; Beeco *et al.*, 2013). Furthermore, the awareness of the problem among the general public is low, although research on the perception of visitors of natural parks is relevant to understand the problem and find solutions (Sterl *et al.*, 2008).

Biking, hiking and running are leisure activities that can trigger degradation processes in natural areas (Thurston and Reader, 2001), although they were created to preserve natural and high value ecosystems (Jackson, 1987). The awareness of visitors and managers in natural parks showed an environmental concern related to the outdoor recreation participation (Jackson, 1986). This is because until recently biking and running were not considered traditional uses in natural areas as was shown by White and Schreyer (1981) for National parks in USA. There has been a strong increase in the number of people that do long runs and bike in natural parks (Knoth *et al*., 2012). This triggered a subsequent growth in research in sport activities (Chavez *et al*., 1993; Rochat *et al*., 2017). There is a worldwide growth in the number of trail running practitioners and many new trails have been opened for this purpose, where runs of sprint trails (11 km), half-marathons (21 km), marathons (42 km) and ultramarathons (100 km or more) have increasing acceptance. This explains the growth in the research related to the medical perspective of the trail running (Scheer and Murray, 2011; Burr *et al*., 2014). The impact of trails on vegetation and fauna has been found to be negative (Dale and Weaber, 1974; Comita and Goldsmith, 2008; Newsome and Davies, 2009) but there is a lack of information about the impact of trails on soil quality, and the key issue to understand changes in soil quality is the impact on soil erosion due to human trampling, surface wash, and the interaction of both. There is also a lack of basic data that is needed to design, management and construction of trails (Symmonds *et al*., 2000), and for the advance towards more sustainable management of mountain trails it is necessary to quantify the soil erosion rates on many locations. In fact, this form of human impact on the landscape is new as the new trails do not follow the conservation strategies in design and maintenance as traditional mountain trails constructed by farmers, shepherds and muleteers do.

Mountain areas can offer multiple ecosystem services including recreational services, which contribute positively to human health (Wolf and Wohlfart, 2014; Brevik *et al*., 2018). They are an ideal backdrop for many people to practice leisure and sport activities such as hiking or trail running. This type of activities has been gaining popularity over the last few years worldwide (Barros *et al*., 2013; Bodoque *et al*., 2017; Ćwiakala *et al*., 2017) and there are growing numbers of people who seek to explore new places or create more appealing and challenging routes, particularly for mountain bikes (Goeft and Alder, 2001), and in recent years more and more for mountain trail running (Farias-Torbidoni *et al*., 2018). This anthropogenic pressure on the environment has effects on ecosystems which implies land degradation due to soil compaction, vegetation removal and soil erosion. The use of trails by hikers can cause (i) loss of plant biomass due to trampling, (ii) introduce exotic species and aid their dispersal, (iii) hinder the movement of wildlife and disturb their habitat, (iv) increase of human waste in the surroundings; and, (v) alter water quality by increasing turbidity due to eroded soil ending up in waterways (Leung and Marion, 2000). Moreover, the main effect of mountain trails is that it triggers land degradation due to the loss of soil fertility and soil quality, which may ultimately lead to the complete loss of the soil due to the human trampling induced soil erosion (Morgan and Smith, 1980) and ecosystems degradation (Burden and Randerson, 1972; Liddle, 1975). Some examples of these impacts are (i) the loss of soil organic matter and soil moisture, (ii) the increase of bulk density by compaction, (iii) the detachment and transport of soil particles causing soil erosion and root exposure, (iv) the increase in surface wash; and, (v) alterations in soil and water chemical properties (Hawkins and Weintraub, 2011). All these impacts are accentuated if we consider the low rates of soil formation and the limited soil depth, especially in some areas such as the Mediterranean and mountains terrains where intensive land use and management has developed over millennia (Butzer, 2005; González Hidalgo *et al*., 2007).

So far, the limited research conducted on trail erosion focussed on trekking trails, but running trails are at higher risk due to the higher impact of runners as a consequence of the speed of the runners, and the energy transferred to the soil surface by each step (Creagh *et al*., 1998).

A trail was selected in a Mediterranean range due to the growing recreational activities in this mountain area and particularly for the purpose of determining erosion rates in a 4-years old mountain running trail. Therefore, the aims of this paper are: i) assess soil erosion rates in a Mediterranean trail caused by trail running; ii) determine the factors that influences the erosion rates; and, iii) develop a new sampling strategy to reduce the time invested in the field work and allow more measurements.

2. Material and methods

2.1. Study area

The study area is located in the East of the Iberian Peninsula and is found in a representative area of the Mediterranean mountains where abandonment took place in the 1960s, the vegetation is a scrubland and the parent material is limestone (Fig. 1). The trail selected for this research is located near the municipality of L'Alcúdia de Crespins and was opened 4 years before the measurements were carried out. Trail runners are the main users, but also bikers and hikers are regular users of the trail. Within the L'Alcúdia de Crespins mountain trail we selected 3 sections that are close to each other, but each of them has different physiographic characteristics such as slope angle and aspect, which allow to research the soil erosion variability on trails due to those variables. We called these sections North-facing (35 meters on a northern hillside), South-facing (70 meters in a southern hillside) and Flat (30 meters on the upper plain). The predominant vegetation in the study site is scrubland (*Globularia alypum, Thymus vulgaris, Rosmarinus officinalis*) with some small dispersed shrubs (*Chamaerops humilis, Quercus coccifera, Pistacia lentiscus*). Trees are scarce, mainly represented by *Pinus halepensis* and *Quercus ilex* at the study area but not present in the trail due to the fact that an area without trees was selected by the trail designer in this part of the trail. The sections of the studied trail are located under an electric line so the periodic clearing for security reasons results in a vegetation cover below 1 m in height, with the exception of a bunch of *Quercus ilex* trees of approximately 2-m in height. The climate in the study area is temperate with an average annual temperature of 17ºC; August is the hottest month and January the coldest. Rainfall is moderately scarce with 426 mm y^{-1}. The driest month is July due to the summer drought and the wettest is October due to easterly winds coming from the Mediterranean Sea.

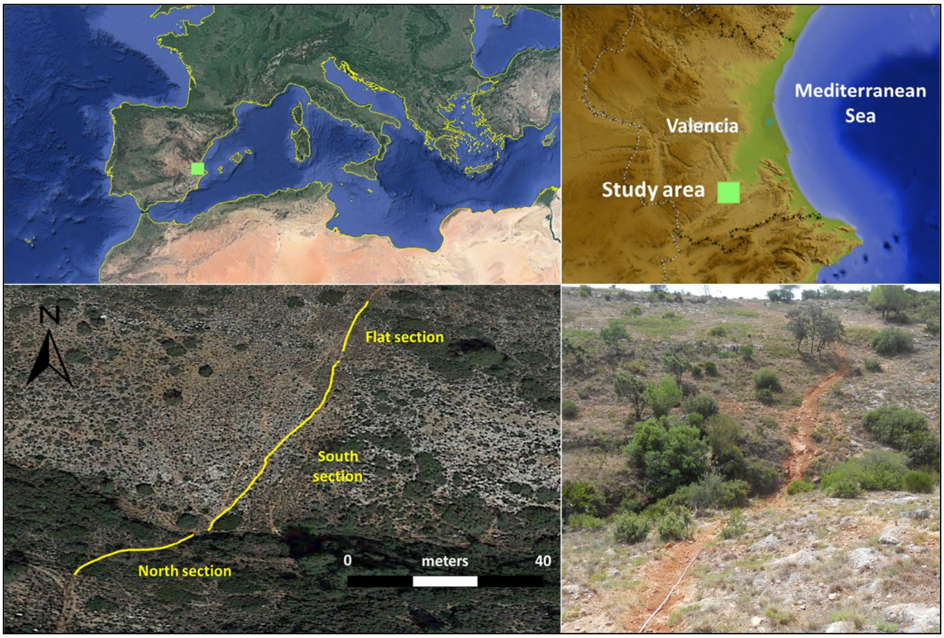

Figure 1. L'Alcúdia de Crespins study area in the province of Valencia (Spain). Lower right panel shows the study site with the North and South sections.

A survey of the trail use by hikers, bikers and runners was done with interviews to the users and information was collected from the organizers of the "L'Alcúdia de Crespins trail run" by means of interviews. The interviews (22 users plus 3 organizers) provided information about how many runners per day used the trail and how many participants yearly use the trail for competition. In addition, we collected information about the use by bikers and trekkers.

2.2. Measurements of soil erosion

The three trail sections were surveyed in September 2018 and we calculated soil erosion rates using the Cross-Sectional-Area (Fig. 2), a widely applied method in trail erosion research (e.g. Fish *et al.*, 1981; Marion and Olive, 2006; Olive and Marion, 2009; Esque *et al.*, 2016; Tomczyk *et al.*, 2016), which is the most replicable method for monitoring trail segments (Jewell and Hammitt, 2000). We measured soil depth every meter of the trail and 10 cm along each cross-section and employed a metal bar which we placed over the edges of the trail considering that it was the original ground surface before the use of the trail (Webb *et al.*, 1978). In each metre we registered the slope angle in the centre of the trail and the rock fragment cover and rock embedded was quantitatively estimated in percentage. From depth measurements in cm, the erosion rates (in cm^3) of the trail were calculated with the following equation:

$$\left[\frac{\{(Z_{a1}+Z_{a2})*5+(Z_{a2}+Z_{a3})*5+_{\dots}(Z_{an}+Z_{an+1})*5\}+\{(Z_{b1}+Z_{b2})*5+(Z_{b2}+Z_{b3})*5+_{\dots}(Z_{bn}+Z_{bn+1})*5\}}{2}\right]*100 \qquad (1)$$

where Z_a represents each soil depth measurement from the metal bar at measurement point a and Z_b each soil depth measurement on the following point measurement (Fig. 3). This calculation was repeated for each metre of the trail and by adding all the calculations, the final volume of soil loss was obtained. With the trail soil samples collected, the soil density was determined in the laboratory to finally obtain the soil erosion rate in Mg ha^{-1} y^{-1}.

Figure 2. Measuring soil depth in the L'Alcúdia Mountain Trail using the Cross-Sectional-Method to calculate soil erosion rates.

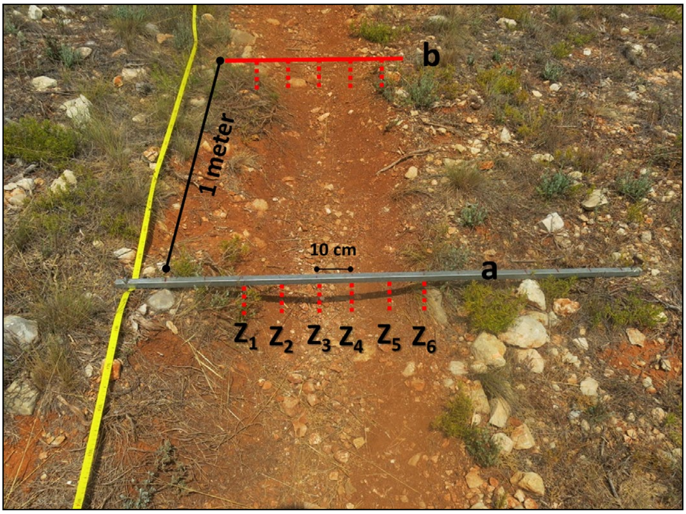

Figure 3. Schematic view of soil depth measurements on the trail. Z represents the height between the metal bar and the ground surface (i.e. the soil lowering) and the lower case letters show the measurement points every meter along the trail.

3. Results

3.1. Runners' use of the L'Alcúdia trail

The interviews with the organizers of races and individual local runners in October 2018 have shown that there is a higher density of runners during the competition events. The trail was opened in September 2014, and in 2015 (25/1/2015) the first trail running competition took place with 401 participants. In 2016 (31/1/2016) the number of runners dropped to 169 and in 2017 (26/3/2017) and 2018 (22/4/2018) the participants' number reached 231 and 253, respectively. The interviews with the runners that use the trail regularly show that on average 30 people per day use the trail for running and 5 for trekking. The interviews showed that the use of the trails varies from 5 to 50 users per day. Bikers are rare in comparison to runners as they are mainly present in the weekends and on average 3 bikes use the trail daily. Those numbers show that in the last four years approximately 1054 runners used the trail for a competition. However, the daily use for training sums up to a total of 43800 runners', 4380 bikers' and 7300 trekkers' passes. Those numbers are based on the calculations of the runners that use the trail, which is the only source of information as there are no official data about the use and the governmental organizations are not involved in the maintenance of the trails or the organization of the competitions.

3.2. Soil erosion

Table 1 shows the descriptive results from the measurements carried out at the studied trails. North-facing section shows the highest slope values (20.97º) and it contains the widest trail of the three sections studied (1.23 m). The north-facing trail section presents a low rock fragment covers in comparison to the south-facing section (17.08% and 26.48% respectively) whereas the flat trail section shows the lowest value of rock fragment cover (2.58%). Furthermore, in the South-facing section we have come across 7 occasions (out of 70) in which the soil lowering was 0 due to the fact that the trail consisted of a rock outcrop while in the North-facing section this was measured twice (out of 35). The total exposure of rock outcrops means that the whole soil profile has been removed and the erosion cannot progress more in depth. Therefore, although the soil losses were registered as 0 (null) in fact the soil erosion already removed the whole soil before the trail was established. Figure 4 showed the basic properties of the 3 studied trail sections: slope angle, soil lowering and trail width. It can be observed how these 3 results from the L'Alcúdia de Crespins trail have the same pattern for the 3 sections we have analysed. The North-facing section presents the highest values of slope angle, soil erosion and trail width. The South-facing section has middle values and the Flat section exhibits the lowest results of slope angle, soil erosion and trail width. As a result, soil erosion volume calculations of the 3 sections are contrasted (Fig. 5). The North-facing section trail shows the most severe soil loss values and has a high variability. In contrast, the Flat section has low soil loss values and is very homogeneous.

Table 1. Topographical characteristics of the three study trails. The standard deviation is indicated in parentheses.

Topographical measurements	North	South	Flat
Length (m)	35	70	30
Average width (m)	1.23 (0.18)	0.86 (0.19)	0.75 (0.11)
Average slope (º)	20.97 (8.08)	10.61 (5.10)	5.48 (3.25)
Age (y)	4	4	4
Area (ha)	0.004	0.006	0.002
Average parent rock (%)	17.08 (27.03)	26.48 (30.64)	2.58 (4.26)
Lowest elevation (m.a.s.l)	255.17	254.56	268.83
Highest elevation (m.a.s.l.)	264.49	267.4	271.08
Change in elevation (m/linear m)	0.27	0.18	0.08

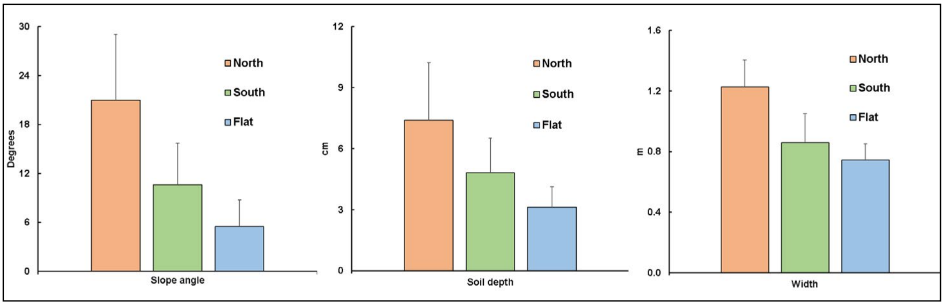

Figure 4. Basic characteristics of the 3 sections of the trail studied. The standard deviation is indicated using bars.

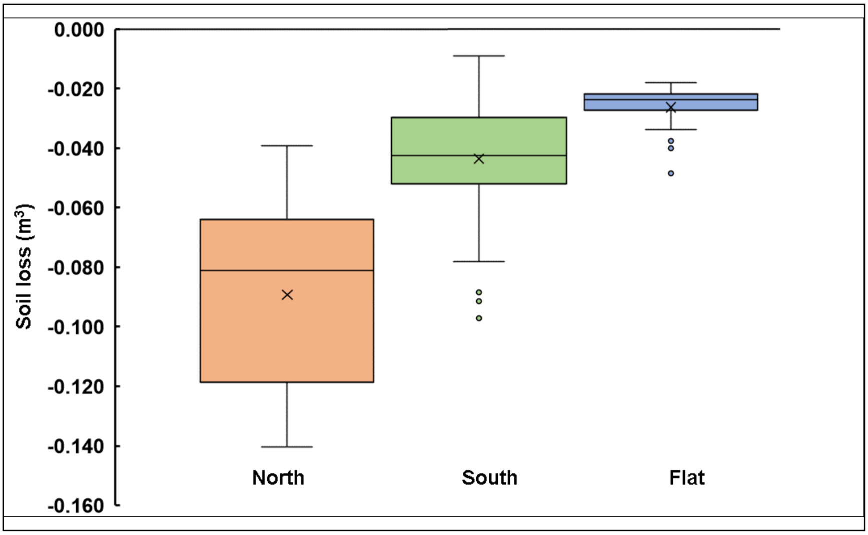

Figure 5. Boxplot diagram for the soil lost calculations of the 3 sections of the trail (median values, average values (with a cross), upper and lower quartiles and outliers).

Table 2 shows the results of the calculations made and the topographical changes in the L'Alcúdia de Crespins trail. These results show very significant soil lowering rates, reaching up to 1.85 cm of soil lost each year in the North-facing section. Even though it is a much lower value, soil lost in Flat section is still considerable (0.78 cm y^{-1}). Whereas this is a trail that has only been in use for four years, the resulting soil erosion rates on the trail surface are totally unsustainable with values ranging between 107.56 and 180.29 Mg ha^{-1} y^{-1} for the Flat and North-facing sections respectively, in other words, for every 100 meters of trail, between 0.78 and 2.28 Mg per year are lost.

Table 2. Topographical changes and soil erosion rates in the three study trails. The standard deviation is indicated in parentheses.

Topographical changes	**North**	**South**	**Flat**
Average soil lowering (cm)	7.40 (2.84)	4.80 (1.72)	3.13 (1.00)
Average soil lowering (cmy^{-1})	1.85	1.20	0.78
Average of highest depth (cm)	15.62 (5.89)	9.40 (3.22)	5.45 (1.52)
Average of soil depth in the centre (cm)	12.85 (6.53)	8.09 (3.01)	5.08 (1.55)
Total soil lost (m^3)	3.03	2.79	0.82
Average soil lost (m^3 m^{-1})	0.09 (0.03)	0.04 (0.02)	0.03 (0.01)
Soil density (Mg m^3)	1.02 (0.12)	1.11 (0.04)	1.18 (0.07)
Soil erosion rate (Mg ha^{-1} y^{-1})	180.29	128.93	107.56

We have also found that a relationship exists between the soil lowering value in the centre of the trail and the calculated soil loss (Fig. 6), especially in the flat section (R^2=0.69). This can be attributed to the strong correlation that exists between erosion value in the middle of the trail and the maximum erosion value at each measurement point (Fig. 7), which in turn, has a significant impact on the erosion rate obtained. Considering this, we can obtain an average of 78.81% of total erosion calculated by measuring only the trail width and the depth of the trail in the middle of the trail (Fig. 8). This finding is of great help for future research as this creates the opportunity to increase the surveyed area with little loss of accuracy.

We have observed a different pattern of soil lowering values depending on the slope angle in which they are found (Fig. 9). At lower slope angle values (0º-5º) soil loss tends to decrease. In areas with intermediate slope values (6º-23º), there is a growing trend of greater soil loss as the angle of the trail increases. At steep slope values (24º-43º), the soil lowering values do not follow any trend and the results show large variability.

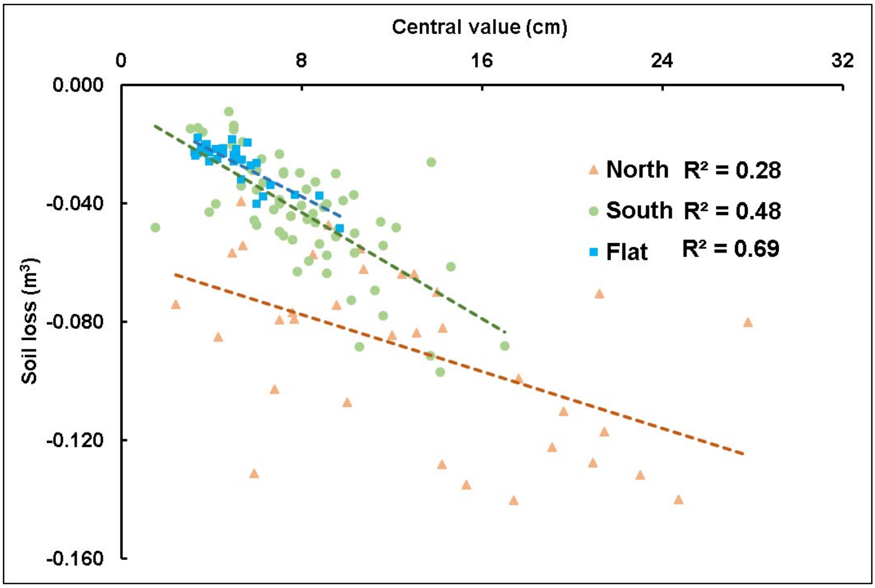

Figure 6. Linear adjustment of soil depth values in the centre of the trail and its corresponding calculated soil erosion value for the 3 trail sections.

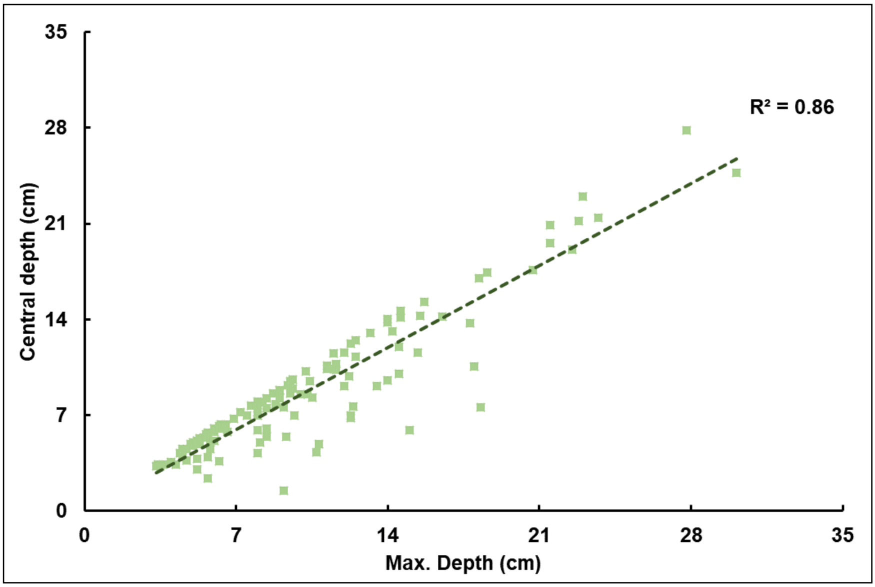

Figure 7. Linear adjustment between the central depth in the trail and the maximum depth in each measurement point.

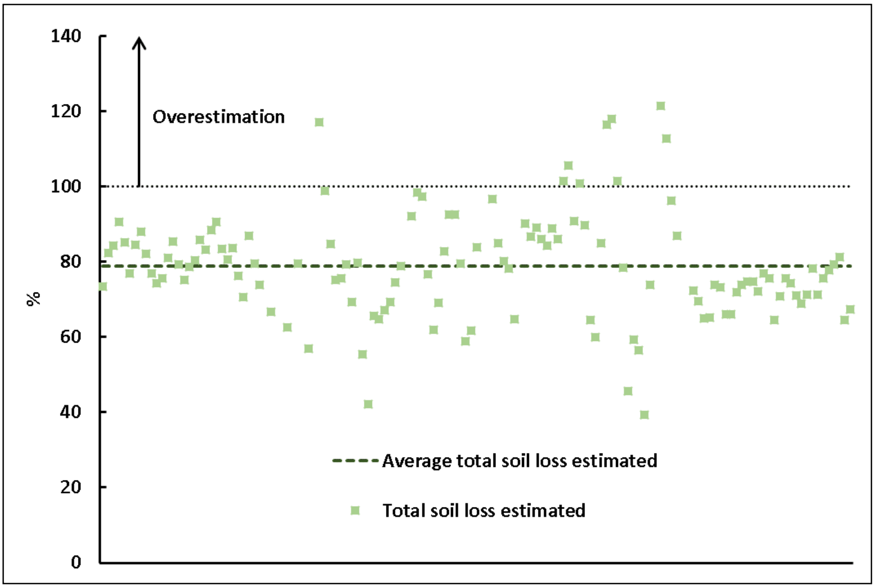

Figure 8. Erosion values estimated by the trail width and depth in the centre of the trail relative to the total erosion calculated with equation (1). The estimated percentage of erosion with respect to the real value reaches 78.81%.

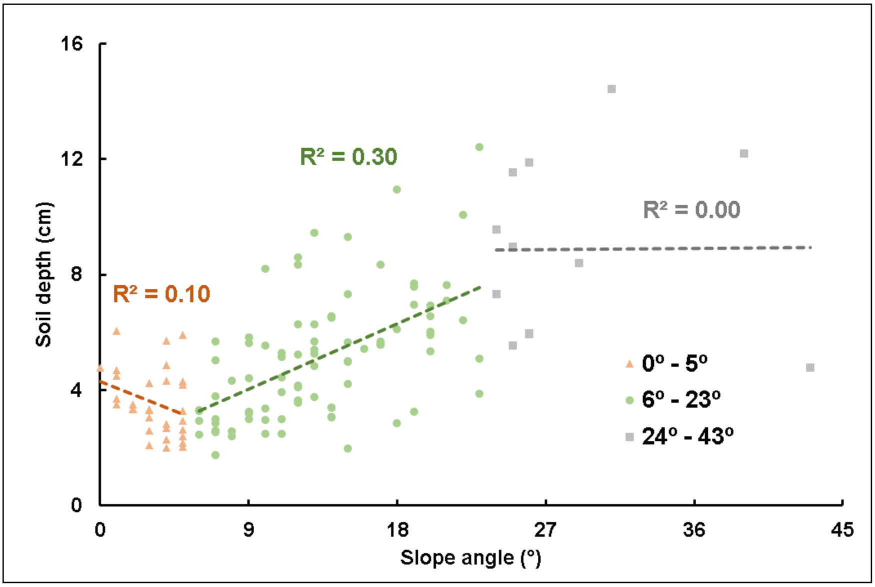

Figure 9. Measured soil depth values grouped into 3 slope angle categories.

4. Discussion

The research on soil erosion should be updated and improved in the next decades (García-Ruiz *et al*., 2017). Soil erosion has been researched in different land uses, but mainly in agriculture land (García-Ruiz, 2010; Antoneli *et al*., 2018; Cerdà *et al*., 2018; Rodrigo Comino *et al*., 2018a; 2018b). On forest ecosystems the impact of fire has been mainly research in the Mediterranean ecosystems (Inbar *et al*., 1998; Fox *et al*., 2006; Di Prima *et al*., 2018) but little is known about how human trampling in natural areas affect the soil erosion processes. Research on soil erosion has been developed since the beginning of the 20th century (Smith, 1914; Munns, 1920) in USA, but trail erosion is a new issue, both on global scale as well as on Mediterranean regional scale. This is due to the fact that mountain areas in developed countries were abandoned and therefore the traditional trails were abandoned too. The abandonment triggered the vegetation cover to recover; the trails were lost and soil erosion was controlled and reduced to the lowest rates. Those changes reduced the connectivity of the flows such as in agriculture land has been demonstrated by Masselink *et al*. (2017a) and should be more researched in natural areas to understand the soil erosion processes and rates (Keesstra *et al*., 2018a). Leisure and sports are bringing human presence back to the mountains, and trail running can be the cause of high erosion rates as we found at the running trail of L'Alcúdia de Crespins with values that are two orders of magnitude higher than what is considered sustainable by the scientific community (Smith and Stamey, 1965). The sport activity can change the connectivity of the systems such as other disciplines have shown (Masselink *et al*., 2017b; Turnbull *et al*., 2018) and we still know little about how this can change the natural system after a shift (Lana-Renault *et al*., 2018; Lasanta *et al*., 2018).

The agriculture abandonment was fast in the Mediterranean landscapes where the Mountainous areas were abandoned suddenly in the 1950s and 1960s (Lasanta-Martínez *et al*., 2005; Serra *et al*., 2008), which caused profound environmental changes (García-Ruiz and Lana-Renault, 2011). The return of people to the mountains for leisure activities, such as trekking has become increasingly popular since the 1970's, but in the 1990s mountain biking arrived and in the last decade trail running became one of the favourite activities for the runners that use to run in urban areas. This increase in trail running results in the creation of new routes and because runners prefer to use trails on steep slopes, the highest impact of trail running in terms of erosion is found on these steep slopes but there are few evidences and proves of this. The fact that there is little information on soil erosion in running and biking trails makes it urgent to create a knowledge base to be able to achieve the goal of sustainable management of existing trails and design of the new trails with proper maintenance. This paper surveys the impact of trail running on soil erosion as a first step to understand the processes and factors that are important, to improve the survey strategies and finally to contribute with information to design restoration and rehabilitation programs and improve the design of a trail for running.

The research on erosion in mountain trails and the effects they cause began to be studied later in the 1970's (Willard and Marr, 1971) in the USA. Willard and Marr (1971) studied the effect of hiking on the vegetation of the alpine tundra in Colorado and the difficulties of recovering from trampling and Helgath (1975), also in USA, continued seeking to determine the influence of different environmental factors in trail degradation. USA has continued leading the investigation at a global scale in the following years, both in the USA and in other countries where trail erosion has been studied by American colleagues (e.g. Farrell and Marion, 2001a; Wallin and Harden, 1996). Those studies were focussed on trails used for trekking and a need of information from trail running impact is necessary.

The Mediterranean areas show little research on the trail erosion. The pioneer research was carried out by Bodoque *et al*. (2005). Pelfini and Santilli (2006) studied the trail erosion in the Italian Alps. And little research was developed afterwards (López-Vicente *et al*., 2013; Tarolli *et al*., 2013). Then, there is little data about trail erosion in the mountains of the Mediterranean basin, and no data available about trail running erosion at all.

Our research demonstrates that soil erosion in running trails results in extremely high erosion rates which are higher than the ones found after forest fires (Shakesby, 2011), bare agriculture soils (García-Ruiz, 2010; Keesstra *et al*., 2014) and in extreme rainfall events (Martínez-Casasnovas *et al*., 2002) in Mediterranean type ecosystems. We found that the soil losses in this trail are on average 138.92 Mg ha^{-1} y^{-1} (14.2 Mg y^{-1} km^{-1}), thereby, our results show that trail erosion is totally unsustainable, especially in semi-arid regions where soil formation rates are very low. The sustainable or non-sustainable use of trails should be considered according to the soil development, which depends on their location. In the Mediterranean area, the frequent use of mountain trails may have a severe effect on the degradation of the soil in an area, since these shallow soils are subjected to intense trampling, and high intensity rainfall events.

The soil erosion in the running trail of L'Alcúdia de Crespins has shown values that are similar to other trails which were not recently opened or were used only for trekking. The trails researched by other scientists such as Stull *et al*. (1979) showed values of 540 Mg ha^{-1} y^{-1} or Johnson and Smith (1983) with 632 Mg ha^{-1} y^{-1}. The highest soil losses were found by Sack and da Luz (2003) with 2090 Mg ha^{-1} y^{-1}. Other authors found values lower, such as Kidd *et al*. (2014) with 20.5 Mg ha^{-1} y^{-1} and Ramos-Scharrón *et al*. (2014) with 81 Mg ha^{-1} y^{-1}. This data is confirmed by the values found in the Mediterranean mountains with values of 170 Mg ha^{-1} y^{-1} found by Bodoque *et al*. (2005) with 151.3 Mg ha^{-1} y^{-1} under trekking and biking conditions; and by Bodoque *et al.* (2017) under hiking conditions. Similar results were registered by López-Vicente and Navas (2009) with 306.3 Mg ha^{-1} y^{-1}, and López-Vicente *et al*., (2013) with 6.1 Mg ha^{-1} y^{-1}. Data coming from different continents show that trail erosion rates are very variable from one location to another, and that this is found also in Mediterranean trails. Our results are in the range of what was found until now and the use as a running trail did not show any special response from the erosional point of view.

The spatial distribution of the soil erosion in the researched trails depends on the physiographic characteristics of the sites and we distinguished between North-facing South-facing and Flat areas. Aspect turned out to be a key factor as vegetation in the trails is negligible, unlike other land uses (Feng *et al*., 2018). Our results show that the soil erosion rates were higher in the north-facing slope, but the scientific literature shows the contrary. The pioneer research of Hughes (1972) shows that the aspect is a relevant variable to explain erosion in the loess area of the Banks Peninsula in New

Zealand. Cerdà (1998) found that the soil erosion is usually higher in the south-facing slope due to lower vegetation cover. And similar findings were highlighted by Agassi *et al*. (1990), Agassi and Ben-Hur (1991), Sidle *et al*. (1993), van Breda Weaver (1991) and Bojie *et al.* (1995). However, at the trail running of L'Alcúdia de Crespins the soil erosion is higher on the north-facing slopes, and this can be explained by the fact that trails behave differently from normal soils due to the lack of vegetation. The north-facing slopes normally have a higher vegetation cover and deeper soils, as the climate is more temperate and this allows for a more favourable condition to form soil (Buol *et al*., 2011; Olivero and Hix, 1998). The south-facing slopes, on the other hand, suffer from hydric stress and the plant cover is lower and soil formation (soil depth) repressed (Måren *et al*., 2015). This situation is well known in different ecosystems (Phillips *et al*., 2008; Begum *et al.,* 2010) and it is also true for Mediterranean type ecosystems (Kutiel, 1992; Kutiel and Lavee, 1999; Sternberg and Shoshany, 2001; Sidari *et al*., 2008). Aspect arises has also been found to be a key factor on soil and soil erosion distribution after a wildfire (Marques and Mora, 1992; Cerdà *et al*., 1995; Pausas *et al*., 1999). In the L'Alcúdia de Crespins running trail, the high erosion rates in the north-facing trail section is due to the deeper soils that are present there, which simply means that there is more soil to be eroded. This situation explains that the running trail almost lost all its soil after 4 years of use, which is confirmed by the high amount of rock outcrops (Fig. 10). Therefore, it can be concluded that mountain trail running contributes to removing almost all soil in a mountainous area with shallow soils. And on locations where more soil is present the impact is higher: which in this case is the north-facing slope. This does not occur when a soil is covered with vegetation as the above-mentioned literature showed, because in these areas the vegetation cover is the key determining parameter (Kirchhoff *et al*., 2017).

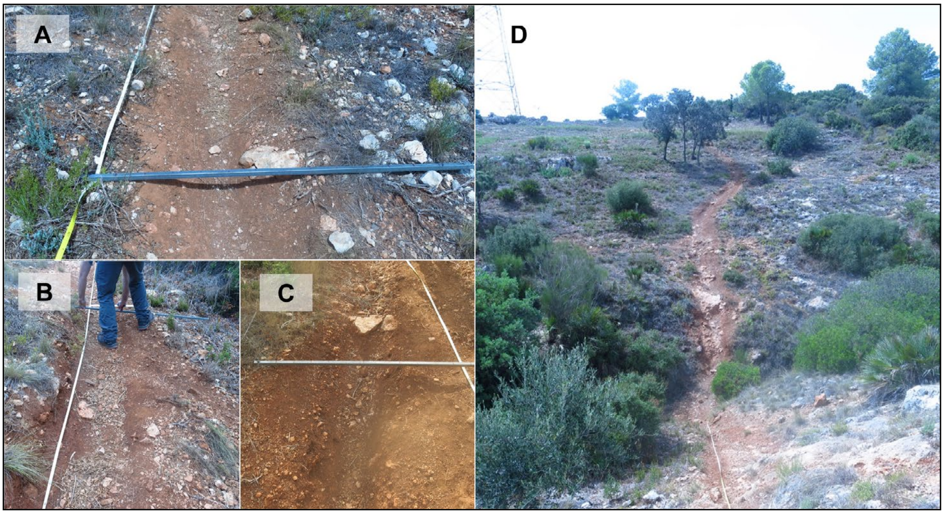

Figure 10. View of the L'Alcúdia de Crespins trail. A, detail of the measurement in the north facing section; B, view of the measurement in the north-facing section; C, Detail of the depth of soil lowering in the south-facing section; and, D, View of the north facing slope from the South-facing section.

The two key factors for soil erosion on trails are the slope angle and the width of the trail. The link between slope angle, soil loss and trail width has been well studied previously by the scientific community. Trail widening is related with flat areas mainly caused by the lack of runoff which often leads to water accumulations and muddiness that result in users trying to avoid the puddle and trampling the vegetation along the trail edges (Monz *et al.*, 2010). However, our results do not support this statement probably caused by the strong influence of slope angle in the steep Mediterranean slopes. Bratton *et al.* (1979) obtained that the slope of the trail is the most important physical factor related to the erosion rate. Greater erosion on steeper trails can be attributed to the greater velocity of runoff, which causes more soil particle detachment, and in addition, protective elements such as stones are easily transported (Farrell and Marion, 2001b). Cao *et al.* (2014) also verified that slope angle is a factor influencing rill erosion in different road types, including trails. In the L'Alcúdia de Crespins trail the low precipitation amount at the Mediterranean areas (500 mm y^{-1}) reduces the effect of the slope angle as the runoff production is lower than in regions with higher rainfall amount.

A further component that has an influence on trail characteristics is the angle formed by the trail compared to the maximum slope angle line of the hillside. This feature is known as trail alignment and it can cause a major influence on the soil loss that takes place (Olive and Marion, 2009). According to Marion and Leung (2004), the main specification to reduce soil erosion rates is to keep the trail slope angle below 12% and the slope alignment angle between 45º and 90º to allow water drainage and avoid incision. None of these two properties are fulfilled in our studied North and South sections. Wimpey and Marion (2010) found that fall-alignment trails (low-level trail alignments) are correlated with wider trails due to the superficial water flow that follows the maximum slope angle, which is encouraged by the trail that functions as a drainage line. The cumulative effect of the slope angle and trail alignment was demonstrated by Marion and Olive (2006) who obtained a greater influence of the slope angle as the trail alignment was reduced.

In the figure 9 we have found different trend patterns of erosion rates with the increase of slope angle. At gentle slopes, a slight increase in the slope angle of the trail reduces the soil loss. This may be caused by the increased mobility of soil particles from surrounding places. As a result, these soil particles are deposited on the trail, as the slope gradient of the trail does not allow them to move further. As the slope angle further increases, the soil loss again becomes higher due to a combined effect of gravity, an enhanced water erosive power and transport capacity and soil particle detachment. Finally, on the steepest slopes no clear trend can be found. The great variability in the erosion values on the steepest slopes is consistent with the results of Randall and Newsome (2008), who found an increasing trend in erosion rates with higher slopes but this trend is no longer valid when the slopes become too high.

It is clear that the pathway trail users take on the trail can influence soil erosion along the trail due to the removal of the vegetation. Plants inside and on trail boundaries can reduce erosion and a forest canopy can reduce rainfall runoff by up to 10% (Goeft and Alder, 2001) and even more, vegetation can constrain traffic in a stable tread width

(Marion and Leung, 2004). Therefore, we think that vegetation should be an essential feature in the process of designing new trails. Another distinctive attribute of L'Alcúdia de Crespins Trail is the time it has been open. As we have already proved, a large amount of soil has been lost in just over 4 years. Nevertheless, some authors report that the higher soil erosion rates on trails occur shortly after their opening or construction (Deluca *et al*., 1998; Nepal, 2003; Ramos-Scharrón *et al*., 2014), so we expect these erosion rates to gradually stabilize as the soil available to be eroded decrease, but to verify this will be upon the improvement of the knowledge. This will contribute to achieve the sustainability (Keesstra *et al*., 2018b).

5. Conclusions

The growing interest in outdoor sport activities is common and mountain trail running is getting more popular. Our measurements determined soil erosion in the L'Alcúdia de Crespins (eastern Spain) running trail to be very high, with an average of 1.28 cm y^{-1}, which results in average erosion rates of 138.92 Mg ha^{-1} y^{-1} on the trail surface. We found that north-facing slopes have the highest erosion rates as this is where there is more soil available to be eroded. We also found that slope angle increases the soil erosion rates and that the comparison with other researches show that the erosion rates are as high as other scientists found in other trails. Our calculations show that 4 years is enough to increase the number of rock outcrops and result in most of the soil on the trail to be lost. There is a need to apply rehabilitation strategies on running trails and design new trails with erosion prevention measures, to avoid that most of the soil is lost after 4 years such as we measured in the L'Alcúdia de Crespins trail.

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References

Agassi, M., Ben-Hur, M. 1991. Effect of slope length, aspect and phosphogypsum on runoff and erosion from steep slopes. *Soil Research* 29 (2), 197-207. https://doi.org/10.1071/SR9910197.

Agassi, M., Morin, J., Shainberg, I. 1990. Slope, aspect, and phosphogypsum effects on runoff and erosion. *Soil Science Society of America Journal* 54 (4), 1102-1106. https://doi.org/10.2136/sssaj1990.03615995005400040030x.

Antoneli, V., Rebinski, E.A., Bednarz, J.A., Rodrigo-Comino, J., Keesstra, S.D., Cerdà, A., Pulido Fernández, M. 2018. Soil Erosion Induced by the Introduction of New Pasture Species in a Faxinal Farm of Southern Brazil. *Geosciences 8*(5), 166. https://doi.org/10.3390/geosciences8050166.

Barros, A., Gonnet, J., Pickering, C. 2013. Impacts of informal trails on vegetation and soils in the highest protected area in the Southern Hemisphere. *Journal of Environmental Management* 127, 50-60. https://doi.org/10.1016/j.jenvman.2013.04.030.

Beeco, J.A., Hallo, J.C., Giumetti, G.W. 2013. The importance of spatial nested data in understanding the relationship between visitor use and landscape impacts. *Applied Geography* 45, 147-157. https://doi.org/10.1016/j.apgeog.2013.09.001.

Begum, F., Bajracharya, R.M., Sharma, S., Sitaula, B.K. 2010. Influence of slope aspect on soil physico-chemical and biological properties in the mid hills of central Nepal. *International Journal of Sustainable Development & World Ecology* 17 (5), 438-443. https://doi.org/10.1080/13504509.2010.499034.

Bodoque, J.M., Ballesteros-Cánovas, J.A., Rubiales, J.M., Perucha, M.Á., Nadal-Romero, E., Stoffel, M. 2017. Quantifying Soil Erosion from Hiking Trail in a Protected Natural Area in the Spanish Pyrenees. *Land Degradation & Development* 28, 2255-2267. https://doi.org/10.1002/ldr.2755.

Bodoque, J.M., Díez-Herrero, A., Martín-Duque, J.F., Rubiales, J.M., Godfrey, A., Pedraza, J., Carrasco, R.M., Sanz, M.A. 2005. Sheet erosion rates determined by using dendrogeomorphological analysis of exposed tree roots: two examples from Central Spain. *Catena* 64 (1), 81-102. https://doi.org/10.1016/j.catena.2005.08.002.

Bojie, F., Xilin, W., Gulinck, H. 1995. Soil erosion types in the Loess Hill and Gully area of China. J*ournal of Environmental Science and Engineering* 7, 266-272. https://doi.org/10.1002/ldr.3400050105.

Borgers, J., Thibaut, E., Vandermeerschen, H., Vanreusel, B., Vos, S., Scheerder, J. 2015. Sports participation styles revisited: A time-trend study in Belgium from the 1970s to the 2000s. *International Review for the Sociology of Sport* 50 (1), 45-63. https://doi.org/10.1177/1012690212470823.

Bowker, J.M., Bergstrom, J.C., Gill, J. 2007. Estimating the economic value and impacts of recreational trails: a case study of the Virginia Creeper Rail Trail. *Tourism Economics* 13 (2), 241-260.

Bratton, S.P., Hickler, M.G., Graves, J.H. 1979. Trail erosion patterns in Great Smoky Mountains National Park. *Environmental Management* 3 (5), 431-445. https://doi.org/10.1007/BF01866582.

Brevik, E.C., Pereg, L., Steffan, J.J., Burgess, L.C. 2018. Soil ecosystem services and human health. *Current Opinion in Environmental Science & Health* 5, 87-92. https://doi.org/10.1016/j.coesh.2018.07.003.

Buol, S.W., Southard, R.J., Graham, R.C., McDaniel, P.A. 2011. *Soil genesis and classification*. John Wiley & Sons.

Burden, R.F., Randerson, P.F. 1972. Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. *Journal of Applied Ecology* 9 (2), 439-457. https://doi.org/10.2307/2402445.

Burr, J.F., Drury, C.T., Phillips, A.A., Ivey, A., Ku, J., Warburton, D.E. 2014. Long-term ultra-marathon running and arterial compliance. *Journal of Science and Medicine in Sport* 17 (3), 322-325. https://doi.org/10.1016/j.jsams.2013.04.018.

Butzer, K.W. 2005. Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion. *Journal of Archaeological Science* 32 (12), 1773-1800. https://doi.org/10.1016/j.jas.2005.06.001.

Cao, L., Zhang, K., Liang, Y. 2014. Factors affecting rill erosion of unpaved loess roads in China. *Earth Surface Processes and Landforms* 39 (13), 1812-1821. https://doi.org/10.1002/esp.3569.

Cerdà, A. 1998. The influence of aspect and vegetation on seasonal changes in erosion under rainfall simulation on a clay soil in Spain. *Canadian Journal of Soil Science* 78 (2), 321-330. https://doi.org/10.4141/S97-060.

Cerdà, A., Imeson, A.C., Calvo, A. 1995. Fire and aspect induced differences on the erodibility and hydrology of soils at La Costera, Valencia, southeast Spain. *Catena* 24 (4), 289-304. https://doi.org/10.1016/0341-8162(95)00031-2.

Cerdà, A., Rodrigo-Comino, J., Giménez-Morera, A., Keesstra, S. D. 2018. Hydrological and erosional impact and farmer's perception on catch crops and weeds in citrus organic farming in Canyoles river watershed, Eastern Spain. *Agriculture, Ecosystems & Environment* 258, 49-58. https://doi.org/10.1016/j.agee.2018.02.015.

Chavez, D.J., Winter, P.L., Baas, J.M. 1993. Recreational mountain biking: A management perspective. *Journal of Park and Recreation Administration* 11 (3), 29-36.

Comita, L.S., Goldsmith, G.R. 2008. Impact of research trails on seedling dynamics in a tropical forest. *Biotropica* 40(2), 251-254. https://doi.org/10.1017/S0266467405002890.

Creagh, U., Reilly, T., Lees, A. 1998. Kinematics of running on 'off-road' terrain. *Ergonomics* 41 (7), 1029-1033. https://doi.org/10.1080/001401398186577.

Ćwiąkała, P., Kocierz, R., Puniach, E., Nędzka, M., Mamczarz, K., Niewiem, W., Wiącek, P. 2017. Assessment of the Possibility of Using Unmanned Aerial Vehicles (UAVs) for the Documentation of Hiking Trails in Alpine Areas. *Sensors* 18 (1), 81. https://doi.org/10.3390/s18010081.

Dale, D., Weaver, T. 1974. Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. *Journal of Applied Ecology* 11 (2), 767-772. https://doi.org/10.2307/2402226.

Deluca, T.H., Patterson, L.V., Freimund, W.A., Cole, D.N. 1998. Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA. *Environmental Management* 22 (2), 255-262. https://doi.org/10.1007/s002679900101.

Di Prima, S., Lassabatere, L., Rodrigo-Comino, J., Marrosu, R., Pulido, M., Angulo-Jaramillo, R., Pirastru, M. 2018. Comparing transient and steady-state analysis of single-ring infiltrometer data for an abandoned field affected by fire in Eastern Spain. *Water* 10 (4), 514. https://doi.org/10.3390/w10040514.

Duglio, S., Beltramo, R. 2017. Estimating the economic impacts of a small-scale sport tourism event: The case of the Italo-Swiss mountain trail CollonTrek. *Sustainability* 9 (3), 343. https://doi.org/10.3390/su9030343.

Esque, T.C., Inman, R., Nussear, K.E., Webb, R.H., Girard, M.M., DeGayner, J. 2016. Comparison of Methods to Monitor the Distribution and Impacts of Unauthorized Travel Routes in a Border Park. *Natural Areas Journal* 36 (3), 248-258. https://doi.org/10.3375/043.036.0305.

Farias-Torbidoni, E.I., Urbaneja, J.S., Ferrer, R., Dorado, V. 2018. Carreras de trail running y marchas por montaña en España. Número, evolución e incidencia sobre la Red Natura 2000. *Pirineos* 173, 9-18.

Farrell, T.A., Marion, J.L. 2001. Trail impacts and trail impact management related to visitation at Torres del Paine National Park, Chile. *Leisure/Loisir* 26 (1-2), 31-59. https://doi.org/10.1080/14927713.2001.9649928.

Farrell, T.A., Marion, J.L. 2001. Identifying and assessing ecotourism visitor impacts at eight protected areas in Costa Rica and Belize. *Environmental Conservation* 28 (3), 215-225. https://doi.org/10.1017/S0376892901000224.

Feng, T., Wei, W., Chen, L., Rodrigo-Comino, J., Die, C., Feng, X., Yu, Y. 2018. Assessment of the impact of different vegetation patterns on soil erosion processes on semiarid loess slopes. *Earth Surface Processes and Landforms* 43 (9), 1860-1870. https://doi.org/10.1002/esp.4361.

Fish, E.B., Brothers, G.L., Lewis, R.B. 1981. Erosional impacts of trails in Guadalupe Mountains National Park, Texas. *Landscape Planning* 8 (4), 387-398. https://doi.org/10.1016/0304-3924(81)90004-6.

Fix, P., Loomis, J. 1997. The economic benefits of mountain biking at one of its meccas: An application of the travel cost method to mountain biking in Moab, Utah. *Journal of Leisure Research* 29 (3), 342-352. https://doi.org/10.1080/00222216.1997.11949800.

Fox, D., Berolo, W., Carrega, P., Darboux, F. 2006. Mapping erosion risk and selecting sites for simple erosion control measures after a forest fire in Mediterranean France. *Earth Surface Processes and Landforms* 31 (5), 606-621. https://doi.org/10.1002/esp.1346.

García-Ruiz, J.M. 2010. The effects of land uses on soil erosion in Spain: a review. *Catena* 81 (1), 1-11. https://doi.org/10.1016/j.catena.2010.01.001.

García-Ruiz, J.M., Lana-Renault, N. 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region–a review. *Agriculture, Ecosystems & Environment* 140 (3-4), 317-338. https://doi.org/10.1016/j.agee.2011.01.003.

García-Ruiz, J.M., Beguería, S., Lana-Renault, N., Nadal-Romero, E., Cerdà, A. 2017. Ongoing and emerging questions in water erosion studies. *Land Degradation & Development* 28 (1), 5-21. https://doi.org/10.1002/ldr.2641.

Goeft, U., Alder, J. 2001. Sustainable mountain biking: a case study from the southwest of Western Australia. *Journal of Sustainable Tourism* 9 (3), 193-211. https://doi.org/10.1080/09669580108667398.

González-Hidalgo, J.C., Peña-Monné, J.L., de Luis, M. 2007. A review of daily soil erosion in Western Mediterranean areas. *Catena* 71 (2), 193-199. https://doi.org/10.1016/j.catena.2007.03.005.

Hawkins, J., Weintraub, M.N. 2011. The Effect of Trails on Soil in the Oak Openings of Northwest Ohio. *Natural Areas Journal* 31 (4), 391-399. https://doi.org/10.3375/043.031.0409.

Helgath, S.F. 1975. *Trail deterioration in the Selway-Bitterroot wilderness* (Research Note INT 193). USDA Forest Service. 15 pp.

Hoffman, M.D., Ong, J.C., Wang, G. 2010. Historical analysis of participation in 161 km ultramarathons in North America. *The International Journal of the History of Sport* 27 (11), 1877-1891. https://doi.org/10.1080/09523367.2010.494385.

Hughes, P.J. 1972. Slope aspect and tunnel erosion in the loess of Banks Peninsula, New Zealand. *Journal of Hydrology (New Zealand)* 11 (2), 94-98.

Inbar, M., Tamir, M.I., Wittenberg, L. 1998. Runoff and erosion processes after a forest fire in Mount Carmel, a Mediterranean area. *Geomorphology* 24 (1), 17-33. https://doi.org/10.1016/S0169-555X(97)00098-6.

Jackson, E.L. 1986. Outdoor recreation participation and attitudes to the environment. *Leisure Studies* 5 (1), 1-23. https://doi.org/10.1080/02614368600390011.

Jackson, E.L. 1987. Outdoor recreation participation and views on resource development and preservation. *Leisure Sciences* 9 (4), 235-250. https://doi.org/10.1080/01490408709512165.

Jewell, M.C., Hammitt, W.E. 2000. Assessing soil erosion on trails: a comparison of techniques. In: D.N. Cole, F.S. McCool, T.W. Borrie, J. O'Loughlin (Comps.), *Wilderness Science in a time of change Conference- Volume 5: Wilderness ecosystems, threats, and management*. USDA Forest Service. pp. 133-140.

Johnson, C.W., Smith, J.P. 1983. Soil loss caused by off-road vehicle use on steep slopes. *Transactions of the ASAE* 26 (2), 402-405.

Keesstra, S.D., Temme, A.J.A.M., Schoorl, J.M., Visser, S.M. 2014. Evaluating the hydrological component of the new catchment-scale sediment delivery model LAPSUS-D. *Geomorphology* 212, 97-107. https://doi.org/10.1016/j.geomorph.2013.04.021.

Keesstra, S., Nunes, J.P., Saco, P., Parsons, T., Poeppl, R., Masselink, R., Cerdà, A. 2018. The way forward: Can connectivity be useful to design better measuring and modelling schemes for water and sediment dynamics? *Science of the Total Environment* 644, 1557-1572. https://doi.org/10.1016/j.scitotenv.2018.06.342.

Keesstra, S., Mol, G., de Leeuw, J., Okx, J., de Cleen, M., Visser, S. 2018. Soil-Related Sustainable Development Goals: Four Concepts to Make Land Degradation Neutrality and Restoration Work. *Land* 7 (4), 133. https://doi.org/10.3390/land7040133.

Kidd, K.R., Aust, W.M., Copenheaver, C.A. 2014. Recreational stream crossing effects on sediment delivery and macroinvertebrates in Southwestern Virginia, USA. *Environmental management* 54 (3), 505-516. https://doi.org/10.1007/s00267-014-0328-5.

Kirchhoff, M., Rodrigo-Comino, J., Seeger, M., Ries, J.B. 2017. Soil erosion in sloping vineyards under conventional and organic land use managements (Saar-Mosel valley, Germany). *Cuadernos de Investigación Geográfica* 43 (1), 119-140. https://doi.org/10.18172/cig.3161.

Knechtle, B., Rosemann, T., Zingg, M.A., Rüst, C.A. 2015. Increase in participation but decrease in performance in age group mountain marathoners in the 'Jungfrau Marathon': a Swiss phenomenon? *Springerplus* 4 (1), 523. https://doi.org/10.1186/s40064-015-1330-y.

Knoth, C., Knechtle, B., Rüst, C.A., Rosemann, T., Lepers, R. 2012. Participation and performance trends in multistage ultramarathons—the 'Marathon des Sables' 2003–2012. *Extreme Physiology & Medicine* 1 (1), 13. https://doi.org/13.10.1186/2046-7648-1-13.

Kutiel, P. 1992. Slope aspect effect on soil and vegetation in a Mediterranean ecosystem. *Israel Journal of Botany* 41 (4-6), 243-250. https://doi.org/10.1080/0021213X.1992.10677231.

Kutiel, P., Lavee, H. 1999. Effect of slope aspect on soil and vegetation properties along an aridity transect. *Israel Journal of Plant Sciences* 47 (3), 169-178.

Lana-Renault, N., López-Vicente, M., Nadal-Romero, E., Ojanguren, R., Llorente, J.A., Errea, P., Pascual, N. 2018. Catchment based hydrology under post farmland abandonment scenarios. *Cuadernos de Investigación Geográfica* 44 (2), 503-534. http://doi.org/10.18172/cig.3475.

Lasanta-Martínez, T., Vicente-Serrano, S.M., Cuadrat-Prats, J.M. 2005. Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. *Applied Geography* 25 (1), 47-65. https://doi.org/10.1016/j.apgeog.2004.11.001.

Lasanta, T., Nadal-Romero, E., García-Ruiz, J.M. 2019. Clearing shrubland as a strategy to encourage extensive livestock farming in the Mediterranean mountains. *Cuadernos de Investigación Geográfica* 45. http://doi.org/10.18172/cig.3616.

Leung, Y.F., Marion, J.L. 2000. Recreation impacts and management in wilderness: a state-of-knowledge review. In: N.D Cole, F.S. McCool, T.W. Borrie, J. O'Loughlin (Comps.), *Wilderness Science in a time of change Conference- Volume 5: Wilderness ecosystems, threats, and management*. USDA Forest Service, pp. 23-48.

Liddle, M.J. 1975. A selective review of the ecological effects of human trampling on natural ecosystems. *Biological Conservation* 7 (1), 17-36. https://doi.org/10.1016/0006-3207(75)90028-2.

López-Vicente, M., Navas, A. 2009. Predicting soil erosion with RUSLE in Mediterranean agricultural systems at catchment scale. *Soil Science* 174 (5), 272-282. http://doi.org/10.1097/SS.0b013e3181a4bf50.

López-Vicente, M., Poesen, J., Navas, A., Gaspar, L. 2013. Predicting runoff and sediment connectivity and soil erosion by water for different land use scenarios in the Spanish Pre-Pyrenees. *Catena* 102, 62-73. https://doi.org/10.1016/j.catena.2011.01.001.

Måren, I.E., Karki, S., Prajapati, C., Yadav, R.K., Shrestha, B.B. 2015. Facing north or south: Does slope aspect impact forest stand characteristics and soil properties in a semiarid trans-Himalayan valley? *Journal of Arid Environments* 121, 112-123. https://doi.org/10.1016/j.jaridenv.2015.06.004.

Marion, J.L., Leung, Y.F. 2004. Environmentally sustainable trail management. In: R. Buckley (Ed.). *Environmental impact of tourism*. CABI Publishing, Wallingford, pp. 229-244.

Marion, J.L., Olive, N. 2006. *Assessing and understanding trail degradation: results from Big South Fork National River and recreational area*. US Geological Survey. 84 pp. https://doi.org/10.3133/5200309.

Marques, M.A., Mora, E. 1992. The influence of aspect on runoff and soil loss in a Mediterranean burnt forest (Spain). *Catena* 19 (3-4), 333-344. https://doi.org/10.1016/0341-8162(92)90007-X.

Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M. 2002. Soil erosion caused by extreme rainfall events: mapping and quantification in agricultural plots from very detailed digital elevation models. *Geoderma* 105 (1-2), 125-140. https://doi.org/10.1016/S0016-7061(01)00096-9.

Masselink, R., Temme, A J.A.M., Giménez, R., Casalí, J., Keesstra, S.D. 2017a. Assessing hillslope-channel connectivity in an agricultural catchment using rare-earth oxide tracers and random forests models. *Cuadernos de Investigación Geográfica* 43 (1), 17-39. http://doi.org/10.18172/cig.3169.

Masselink, R.J., Heckmann, T., Temme, A.J., Anders, N.S., Gooren, H.P., Keesstra, S.D. 2017b. A network theory approach for a better understanding of overland flow connectivity. *Hydrological Processes* 31 (1), 207-220. https://doi.org/10.1002/hyp.10993.

Monz, C.A., Cole, D.N., Leung, Y.F., Marion, J. L. 2010. Sustaining visitor use in protected areas: future opportunities in recreation ecology research based on the USA experience. *Environmental Management* 45 (3), 551-562. http://doi.org/10.1007/s00267-009-9406-5.

Morgan, R.P.C., Smith, A.J. 1980. Simulation of soil erosion induced by human trampling. *Journal of Environmental Management* 10, 155-165.

Munns, E.N. 1920. Chaparral cover, run-off, and erosion. *Journal of Forestry* 18 (8), 806-814. https://doi.org/10.1093/jof/18.8.806.

Nepal, S K. 2003. Trail impacts in Sagarmatha (Mt. Everest) National park, Nepal: a logistic regression analysis. *Environmental Management*, 32 (3), 312-321. . https://doi.org/10.1007/s00267-003-0049-7.

Nepal, S.K., Nepal, S.A. 2004. Visitor impacts on trails in the Sagarmatha (Mt. Everest) National Park, Nepal. *Ambio* 33 (6), 334-340.

Nepal, S.K., Way, P. 2007. Characterizing and comparing backcountry trail conditions in Mount Robson Provincial Park, Canada. *Ambio* 36 (5), 394-400.

Newsome, D., Davies, C. 2009. A case study in estimating the area of informal trail development and associated impacts caused by mountain bike activity in John Forest National Park, Western Australia. *Journal of Ecotourism*, 8 (3), 237-253. https://doi.org/10.1080/14724040802538308.

Olive, N.D., Marion, J.L. 2009. The influence of use-related, environmental, and managerial factors on soil loss from recreational trails. *Journal of Environmental Management* 90 (3), 1483-1493. https://doi.org/10.1016/j.jenvman.2008.10.004.

Olivero, A.M., Hix, D.M. 1998. Influence of aspect and stand age on ground flora of southeastern Ohio forest ecosystems. *Plant Ecology* 139 (2), 177-187. https://doi.org/10.1023/A:1009758501201.

Pausas, J.G., Carbó, E., Caturla, R.N., Gil, J.M., Vallejo, R. 1999. Post-fire regeneration patterns in the eastern Iberian Peninsula. *Acta Oecologica* 20 (5), 499-508. https://doi.org/10.1016/S1146-609X(00)86617-5.

Pelfini, M., Santilli, M. 2006. Dendrogeomorphological analyses on exposed roots along two mountain hiking trails in the Central Italian Alps. *Geografiska Annaler: Series A. Physical Geography* 88 (3), 223-236. https://doi.org/10.1111/j.1468-0459.2006.00297.x.

Phillips, J.D., Turkington, A.V., Marion, D.A. 2008. Weathering and vegetation effects in early stages of soil formation. *Catena* 72 (1), 21-28. https://doi.org/10.1016/j.catena.2007.03.020.

Ramos-Scharrón, C.E., Reale-Munroe, K., Atkinson, S.C. 2014. Quantification and modeling of foot trail surface erosion in a dry sub-tropical setting. *Earth Surface Processes and Landforms* 39 (13), 1764-1777. https://doi.org/10.1002/esp.3558.

Randall, M., Newsome, D. 2008. Assessment, evaluation and a comparison of planned and unplanned walk trails in coastal south-western Australia. *Conservation Science Western Australia* 7 (1), 19-34.

Rochat, N., Hauw, D., Philippe, R.A., von Roten, F.C., Seifert, L. 2017. Comparison of vitality states of finishers and withdrawers in trail running: An enactive and phenomenological perspective. *PloS One* 12 (3), e0173667. https://doi.org/10.1371/journal.pone.0173667.

Rodrigo-Comino, J., Keesstra, S., Cerdà, A. 2018. Soil Erosion as an environmental concern in vineyards. The case study of Celler del Roure, Eastern Spain, by means of rainfall simulation experiments. *Beverages* 4 (2), 31. https://doi.org/10.3390/beverages4020031.

Rodrigo-Comino, J., Taguas, E., Seeger, M., Ries, J.B. 2018. Quantification of soil and water losses in an extensive olive orchard catchment in Southern Spain. *Journal of Hydrology* 556, 749-758. https://doi.org/10.1016/j.jhydrol.2017.12.014.

Sack, D., Da Luz, S. 2003. Sediment flux and compaction trends on off-road vehicle (ORV) and other trails in an Appalachian forest setting. *Physical Geography* 24 (6), 536-554. https://doi.org/10.2747/0272-3646.24.6.536.

Scheer, B.V., Murray, A. 2011. Al Andalus Ultra Trail: an observation of medical interventions during a 219-km, 5-day ultramarathon stage race. *Clinical Journal of Sport Medicine* 21 (5), 444-446. https://doi.org/10.1097/JSM.0b013e318225b0df.

Serra, P., Pons, X., Saurí, D. 2008. Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. *Applied Geography* 28 (3), 189-209. https://doi.org/10.1016/j.apgeog.2008.02.001.

Shakesby, R.A. 2011. Post-wildfire soil erosion in the Mediterranean: review and future research directions. *Earth-Science Reviews* 105 (3-4), 71-100. https://doi.org/10.1016/j.earscirev.2011.01.001.

Sidari, M., Ronzello, G., Vecchio, G., Muscolo, A. 2008. Influence of slope aspects on soil chemical and biochemical properties in a Pinus laricio forest ecosystem of Aspromonte (Southern Italy). *European Journal of Soil Biology* 44 (4), 364-372. https://doi.org/10.1016/j.ejsobi.2008.05.001.

Sidle, R C., Brown, R.W., Williams, B.D. 1993. Erosion processes on arid minespoil slopes. *Soil Science Society of America Journal* 57 (5), 1341-1347. https://doi.org/10.2136/sssaj1993.03615995005700050030x.

Smith, J.R. 1914. Soil erosion and its remedy by terracing and tree planting. *Science* 39 (1015), 858-862.

Smith, R.M., Stamey, W.L. 1965. Determining the range of tolerable erosion. *Soil Science* 100 (6), 414-424.

Sterl, P., Brandenburg, C., Arnberger, A. 2008. Visitors' awareness and assessment of recreational disturbance of wildlife in the Donau-Auen National Park. *Journal for Nature Conservation*, 16 (3), 135-145. https://doi.org/10.1016/j.jnc.2008.06.001.

Sternberg, M., Shoshany, M. 2001. Influence of slope aspect on Mediterranean woody formations: comparison of a semiarid and an arid site in Israel. *Ecological Research* 16 (2), 335-345. https://doi.org/10.1046/j.1440-1703.2001.00393.x.

Stull, R., Shipley, S., Hovanitz, E., Thompson, S., Hovanitz, K. 1979. Effects of off-road vehicles in Ballinger Canyon, California. *Geology* 7 (1), 19-21. https://doi.org/10.1130/0091-7613(1979)7<19:EOOVIB>2.0.CO;2.

Symmonds, M.C., Hammitt, W.E., Quisenberry, V.L. 2000. Managing recreational trail environments for mountain bike user preferences. *Environmental Management* 25 (5), 549-564. https://doi.org/10.1007/s002679910043.

Tarolli, P., Calligaro, S., Cazorzi, F., Fontana, G.D. 2013. Recognition of surface flow processes influenced by roads and trails in mountain areas using high-resolution topography. *European Journal of Remote Sensing* 46 (1), 176-197. https://doi.org/10.5721/EuJRS20134610.

Thurston, E., Reader, R.J. 2001. Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest. *Environmental management* 27 (3), 397-409. https://doi.org/10.1007/s002670010157.

Tomczyk, A.M., White, P.C., Ewertowski, M.W. 2016. Effects of extreme natural events on the provision of ecosystem services in a mountain environment: The importance of trail design in delivering system resilience and ecosystem service co-benefits. *Journal of Environmental Management* 166, 156-167. https://doi.org/10.1016/j.jenvman.2015.10.016.

Turnbull, L., Hütt, M.T., Ioannides, A.A., Kininmonth, S., Poeppl, R., Tockner, K., Bracken, L., Keesstra, S., Liu, L., Masselink, R., Parsons, A.J. 2018. Connectivity and complex systems: learning from a multi-disciplinary perspective. *Applied Network Science* 3 (1), 11. https://doi.org/10.1007/s41109-018-0067-2.

van Breda Weaver, A. 1991. The distribution of soil erosion as a function of slope aspect and parent material in Ciskei, Southern Africa. *GeoJournal* 23 (1), 29-34. https://doi.org/10.1007/BF00204406.

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J., Smith, C.J. 2009. Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews* 94, 23-38. https://doi.org/10.1016/j.earscirev.2009.02.003.

Wallin, T.R., Harden, C.P. 1996. Estimating trail-related soil erosion in the humid tropics: Jatun Sacha, Ecuador, and La Selva, Costa Rica. *Ambio* 25 (8), 517-522.

Webb, R.H., Ragland, H.C., Godwin, W.H., Jenkins, O. 1978. Environmental effects of soil property changes with off-road vehicle use. *Environmental Management* 2 (3), 219-233. https://doi.org/10.1007/BF01866550.

White, R.G., Schreyer, R. 1981. Nontraditional uses of the National Parks. *Leisure Sciences* 4 (3), 325-341. https://doi.org/10.1080/01490408109512971.

Willard, B.E., Marr, J.W. 1971. Recovery of alpine tundra under protection after damage by human activities in the Rocky Mountains of Colorado. *Biological Conservation* 3 (3), 181-190. https://doi.org/10.1016/0006-3207(71)90162-5.

Wimpey, J.F., Marion, J.L. 2010. The influence of use, environmental and managerial factors on the width of recreational trails. *Journal of Environmental Management* 91 (10), 2028-2037. https://doi.org/10.1016/j.jenvman.2010.05.017.

Wolf, I.D., Wohlfart, T. 2014. Walking, hiking and running in parks: A multidisciplinary assessment of health and well-being benefits. *Landscape and Urban Planning* 130, 89-103. https://doi.org/10.1016/j.landurbplan.2014.06.006.