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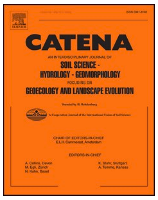

Shrub removal effects on runoff and sediment transport in a mediterranean experimental catchment (Vernegà River, NE Spain)

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ABSTRACT

Shrub removal works in the Gavarres massif (NE Spain) have impacted runoff and sediment transport in a first-order experimental catchment (2.5 km^2), named Vernegà. These works have consisted in removing the shrub layer that grows under a typical mixture of cork oak tree and Mediterranean pine forest, and have been undertaken regularly since 2002 to reduce risk of forest fire and increase cork oak productivity. In 2005, the works affected the catchment headwaters, resulting in significant changes in runoff and sediment transport rates. This study aimed to assess short-term changes in runoff and sediment transport rates in the experimental catchment by comparing them to rates prior to 2005.

Measurements were made at two monitoring stations within the basin: i) Bosc (1.6 km^2), where the main land use is forest; and ii) Campàs (2.5 km^2), the catchment outlet, where the main land use is agriculture.

Mean annual runoff increased from 11.7 mm before 2005 to 33.1 mm after 2005 at the Bosc station. At the Campàs station, runoff increased from 81.9 mm to 92.2 mm. These changes can be observed in the flow duration curves of both stations. An increase on the frequency when low flows (<5 l/s) take place has been observed, while the occurrence of high flows remains unchanged. The low flow increase period had a concomitant reduction of the no flow period, which reduced about 30 days in Bosc station.

Suspended sediment yield increased from 250 kg·km^{-2}·yr^{-1} at Bosc and 430 kg·km^{-2}·yr^{-1} at Campàs to 940 kg·km^{-2}·yr^{-1} and 4,350 kg·km^{-2}·yr^{-1} respectively after forest works. Dissolved sediment yield also increased but did so solely as a result of the increase in runoff rates rather than of the increase in dissolved concentrations.

1. Introduction and study aims

Various studies examining the impact of forest management works (e.g. forest thinning, logging and timber harvesting) on the hydrological cycle have identified variations in runoff rates and changes in the annual water yield in river catchments (Hewlett and Hibbert, 1967; Stednick, 1996; Croke et al., 1999b). The associated increase in stream flow is reported as being a common outcome in several catchments across different climatic environments. For example, the classical study undertaken by Hewlett and Hibbert (1967) reported that a decrease in forest cover led to an increase in water yield, while Bosch and Hewlett (1982) estimated different increases in runoff rates according to forest type and harvested area. Additional studies reporting catchment and parcel experiments to determine the effects of forest harvesting on runoff have found a positive relationship whereby annual water yield increases with size of the harvested area (Stednick, 1996; Sahin and Hall, 1996; Johnson, 1998; Andréassian, 2004; Brown et al., 2005; Dung et al., 2012; Zhang et al., 2017; Úbeda et al., 2020).

Less attention has been paid to studying the effects and consequences of removal of the shrub layer or understory vegetation in a Mediterranean forest. One of the reasons for removing or thinning this shrub layer in Mediterranean forests is that it affects the forest ecosystem water budget by reducing soil moisture and increasing evapotranspiration rates (Prévosto et al., 2019), leading to competition for groundwater (Giuggiola et al., 2018). Another reason is that a dense shrub layer in Mediterranean forests represents a forest fire risk, and actions taken by administrations to reduce the risk of ignition and propagation include the removal of this layer (Baeza et al., 2005). In intermittent or non-perennial streams (i.e. a stream that flows in response to a seasonally fluctuating water table), there is evidence that forest management or disturbing the forest cover is associated with an increase in runoff and the length of the flow duration, especially in the case of low flows

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(Johnson, 1998; Gallart and Llorens, 2003). This is a very important issue to bear in mind in the management of this specific type of river, especially in Mediterranean environments (Borg et al., 2019), where water scarcity is increasing due to climatic factors, but also due to the stress placed on water resources by human demand (Gallart and Llorens, 2003) and tree densification due to land abandonment, absence of animal grazing and unmanaged forests (Rodríguez-Carreras et al., 2014; Llorens et al., 2018).

Other studies examining the geomorphological impact of forest management works on river channels have also observed changes in sediment dynamics and transport (Stott et al., 2001). The principal effects of forest works on rivers include the redistribution of sediment particles within river beds (Croke et al., 1999a); an increase in sediment concentrations in rivers close to managed areas (Jolicoeur et al., 2007); changes in sediment yields (Hotta et al., 2007); and alterations in river channel morphology (Church, 2002). In addition, the amount of sediment produced is important given that increased mobilisation of particulate sediment may affect flow competence (Croke et al., 1999a), hindering transportation and causing a build-up of sediment in the channel, which could produce alterations to aquatic life (Jolicoeur et al., 2007). Furthermore, the use of less aggressive harvesting techniques would prevent increases in suspended sediment yields in the harvested area (Hotta et al., 2007; Kreutzweiser et al., 2009), given that increased sediment yields in specific fluvial systems prone to drought periods may compromise water security (Owens, 2020).

Within this context, the aim of this paper is to evaluate the effects of shrub layer removal on runoff, water yield and sediment yield by comparing these outcomes with water and sediment data prior to shrub removal in a small experimental catchment located in a low mountain forest in the Mediterranean region.

2. Study area

The Vernegà experimental catchment (2.5 km^2) is a headwater and first-order intermittent stream, which lies within the Gavarres massif, a typical medium-sized Mediterranean mountain (533 m.a.s.l.), located in the north-east of the Iberian Peninsula (Fig. 1).

2.1. Climatology and hydrology

The study area has a Mediterranean sub-humid climate with an average annual rainfall of 688 mm according to rainfall records from 1983 to 2012. Rainfall exhibits a seasonal pattern, where annual maximum precipitation occurs in autumn, followed by spring, and both seasons together account for 60% of annual rainfall. Winter and summer are the dry seasons, with July being the driest month of the year (Pacheco et al., 2011).

2.2. Geology and soils

The underlying bedrock material is primarily granite, often highly weathered, forming weakly structured accumulations (Úbeda et al., 1998). Soil texture is loamy sand, with sands accounting for 80% of soil content and silts 18%. Clays only represent 2% and consequently, these soils show good porosity ranging from 54 to 63%, and exhibit a high infiltration capacity (Úbeda et al., 2012). Where conifers predominate, the organic matter content of the soil is 8.0%, while in the deciduous oak area it reaches 19%. Lastly, pH values tend to be acidic, ranging from 5.35 up to 6.69 (Úbeda et al., 2012).

2.3. Land use

Dense forest covers 1,6 km^2 of the study catchment and it is essentially conformed by a mixture of cork oak trees (*Quercus suber*), perennial oaks (*Quercus ilex* and *Quercus robur*) and different types of pine (mainly *Pinus halepensis*, *Pinus pinaster* and *Pinus pinea*,). The dense shrub layer emerged following forest degradation due to abandonment of traditional activities such as cork and wood extraction and vegetation

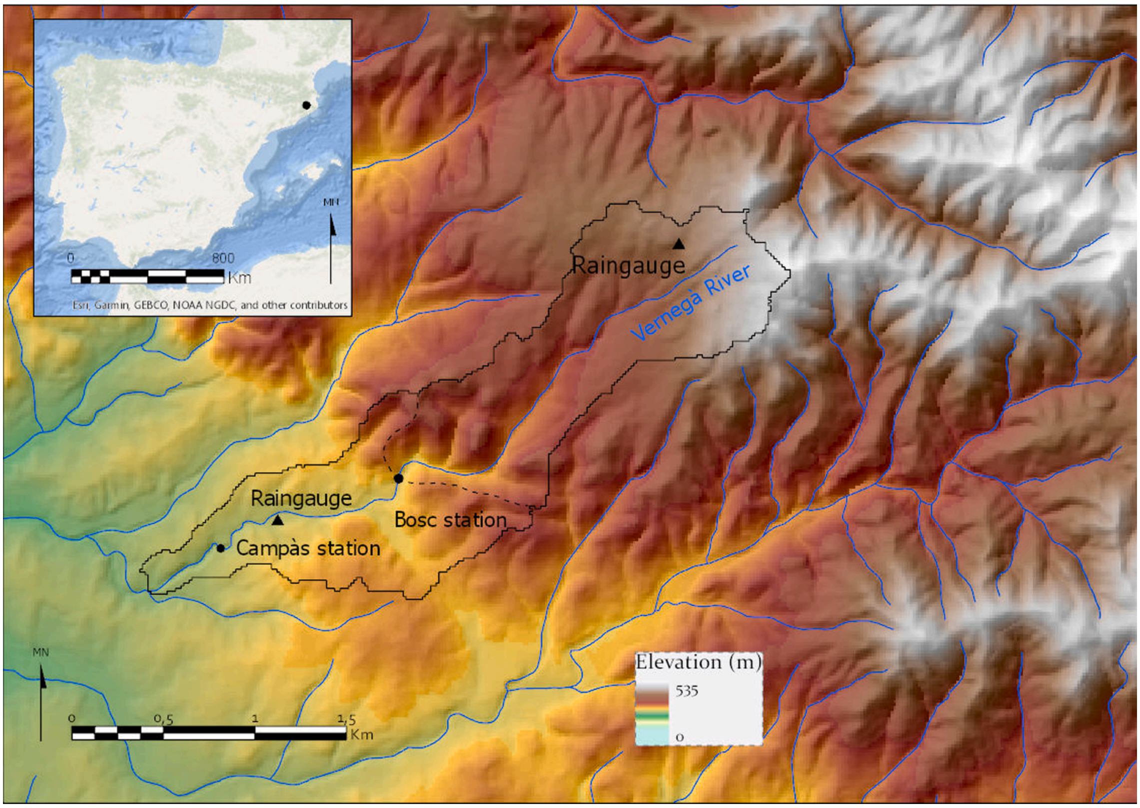

Fig. 1. Location and elevation of the study area.

regrowth after forest fires. Shrub formations are representative of typical Mediterranean species, of which the most dominant and abundant are *Rosmarinus officinalis*, *Thymus sylvestris*, *Erica arborea*, *Cistus albidus*, *Cistus salvifolius*, *Cistus monspeliensis*, *Arbutus unedo*, *Pistacia lentiscus* and *Ulex parviflorus* (Úbeda et al., 2012). The agricultural area of the catchment represents 0.98 km^2 and it is basically covered by annual cereal crops such as oats and ryegrass.

2.4. *Forest management plans*

Forest management practices have been implemented in Catalonia since 2002 as part of the regional land-use plans (Plana, 2011), implemented by the Center for Forest Property (CPF) through so-called Forest Planning Instruments (IOFs). These IOFs determine the actions that should be carried out in a forest parcel, for a period no longer than 10 years, to achieve the goals proposed by the landowner and the forest manager (Úbeda et al., 2020). Such goals include the reduction of forest fire risk, increase the forest production or the conservation of biodiversity (Plana, 2011).

The management practices undertaken in the study catchment affected 15% of the total catchment area (Fig. 2). These involved the use of heavy machinery to remove the shrub layer on the steeper part of the catchment, with slopes over 10% (Outeiro et al., 2010). The work sought to fulfil two main goals:

a) To reduce the risk of forest fires
b) To reduce competition between trees and shrubs for water and nutrients, thus encouraging growth and increasing wood and cork productivity.

These management practices were undertaken only in 2005. As a consequence of the use of heavy machinery, topsoil was left bare and loose soil particles were mobilised when heavy rains fell after shrub removal (Outeiro et al., 2010). Since then, no further shrub removal has been carried out in the catchment.

3. Materials and methods

Since its inception, the monitoring programme in the Vernegà experimental catchment has been aimed at comparing runoff and sediment production in two distinct areas within the catchment with different land uses. This has been achieved by installing two integrated gauging stations as follows.

3.1. *Research planning and discharge measurement*

The station at the outlet (named Campàs) was set up in 1993 and drains an area of 2.5 km^2. Land use in the area is a mixture of forest and agricultural fields, which represent 10% of the catchment area. The gauging station consists of a V-notch triangular section for low flows (those under 50 cm of stage) and a rectangular section for higher flows. The station is equipped with a manual OTT limnigraph and an automatic stage recorder, installed in 2007. An ISCO 3700 automatic pump

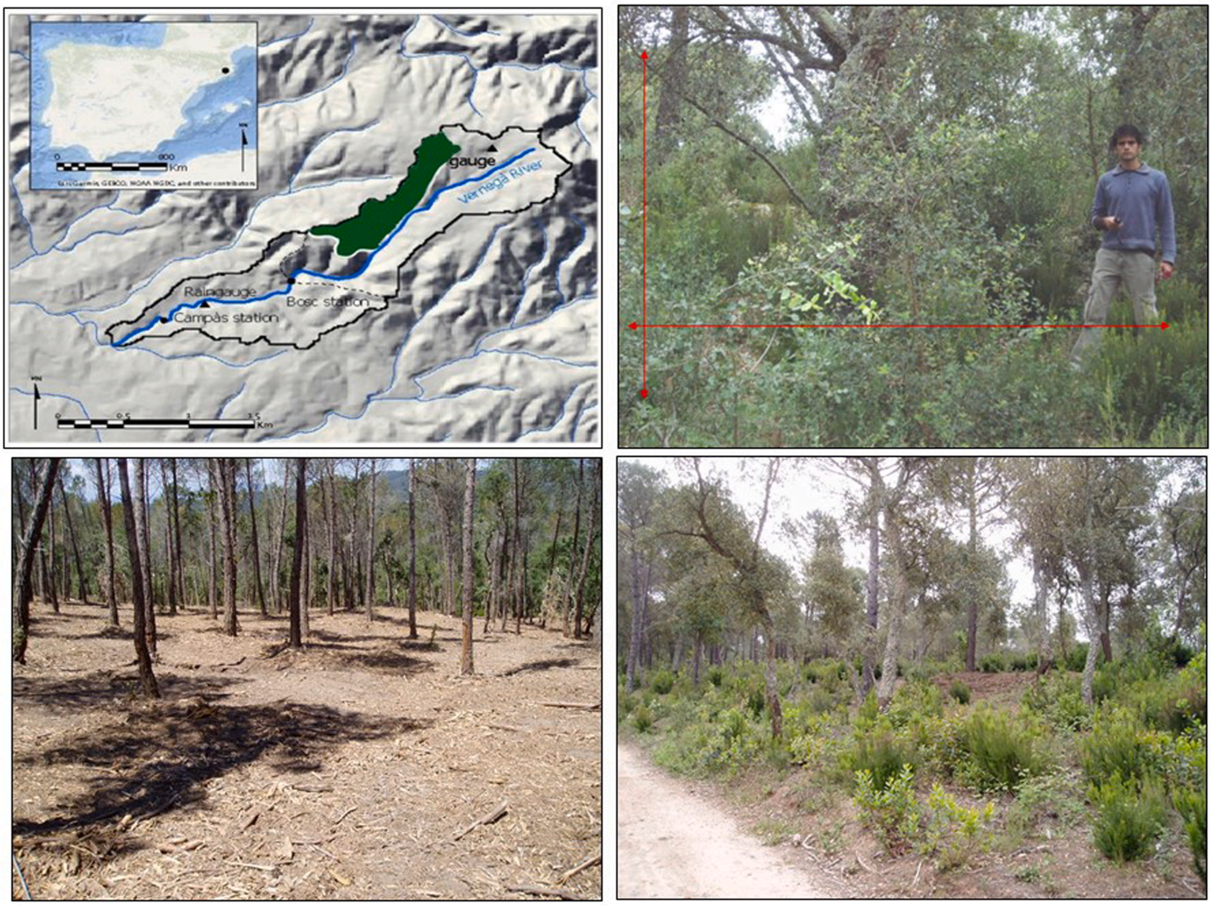

Fig. 2. (a) Shrub removal area within the Vernegà catchment in 2005 (shaded in dark green); (b) photograph of an area where no forest works have been undertaken. The arrows indicate the height and width of the shrub layer; (c) an area of the catchment where the shrub layer has been removed; (d) Example of an area after two years of shrub management (out of the study catchment but in the same massif). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sampler is used to obtain water and sediment samples.

The Bosc station was set up in 1995. It drains an area of 1.6 km^2 and controls runoff solely from the forested area (100% of the area). The measuring section has a narrow-crested spillway section consisting of a 45° triangle and a rectangular opening on top. The V-notch has an estimated capacity of 0.255 m^3s^{-1}. The highest point of the catchment reaches 440 m.a.s.l. and the outlet is located at 190 m.a.s.l. (Fig. 1). The river is 4 km long and the average slope is about 5%. The station has a manual OTT hydrograph to measure stage and an ISCO 3700 automatic sampler.

Rainfall data has been collected since 1983 using a Hellman manual rain gauge, and a complete automatic meteorological station was also installed in 1994 (Fig. 1).

Sediment is monitored by means of ISCO 3700 automatic pump samplers, which consist of cylindrical devices containing 24 plastic bottles. The sampler installed at Campàs has 1-litre capacity bottles, while the one installed at Bosc has 0.5-litre capacity bottles. Sampling frequency and volume is controlled by a computer programme. Sampling was conducted at hourly intervals during events and the volume collected was up to 750 ml at Campàs and up to 450 ml at Bosc. Water enters the bottle through an automatic arm. Each bottle is rinsed before taking a sample and once the bottle is full, the automatic arm moves forwards to the following bottle and waits for the next programmed sampling time (Sala and Farguell, 2002; Úbeda et al., 2020; Pacheco et al., 2011). The automatic sampler at Bosc was installed, however during 2003 and only some manual sediment records exist at Bosc station during 1995 and 2003. Data used for this period was extracted from Sala and Farguell (2002), and Outeiro et al. (2010).

Manual water samples were collected at weekly intervals during flow periods and at fortnightly intervals during dry periods (winter and summer, respectively).

3.2. Determination of sediment concentrations and data quality assurance

Suspended sediment refers to all soil particles —mainly silts and clays— travelling in suspension within a river and is produced largely by rock weathering processes but can also come from agricultural fields or unpaved forest roads, where soil particles are loose. Suspended sediment is generally transported during flood events, while dissolved concentrations are found within the water during the whole flow period.

Suspended sediment concentrations were obtained from samples by filtering 250 ml of sampled water through a 0.45 μm pore size filter using a vacuum pump. This pore size separates sediment transported in suspension (i. e. silts and clays) from that dissolved in water (ionic elements). Filters were weighed before filtration using a high-resolution scale. After filtration, samples were air dried in a sealed container and weighed again when dry. Sediment concentrations were computed according to the difference in filter weight divided by the volume of sample filtered (Úbeda et al., 2012).

In order to calculate sediment loads, the concentrations obtained were multiplied by hourly discharge. Organic matter was not subtracted from filtered samples. Soil descriptions based on early studies suggest that the organic content of soils was low according to the texture of soils in the study area, which are mainly sandy loam soils (Úbeda et al., 2012).

Dissolved sediment refers to all sediment travelling in ionic form within the water (i.e. dissolved). Such sediment is the result of rock weathering and other organic and inorganic processes within soils and rocks. When water flows over soil or rock, it collects ionic elements and transports them to the river. The amount of dissolved elements in a given volume of water determines the dissolved sediment concentration.

Such sediment concentrations are measured indirectly using a conductivity meter, which is based on the principle that water conducts electricity poorly but is a better conductor when it contains dissolved salts. Thus, as the amount of salt increases in water, the electrical conductivity value rises, and this is measured in μS/cm.

Concentrations were directly derived from conductivity values measured from water samples in the laboratory, using an EC-GLP 31 (CRISON®) conductivity meter. According to the manufacturer, the standard conversion factor is established at 0.64 (http://www.crisoninstruments.com). At the time in which we acquired this meter, a comparison between manual analysis of the dissolved concentration and the readings provided by the meter did not show significant differences. For this reason, we took for granted the concentration readings coming from the meter.

3.3. Determination of sediment load

Once sediment concentrations had been obtained, sediment load was computed by multiplying sediment concentration by discharge for a given unit of time, which was usually one hour. The result was multiplied again by a constant to change units, and the final result represents the amount of sediment (in kg) or specific sediment yield ($kg{\cdot}km^{-2}$), either for suspended or dissolved sediment.

Unfortunately, gaps on the measuring period due to gauging station sensors malfunction or periods during which sampling was impossible exist. For suspended and dissolved sediment load calculation, extrapolation using a sediment rating curve has been used in periods where flow was available. Although this procedure tends to underestimate or overestimate loads, it has been widely used in literature (Walling, 1977; Walling and Webb, 1981, 1988). However, for the period where no flow could be measured for economic or human resources constraints, no interpolation has been done and that year has not been considered nor for water yield nor sediment load. Major periods without data that have not been considered for the study are the water years 1997–98; 2003–04 and 2004–05.

4. Results

4.1. Changes in rainfall-runoff relationships

Precipitation in the study area showed a positive trend over the period 1983–2012 (p-value < 0.001) (Fig. 3). The lowest value in this period, 294 mm, was recorded in the year 1993–1994, while the maximum value, 1.038 mm, was recorded in the year 2003–04. The average for the above mentioned period was 699.4 mm and the mean for the period prior to shrub removal (1994–2005) was 699.6 mm. After shrub removal (2005–2012), mean annual rainfall was 719.3 mm.

Prior to shrub removal works, there was no relationship between rainfall and runoff at either stations (Fig. 4). Rainfall explained only 6% of the variance at both stations, indicating that other parameters exerted a stronger influence on the generation of direct runoff in the catchment such as interception by vegetation, evapotranspiration rates or infiltration and groundwater circulation. Following shrub removal, however, an improvement was observed in this relationship at both stations (R^2 Bosc $= 0.50$ and R^2 Campàs $= 0.52$). Furthermore, the higher the rainfall, the stronger the correlation, suggesting an enhanced association between rainfall and runoff, possibly due to a reduction in interception because of forest clearance. For low rainfall values (<20 mm), the scatter in the relationship remained (Fig. 4). The similar increase at both stations was probably linked to the nested stations, as an increase at Bosc was also observed at Campàs (Table 1).

4.2. Change in flow duration curves

The general increase of rainfall-runoff correlations had an effect on the flow duration curves at both stations in the same period (Fig. 5), especially for low and very low flows. At the Bosc station, for instance, the flows that increased duration were those smaller than 1 $l{\cdot}s^{-1}$. These flows were to occur 16% of the time before the shrub removal and after it, they were equalled or exceeded 29% of the time. Similarly, at Campàs

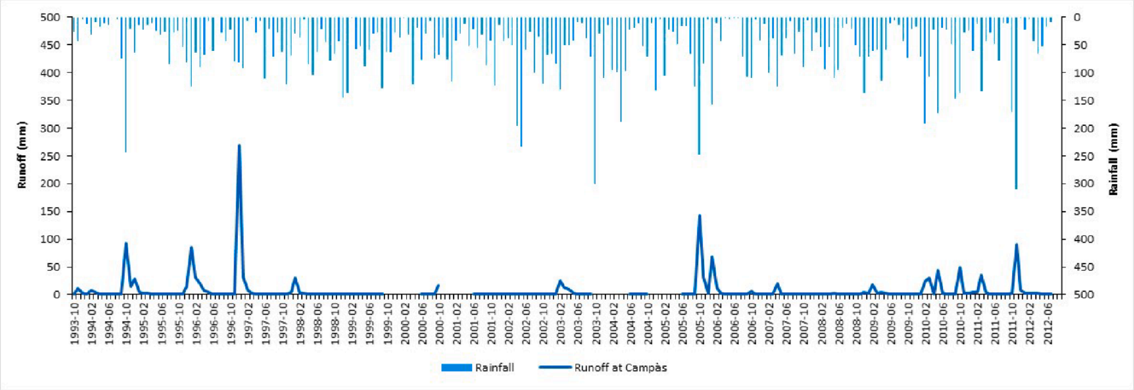

Fig. 3. Total anual rainfall during the study period and the associated runoff.

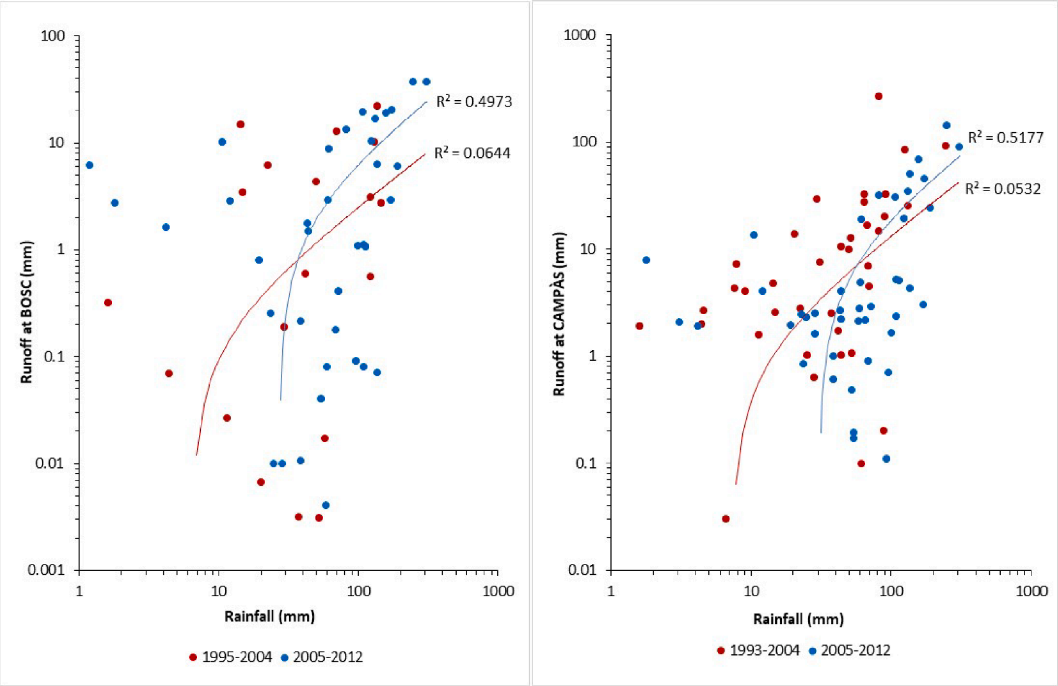

Fig. 4. Scatter plots between runoff and rainfall events at a) Bosc and b) Campàs stations during the periods prior and after the shrub removal.

Table 1

Mean annual values of rainfall, runoff and the runoff coefficient at the Bosc and Campàs stations before and after shrub layer removal.

Period of study	Annual rainfall (mm)	Annual runoff (mm)				Runoff Coefficient (%)	
	Mean	Mean		Std. Deviation			
		Bosc	*Campàs*	*Bosc*	*Campàs*	*Bosc*	*Campàs*
October 1st 1994/95 to September 30th 2004/05	681	11.7	81.9	2.14	16.4	1.7	12.0
October 1st 2005/06 to September 30th 2011/12	719	33.1	92.2	6.62	16.1	4.6	12.8

station, flows smaller than 3 $l\cdot s^{-1}$ increased its duration from 36% of the time up to 43% of the time.

The flow duration plots show that high flows, however, did not change at any station given that both lines remained essentially the same (Fig. 5). This fact suggests that the shrub forest clearance had not only effects on the direct runoff processes, but also on the amount of water infiltrating through soil and possibly enhancing groundwater recharge, although it has not been assessed in this study. Furthermore, these changes in the flow duration curves show a concomitant reduction in the zero-flow time. At the outlet, at Campàs station, the zero flow represented 56.3% of the time before the forest management works, while after them it decreased down to 54.9 %, which represented a decrease in 30 days per year in the number of no-flow days.

4.3. *Changes in sediment fluxes*

The most important change in relation to sediment concerned concentrations, especially of suspended sediment, reflecting land cover changes. Echoing the changes observed in runoff, an increase was detected in mean annual sediment concentrations at both stations

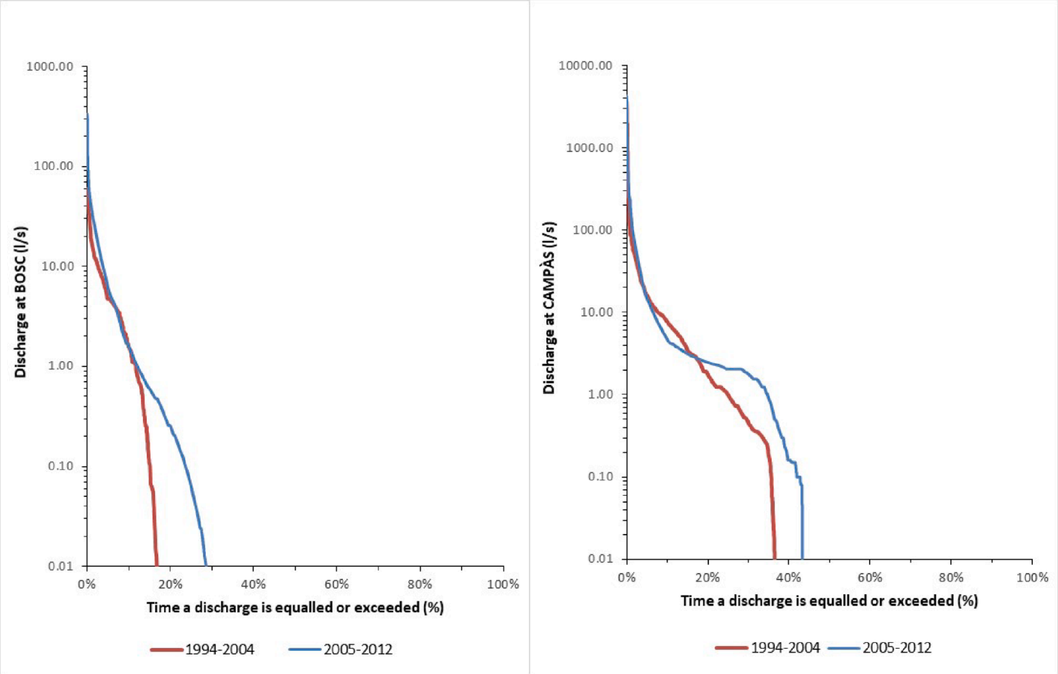

Fig. 5. Flow duration curves at a) Bosc and b) Campàs stations during the periods prior and after the shrub removal.

following shrub removal (Table 2).

4.3.1. *Changes in sediment concentrations*

Few data on solute or dissolved sediment concentrations at Bosc was available before the forest works, and records have been obtained from Sala and Farguell (2002), who reported mean values of 105 mg·l^{-1} and low variability in magnitude. Concentrations at Campàs were around 200 mg·l^{-1} for the period prior to forest management works. After them, although concentrations remained within the same order of magnitude, an increase of peak concentrations were detected at both stations, reaching 450 and 550 mg·l^{-1} at Bosc and Campàs respectively and occurring 10% of the time (Fig. 6a). This increase in the dissolved concentrations could be related to the increase of water infiltration and groundwater recharge, given that water incorporates dissolved ions from weathered rock and soils into it while flowing.

On the other side, suspended sediment concentrations were very low or meaningless at Bosc station before the forest management works, as reported by Sala and Farguell (2002). At Campàs station, suspended sediment were coming only from the agricultural fields, given that Bosc was not generating any sediment, and peak concentrations were as high as 200 mg·l^{-1} before forest works (Fig. 6b). After them, suspended sediment concentrations changed in three ways: a) concentrations increased dramatically at Bosc, reaching values greater than 100 mg·l^{-1} and occurred 20% of the time; b) peak concentrations increased at Campàs, reaching up 1,000 mg·l^{-1}, while before the management works were barely 100 mg·l^{-1}; and c) both stations show similar concentrations curves, which suggest that the main source of suspended sediment on the basin shifted from the agricultural fields in the forest catchment.

Table 2
Suspended and dissolved sediment yield before and after shrub removal.

	Mean annual suspended sediment yield (kg km^{-2}yr^{-1})		Mean annual dissolved sediment yield (kg km^{-2}yr^{-1})	
	Bosc	*Campàs*	*Bosc*	*Campàs*
October 1st 1994/95 to September 30th 2004/05	0.01	0.7	400	800
October 1st 2005/06 to September 30th 2011/12	940	4,340	1,540	7,100

Finally, there is a general decline of the magnitude of concentrations occurring from 10% up to 99% of the time in the catchment outlet, which could be related, in one hand, with the runoff increase and a concomitant dilution effect on sediment concentrations, and, on the other hand, with the settlement of sediment within the channel from the forested area to the outlet due to channel slope decrease and low magnitude events.

4.3.2. *Sediment yields*

The final consequence of increases in runoff and sediment concentrations shifts was a general increase in total sediment yield after shrub removal in the Vernegà catchment (Fig. 7a). However, differences existed when dealing with dissolved load or suspended load (Table 2). Dissolved sediment yield increased at both stations (Fig. 7b), due to the increase in runoff as well as the increase in dissolved concentrations alike at both sites. In this sense, the increase of the duration of the lower flows plays a very important role in increasing the dissolved sediment yield, given that the greater the time the water is flowing within the river, the greater the dissolved sediment yield.

On the other side, suspended sediment yield at Bosc station increased by one order of magnitude, due to shrub removal, which eliminated soil cover, combined with good connectivity between slopes and channel. However, at the catchment outlet (Campàs) a reduction on suspended sediment yield was observed, possibly due to the decrease of mean concentrations which has been greater than the increase in runoff (Fig. 7c).

5. Discussion

5.1. *Runoff changes*

According to results, mean annual runoff at Bosc station increased by 22 mm·yr^{-1}, while at Campàs the increase was 11 mm·yr^{-1}. These results lie within the orders of magnitude documented by several authors that reported these similar changes in runoff according to vegetation

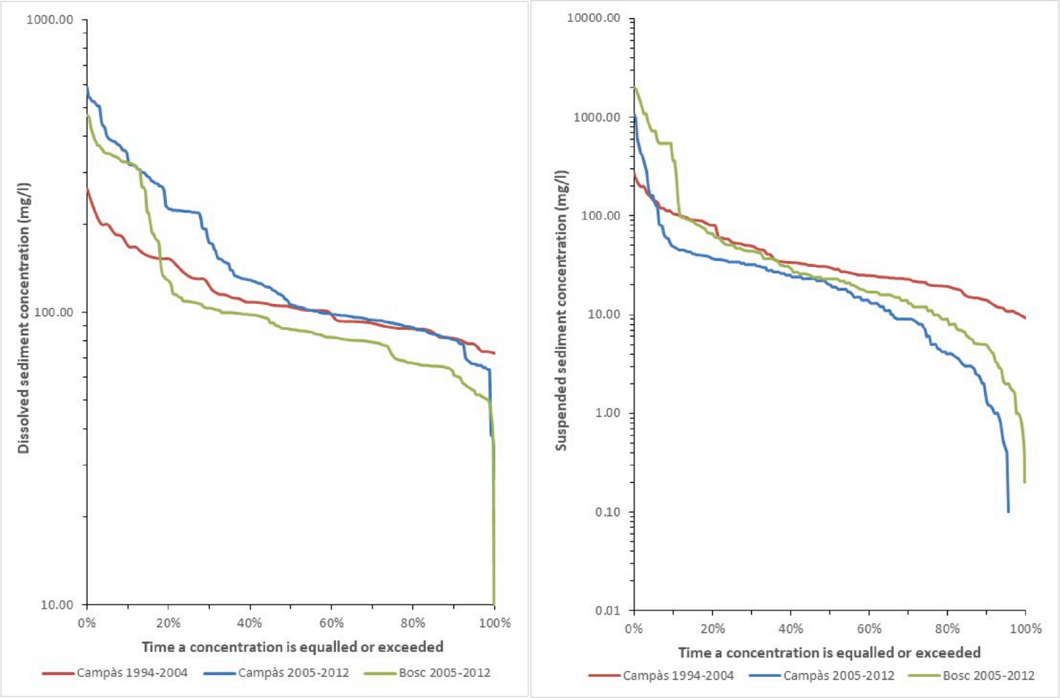

Fig. 6. Sediment duration curves at a) Bosc and b) Campàs stations during the periods prior and after the shrub removal.

type and harvested areas in parcels or experimental catchments (Bosch and Hewlett, 1982; Sahin and Hall, 1996; Andréassian, 2004; Webb et al., 2012; Zhang et al., 2017). In addition to the global increase in water yield during the study period, results show that there has also been an increase in the time that low flows remain in the channel, with a concomitant reduction in the no-flow period. Similar findings were reported by Johnson (1998) and Andréassian (2004) who stated that that a reduction in forest cover leads to an increase in low flows due to a decrease of rainfall interception and evapotranspiration rates and an increase of soil moisture (Giuggiola et al., 2018; Prévosto et al., 2019). According to this, the Vernegà catchment increased low flows and reduced the no flow period, while high flows remained essentially the same. These conclusions have been reported by Dung et al. (2012), in two experimental plots of 0.19 and 0.35 ha, who stated that flow duration in an ephemeral channel increased but hortonian flow did not and therefore, it did not contribute to the increases in catchment runoff after a plot forest treatment. Thus, considering that soils in the Vernegà basin have a high infiltration capacity (Úbeda et al., 2012), shrub removal works would have enhanced infiltration by covering the ground with vegetation left-overs (Úbeda et al., 2020), and also would have increased ground-water recharge, which in turn, would have contributed to the increase of low flows. Bent (2001), suggested that a greater amount of rainfall reached the ground after forest treatment and that led to an increase of the ground-water recharge and an increase of the base flow of the Cadwell Creek, Massachusetts, USA. Further investigation regarding to the alteration of the whole water cycle needs to be done to fully understand the processes involved within this catchment.

5.2. Changes in sediment fluxes

An increase in the amount of loose soil particles due to shrub removal combined with good connectivity between potential sediment sources and river systems may be responsible for the increase in suspended sediment concentrations within the catchment, especially at Bosc. Gallart and Llorens (2003) have reported that forest removal practices may cause severe soil erosion in managed areas with slopes steeper than 10%, and the particles would easily be transported to the channel due to the characteristics of the headwaters and first-order streams (Church, 2002). Several other studies have also documented sediment increases after forest removal (Croke et al., 1999a; Stott et al., 2001; Pacheco et al., 2011), but also, it has been reported that eroded sediment does not leave the catchment in a single event and is temporarily stored on the channel banks (Croke et al., 1999a). This may explain why suspended sediment concentrations decreased throughout the period 2005–2012 in the outlet (Campàs), given that although low flows increased in duration length, they were insufficient to transport suspended sediment and high flows remained essentially the same. In addition, a possible dilution effect of sediment concentrations due to an increased volumes of base-flow during the flowing period, as reported by Walling and Webb (1982) could also result in suspended concentration decrease.

On the other hand, it is likely that dissolved sediment concentrations may have risen due to an increase in the soil infiltration rates and an increase of groundwater fluxes as suggested by Sophocleous (2002).

5.3. Sediment yields

Increased runoff and sediment concentrations resulted in an increase in sediment yields, especially at Bosc, where both dissolved and suspended yields increased. Dissolved load increased as a result of an increase in runoff and in dissolved sediment concentrations at both stations. However, the increase on suspended sediment yield was very high at Bosc, but it reduced at the outlet site (Campàs). In a summary of several studies conducted throughout Great Britain, Stott et al. (2001) reported a percentage of change in sediment yields ranging from 62% up to more than 700% in catchments where only 15% of the area was affected. In the present study, for the same area affected, the sediment yield also increased by similar orders of magnitude, especially suspended sediment at Bosc.

6. Conclusions

Shrub layer removal in a forested area of an experimental catchment measuring 2.5 km^2 affected 15% of the area and resulted in an increase in water and sediment yield.

Results obtained indicate that removal of the shrub layer or the understory in a Mediterranean forest has similar effects on runoff and

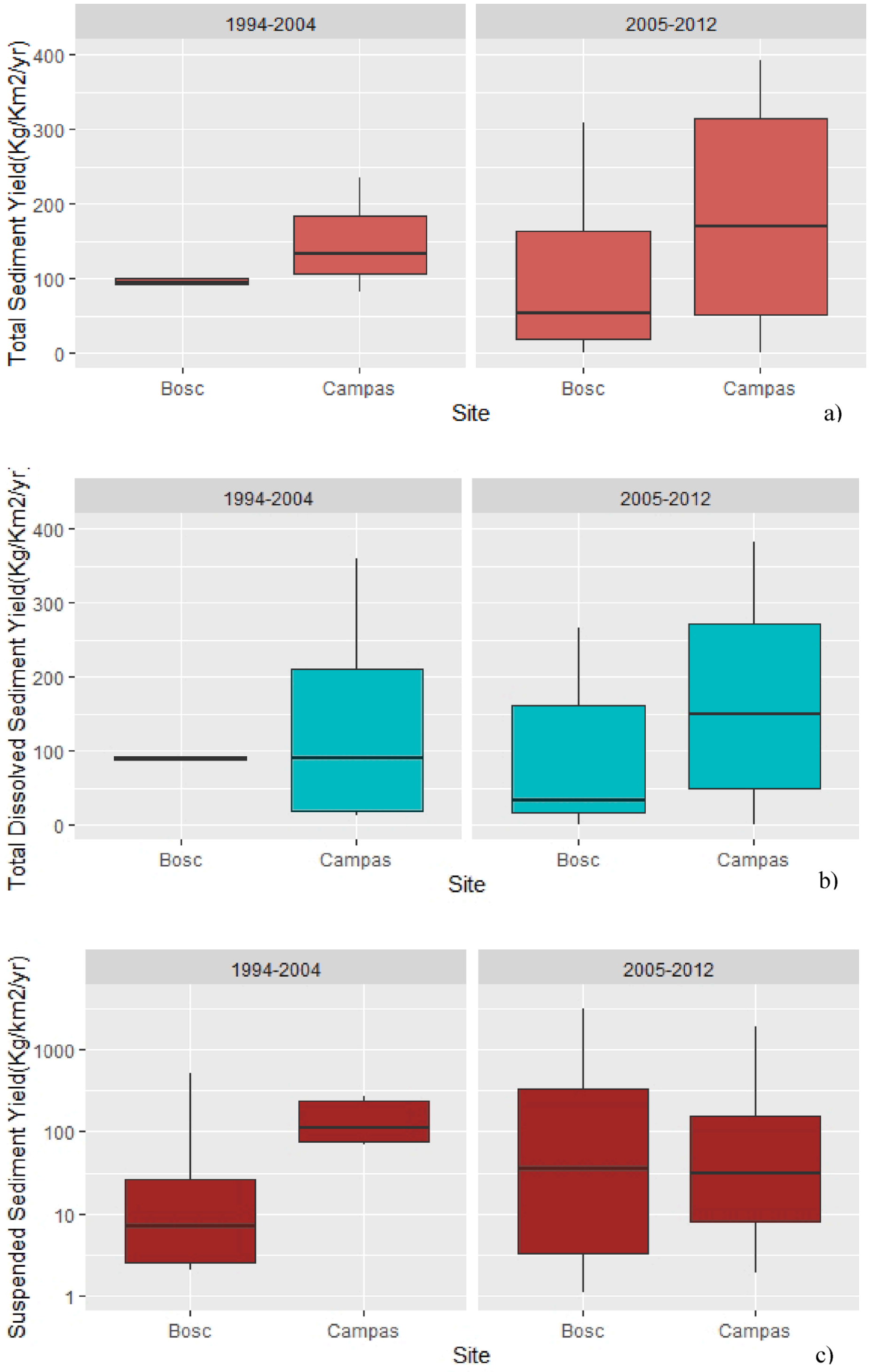

Fig. 7. a) Boxplot of total sediment yield before and after shrub removal; b) Boxplot of dissolved sediment yield before and after shrub removal and c) Suspended sediment yield before and after shrub removal.

sediment yield to those reported in studies on forest clearance, thinning or harvesting. Thus, the shrub layer is a part of the Mediterranean forest and its management has important consequences on total water and sediment yield. The observed increase in water yield, due to an increase of low flows and a reduction of the no flow period rather than an increase of flood frequency and magnitude, can be viewed positively given the scarcity of water availability in Mediterranean environments, and forest management appears to be a tool to avoid forest fires but also have a key impact on the water cycle in ephemeral catchments. Regarding the sediment yield, dissolved loads increased due to the increase in runoff but also for an increase in concentration that is likely to be related with the water infiltration and ground water recharge increase. On the other hand, while suspended sediment loads increase at Bosc, it decreased at the catchment outlet, due to sedimentation within channel banks and a possible dilution effect of suspended sediment concentrations during events given to increased volumes of baseflow.

Further research is required to determine i) the duration of the effects of shrub removal on runoff and sediment production, as vegetation regrowth will gradually reduce runoff, ii) the effects of the shrub removal to the overall water budget of the catchment and the role on infiltration and ground-water recharge, and iii) it remains yet unclear whether all particulate sediment released has already been flushed out of the catchment or, on the contrary, if it has been deposited in the channel, and if so, what flow capacity is needed to remove it.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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