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Results of a long-term study on an experimental watershed in southern Italy

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Abstract

Forested watersheds offer a wide array of benefits. In fact, forest cover affects the hydrological response of a basin, regulating the volumes of water content in the soil through processes of interception, infiltration, and evapotranspiration. Altering forest cover can significantly influence water balances at both site and watershed scale. Understanding the relationship between vegetation and streamflow is vital to assess the effects of forest disturbance on hydrologic response, and to identify best management practices in a watershed. The aim of the present research was to evaluate the role of forests in the hydrological processes which occur in a headwater basin draining a Calabrian pine forest (*Pinus laricio* Poiret). Moreover, the analysis also involved studies of forest carbon uptake. Since 1986 the Bonis watershed has been instrumented and precipitation, runoff, throughfall, stemflow, and some climatic parameters have been measured. Recently, in order to study carbon and water cycle dynamics (for climate change mitigation assessment) and to give information about the amount of water used by plants, a tower with Eddy covariance technique was installed. The study concerned the analysis of precipitation and the interaction between forest cover and throughfall, stemflow and runoff after a thinning treatment. Investigation on CO_2 and evapotranspiration with the Eddy covariance methodology has also been performed. Results have shown an increase (more than 50%) of the runoff in the basin after the forest thinning (50% of the stems corresponding to 30% of the basal area) while no significant differences in rainfall have been detected before and after the forest thinning. In particular, after the thinning, the runoff coefficient increased from 0.21 to 0.29 during the autumn-winter period, while in the summer season it shifted from 0.16 to 0.41. The results of this study evidenced the effect of a silvicultural practice on the runoff response thus showing that an appropriate forest management can have a key role in water management at basin scale.

Keywords: *forest cover, runoff, stemflow, thinning, throughfall*

Rezumat. Rezultatele unui studiu pe termen lung cu privire la un bazin hidrografic experimental din sudul Italiei

Bazinele hidrografice împădurite oferă o gamă largă de beneficii. De fapt, acoperirea cu pădure afectează răspunsul hidrologic al unui bazin, regularizează volumul de apă din sol prin procese de interceptare, infiltrare, și evapotranspiraţie. Despăduririle poate să influențeze în mod semnificativ bilanțul apei la scara locală și scara bazinului hidrografic. Înțelegerea relației dintre vegetație și scurgere este vitală pentru a evalua efectele despăduririi asupra răspunsului hidrologic, precum și pentru a identifica cele mai bune practici de management într-un bazin hidrografic. Scopul prezentului studiu a fost de a evalua rolul pădurilor în procesele hidrologice care au loc într-un bazin hidrografic cu pădure de pin calabrian (*Pinus laricio Poiret*). În plus, analiza a implicat, de asemenea, studii de absorbție de carbon a pădurilor. Din 1986 bazinul hidrografic Bonis a fost echipat și au fost măsurate precipitațiile, scurgerea, precipitația interceptată şi căzută de pe frunze, și unii parametri climatici. Recent, în scopul de a studia dinamica circuitului carbonului și apei (pentru evaluarea măsurilor de atenuare a schimbărilor climatice), precum și pentru a se obține informații cu privire la cantitatea de apă utilizată de plante, a fost instalat un turn cu tehnica covarianței Eddy. Studiul a vizat analiza precipitațiilor și interacțiunea dintre suprafața împădurită și precipitația interceptată şi căzuta de pe frunze și scurgerile după un tratament de rărire. De asemenea, cu tehnica covarianței Eddy, au fost efectuate investigații privind emisiile de CO2 și evapotranspiraţiei. Rezultatele au arătat o creștere (de peste 50%) a scurgerii în bazinul după rărirea pădurii (50% din tulpinile care corespund cu 30% din suprafața de bază), în condițiile în care înainte și după rărirea pădurii, nu au existat diferențe semnificative în ceea ce privește precipitațiile. În special, după rărirea pădurii, coeficientul de scurgere a crescut de la 0.21 la 0.29 în perioada de toamnă-iarnă, în timp ce în sezonul de vara s-a schimbat de la 0.16 la 0.41. Rezultatele acestui studiu au evidențiat efectul practicii silvice asupra răspunsului hidrologic, arătând astfel că o gestionare corespunzătoare a pădurilor, poate avea un rol-cheie în gestionarea apei la scara bazinului hidrografic.

Cuvinte-cheie: *acoperire cu pădure, scurgere, precipitația interceptată și căzută de pe frunze, rărirea pădurii*

Introduction

Forestry and water are inseparable, plant a tree and it will use water, cut a tree and its water use ceases. In fact, forest cover influences the hydrological response of a basin, by adjusting the volumes of water content in the soil through processes of interception (Breda et al., 1995; Lesch and Scott, 1997; Aboal et al., 2000; Rahman et al., 2002), infiltration (Lane and Mackay, 2001; Grace et al., 2006b) and evapotranspiration (Van der Zel, 1970; Baker, 1986; Ruprecht et al., 1991; Breda et al., 1995; Ozyuvaci et al., 2004; Grace et al., 2006a; Serengil et al., 2007). Vegetation cover has then an important influence on the hydrological cycle. Understanding the relationships between canopy characteristics and interception is essential for quantitative prediction of the effects of deforestation (Gash et al., 1980) and changes in land use and vegetation on water yield (Bosch and Hewlett, 1982). Indeed, the water yield of a forest is a measure of the balance between incoming precipitation and outflow of water as runoff. The amount in water yield depends on annual precipitation as well as on type and canopy density. The transpiration rates of different forest types depend upon their stomatal sensitivity to saturation deficit, species differences in maximum canopy conductance, and differences in leaf area index, regardless of whether they are managed plantations or natural forests (Cannell, 1999). Although their leaf area indices can be large, conifer species have usually lower transpiration rates (about 2–4 mm/day) than broadleaved species, due to constraints by the closure of stomata in response to increasing saturation deficits (Whitehead and Jarvis, 1981) and to their specific hydraulic architecture. In addition to tree species, also tree density influences water yield, with higher densities generally resulting in streamflow decreases as a result of increased transpiration losses.

At basin scale, silvicultural practices can increase water reserves while the afforestation may cause a decrease in water availability and thus a runoff decrease (Ganatsios et al., 2010). This increase or decrease in water availability depends on the area of harvesting treatments in a given watershed (Bosch and Hewlett, 1982) and, in case of decrease in water availability, it is strictly related to canopy removal (Baker, 1986; Lane and Mackay, 2001). Hydrologic consequences of forest management have been investigated in many parts of the world during the last years, showing that water yield usually increases immediately after timber harvest, due to reductions in evaporation and transpiration (see e.g. Zhang et al., 2001; Wilcox, 2002; Callegari et al., 2003; Andreassian, 2004; Oudin et al., 2008; Wei and Zhang, 2010; Zhao et al., 2010). The most commonly used methodology is that of paired watershed experiments involving two or more watersheds with similar characteristics in terms of slope, aspect, soils, area, climate, and vegetation, located adjacent to or in close proximity to each other (experiments reviewed by Brown et al., 2005), which are concurrently monitored during pre-treatment and post-treatment periods. The single watershed approach also involves two study periods: a pre-treatment period and a treatment period. In South Africa, Lesch and Scott (1997) found that a 22–46% forest thinning in a 27.2 ha catchment increased annual runoff by 10–71% in the first 3 years after thinning. Similar results have been obtained in the coastal area of North Carolina (USA), where both daily outflows and peak flow increased during the thinning treatment (Grace et al., 2003). Only insignificant changes in annual runoff after thinning timber volume by 6.4% and 33% in a 27 ha watershed have been detected in Japan (Rahman et al., 2002; 2005) but, as evidenced by the authors, the method used in the paper probably was not suitable for detecting the effects of the thinning on the runoff. Most of these studies focused on the extent to which a thinning decreases canopy interception and evapotranspiration, which may explain the diverse results regarding changes in runoff which are strongly scale-dependent, ranging from the hillslope to the entire catchment (Sidle et al., 2000; Gomi et al., 2008b).

In fact, the hydrological processes in hillslope, headwater, and downstream areas may differ in relationship to differences in vegetation type, topography, and soil properties (Stomph et al., 2002; Cammeraat, 2004; Sidle et al., 2011). Therefore, the effects of forest management can affect hydrological processes and their effects can be scale determined (i.e. hillslope or catchment). Thinning at hillslope scales alters net precipitation and infiltration, such change does not necessary produce changes in runoff components and associated catchment runoff (Miyata et al., 2010; Dung et al., 2011). Rather, catchment runoff may be influenced by the effects of forest management which in turn are dependent on the continuity or discontinuity of hydrological processes from hillslope to catchment (Sidle et al., 2000; 2007; Gomi et al., 2002; Joel et al., 2002; Van de Giesen et al., 2000; Gomi et al., 2008a). Therefore, assessing the complex interactions between vegetation and hydrological processes at various scales is paramount for evaluating runoff responses associated with forest management (Dos Reis Castro et al., 1999; Stomph et al., 2002; Miyata et al., 2010).

This study presents the results of the experimental observations on a forested watershed in southern Italy. In addition to monitoring of the hydrological cycle, the watershed has been instrumented with a tower to calculate CO_2 and H_2O fluxes (with the Eddy covariance technique), to study carbon and water cycle dynamics (for climate change mitigation assessment) and to gather information about the amount of water used by plants. In particular, in this paper we report the results of a study conducted from 1986 to 2002 in the basin through which we assess the effects of a thinning (in 1993) on the basin runoff by analyzing the hydrological behavior before and after silvicultural treatment (thinning).

The hydrological processes were monitored from 1986 until 2002 and the data preceding and following the thinning were compared in order to investigate possible changes that occurred after the silvicultural treatment. The main objective of this study is to investigate integrated data in order to understand the relationship between forest, soil, water and the atmosphere in order to provide information and guidance for a sustainable management of forested mountainous watersheds in the Mediterranean.

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Materials and methods

Study area and data

The Bonis experimental watershed (Fig. 1) is located in the mountain area of Sila Greca (39°25′15″N, 16°12′38″W), in the Calabria region (southern Italy).

The catchment has a surface of 1.39 km^2, a mean elevation of 1131 m a.s.l. and it was instrumented in 1986. Almost 93% of the total area is covered by forest stand, dominated by about 50 year old Calabrian pine (*Pinus laricio* Poiret) forests. There are also small stands of chestnut (*Castanea sativa* Mill.) and riparian forests of common alder (*Alnus glutinosa* L).

Finally, a small portion of the catchment (about 6% of the drainage area) has no tree cover and is largely devoid of vegetation. The forest cover characterization has been identified by photographic surveying and by mapping resolution at 1:2000 scale.

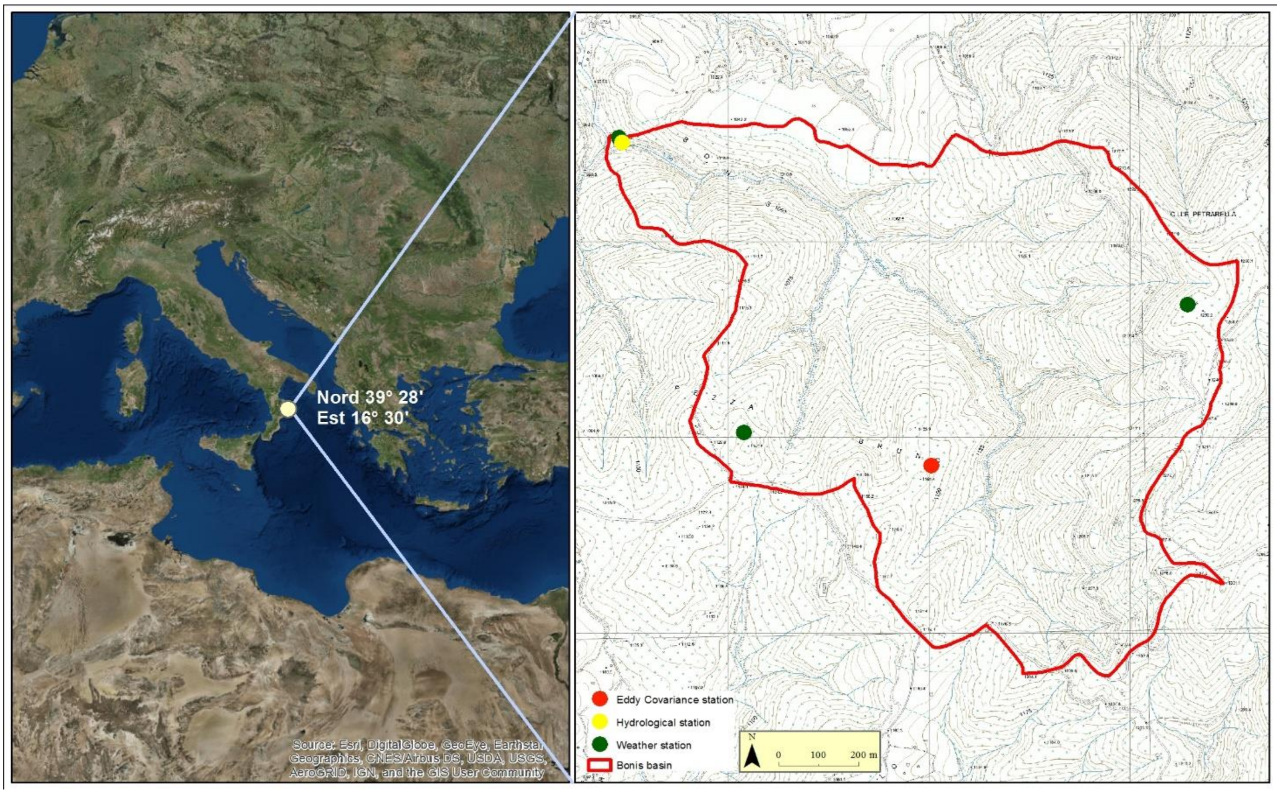

Fig. 1: Map of the Bonis basin with the station

The survey of forested areas has been carried out by means of a special sampling of test areas and transects. The surveys, first performed in 1986 have been repeated in 1993 and 1999 (Table 1).

Geologically, the catchment is underlain by acid plutonic rocks (Callegari et al., 2003) characterized as Typic Xerumbrepts and Ulpic Haploxeralfs. The climate of the area is typical of the mountain areas of Calabria which, due to its geographic position and mountainous nature, is characterized by mild winters and hot summers with little precipitation. In the inland zones, colder winters with snow and fresher summers with some precipitation are observed (Caloiero et al., 2011). The main features of the study area are reported in Table 2.

Rainfall was measured by three mechanical rain gauges (with a tipping bucket), 20 minute-span interval, located at the basin outlet (Outlet: 975 m a.s.l.) and at representative sites within the north-eastern (Petrarella: 1258 m a.s.l.) and southwestern (Don Bruno: 1175 m a.s.l.) parts of the catchment (Fig. 1). Runoff was measured at the catchment outlet using a Thomson weir (capable of measuring discharges up to 17 m^3/s) at the end of a gauging structure comprising a concrete-lined channel and equipped with a mechanical stage recorder. Besides rainfall and runoff, other data (temperature and wind speed) were measured.

Throughfall and stemflow were also measured since their inputs are of critical importance to wooded ecosystems and constitute the majority of incident precipitation, ranging in most cases from 70 to 90% of incoming precipitation with the remainder lost to interception (Levia and Frost, 2003).

Fifteen throughfall collectors and tipping buckets with an orifice of 962 cm^2, were placed at 70 cm above the ground on a regular grid, together with 10 collectors for stemflow, inside two 150 m^2 sample areas, randomly selected within the dominant pine stands, differing in tree density (control plot and thinned plot) (Fig. 2).

Table 1: The dendrological data at 1986 (study first stage), 1993 (before and after the thinning) and 1999

Stand Type	D	A (%)	1986			1993 before thinning			1993 after thinning			1999		
			Nt	Ba (m^2)	Md (cm)	Nt	Ba (m^2)	Md (cm)	Nt	Ba (m^2)	Md (cm)	Nt	Ba (m^2)	Md (cm)
natural	High	13.3	4000	52.8	13	3120	50.7	14.4	1270	37.4	19.2	1240	48.9	22.4
	Low	3.4	2700	52.3	15.7	1870	47.8	18	1100	35.8	20	1000	43.9	23.6
artificial	High	48.8	2200	55.8	18	1701	52.2	19.8	1150	39.2	20.8	1102	49.1	23.8
	Low	5	1250	40.2	20.2	1162	43.2	21.8	800	32.4	22.8	775	45.8	27.4
mixed	-	4.7	1325	43.9	21	1208	46.4	22.1	900	34.8	22.3	888	48.6	26

Note: D=density; A=area; Nt=Number of trees; Ba=Basal area evaluated as function of Md; Md=Mean diameter at 1.3 m from the bottom of the tree trunk

Table 2: Main features of the study area

Feature	Value
Area (sq km)	1.39
Perimeter (km)	5.9
Mean elevation (m)	1131
Maximum elevation (m)	1301
Outlet elevation (m)	975
Mean slope of the basin (%)	43.4
Drainage network length (km)	10.5
Main reach length (km)	2.2
Mean annual rainfall (mm)	915
Main annual temperature (°C)	8.9
Mean temperature of the coldest month (°C)	0.1
Mean temperature of the hottest month (°C)	18.3

Note: Rainfall and temperature values refer to the measurement period

Fig. 2: Stemflow and throughfall measurements in the control plot

Methodology

Forest cover aerial photo-interpretation (examination of photographic images with the purpose of identifying forest stand types) was carried out at a 1:2000 scale. Then, on the basis of forest stand types (natural stands, plantations, etc.) and tree density, a zoning procedure was performed. This procedure consists in subdividing forested area into homogeneous sectors based on density, age, origin, etc. For every stand type, surveys of dendrometric parameters through sample areas and transects, were carried out in 1986, 1993, and 1999.

A selective thinning was carried out in 1993. On average, density was reduced by 55% (38% in low-density stands, 69% in high-density stands).

The hydro-meteorological parameters were monitored from 1986 to 2002 and rainfall and runoff values before and after the thinning were compared in order to investigate the possible changes that occurred as a result of this silvicultural treatment. Before the analysis, the problem of the data quality has been examined; in fact, in the analysis of hydrological series, such as the ones used in this study, attention must be paid to inhomogeneities of data series and missing data (about 50% of the data in some series). Particularly, the latter problem affects all the instrumental period, and especially the 1999-2000 period, because of occasional interruptions in automatic recorders and failure of instrumentation. Excluding periods with missing values from data analyses may lead to disregard valuable information, and to induce errors in temporal analyses. The homogenization approach applied in this work was similar to the one discussed in Brunetti et al. (2012). This approach has been widely used in the Calabria region for the detection of inhomogeneities of several variables (Caloiero et al., 2015a,b; Longobardi et al., 2016; Caloiero et al., 2017). Specifically, in this work, each of the three rainfall series (Outlet, Petrarella and Don Bruno) was tested against other rainfall series, recorded by the Multi-Risk Functional Centre of the Calabria region and identified as homogeneous in Brunetti et al. (2012), by means of a multiple application of the Craddock test (Craddock, 1979). The estimation of the missing data was performed by applying a recently developed two-step procedure (Simolo et al., 2010) which allows to preserve both the correct event time location (wet/dry days) and the statistical properties of daily precipitation series. Moreover, in order to identify possible change points in the runoff series due to the thinning, in this study a particular form of the non-parametric Mann-Whitney (MW) test, developed by Pettitt (1979), has been employed (Kiely et al., 1998, Kiely, 1999). The Pettitt form of the MW test is extremely useful for detecting shifts in the mean of a sample series when the change point is unknown, and, in any case, it provides the most probable change point year of the time series.

Hydrological studies were carried out at two levels: basin scale and plot scale. Data used for the analysis were precipitation, stemflow, throughfall, and runoff. Two plots were defined for stand scale analysis. Control plot had a density of 1500 trees per hectare, the plot subjected to a low selective thinning, which removed 50% of trees (30% of basal area) had a density of 867 trees per hectare.

Results and Discussion

For the application of the homogenization procedure and of the techniques for filling-in missing data, some homogeneous series from the Multi-Risk Functional Centre network have been used as reference series. Following the application of the Craddock test, the Don Bruno and the Petrarella rainfall series showed inhomogenities, so they were discarded because of their very low quality. In particular, as a result of the application of the Craddock test, the Petrarella rain gauge evidenced an underestimation of the actual rainfall data; the Don Bruno rain gauge not only showed an underestimation of the actual rainfall data, but also presented several missing data. Only the Outlet rain gauges appear homogeneous and, consequently, this was the only rain gauge which was used in the subsequent rainfall analyses. Moreover, the technique for filling-in missing data proposed by Simolo et al. (2010) was applied to this daily rainfall series. The reconstructed period spans from January 1986 up to December 2002, during which a total amount of 33% of daily data were missing and required reconstruction.

The final rainfall and runoff values are displayed in Figure 3, which shows that, after thinning, discharge, and peak flow rates increased, probably as a result of lesser interception losses. In particular, on January 2001, the highest runoff values have been detected (about 658 l/s); thus, rainfall did not show extreme value. This value can probably be due to a landslide which hit the basin causing the partial obstruction of the gauging structure.

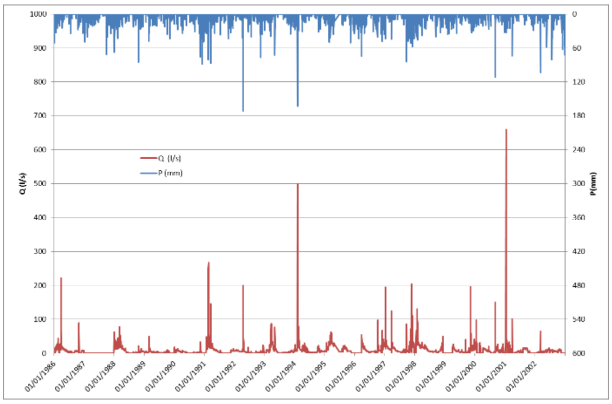

Fig. 3: Daily rainfall and runoff database after the estimation of the missing data

Mean daily precipitation during the monitoring period was 3.32 mm with maximum daily values of 171.2 mm in 1992 and 163.2 mm in 1994. The mean annual precipitation of the basin was 1194.5 mm, with a maximum annual value of 1985.2 mm in 1996 and a minimum annual value of 841.6 mm in 1989. Monthly precipitation was the highest in winter and the lowest in summer (Fig. 4a). The average yearly runoff during the same period was 11.5 l/s, the maximum annual value was 15.9 l/s, in 1997 while the minimum was 3.4, in 1989. The mean monthly runoff varied between a minimum of 3.0 l/s, in July, and a maximum of 20.2 l/s, in February (Fig. 4b).

After the estimation of the missing rainfall data, the rainfall and the runoff data before and after the thinning were compared (Table 3).

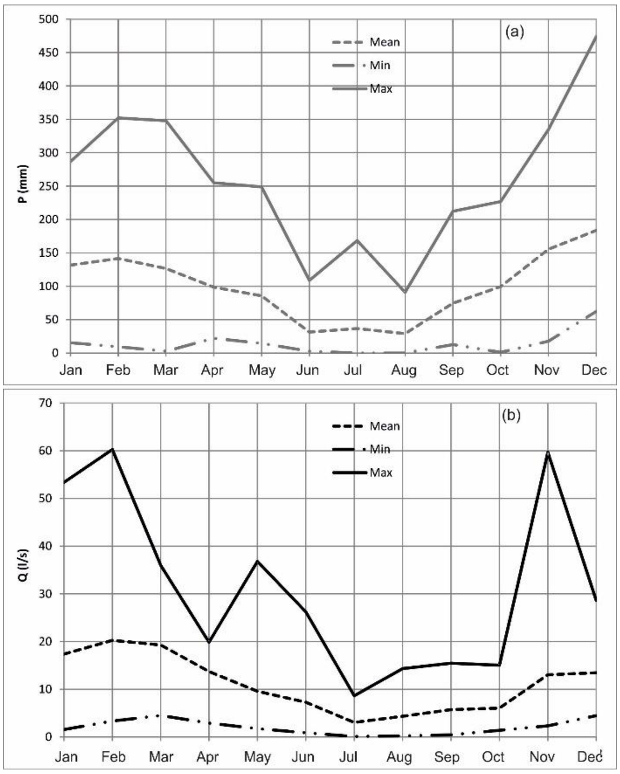

Fig. 4: Maximum, minimum and mean monthly rainfall (a) and runoff (b) values evaluated in the whole observation period

Table 3: Mean, minimum, maximum, and standard deviation daily values of rainfall and runoff before and after the thinning

Rainfall (mm)	Pre-Thinning	Post-Thinning	Runoff (l/s)	Pre-Thinning	Post-Thinning
Mean	3.30	3.33	Mean	7.92	12.31
Max	171.20	163.20	Max	266.94	658.86
Min	0.00	0.00	Min	0.00	0.71
SD	8.71	8.72	SD	15.48	21.09

The magnitude of daily precipitation is similar during the pre- and post-thinning periods (Table 3); in fact from 1986 to 1993 the average rainfall is 3.30 mm while from 1994 to 2002 is 3.33 mm. The thinning experiment resulted in an increase in runoff. Mean daily catchment runoff (i.e., the average value of daily runoff not including days without flow) during the pre-thinning period was 7.92 l/s. During the post-thinning period, mean daily runoff from Bonis increased from 7.92 to 12.31 l/s, which means a runoff increase of about 50% after the thinning. The mean annual runoff coefficient was 0.185 before thinning, 0.347 after thinning. After the thinning, it increased from 0.21 to 0.29 during autumn-winter, while in the summer season, the increase was higher, shifting from 0.16 to 0.41.

Figure 5 shows the ratios between the annual and the mean annual values (evaluated in the period 1986-2003) of rainfall (Fig. 5a) and runoff (Fig. 5b). As a result, in the post-thinning period increases in annual runoff almost two times the average in 1995, 1997 and 1998 have been detected, while no significant differences can be noted for rainfall, with the exception of 1996. This result confirms that although no significant changes in annual rainfall have been detected, an increase in runoff after the thinning has been observed, probably as a result of lesser interception losses. In fact, after 1993, the yearly runoff values are always higher than the average, with the only exception of 2002. The effect of the thinning at the end of the measurement period looks similar to that at the beginning, a fact which can be explained considering that the canopy of the existing trees were getting more space after the thinning of their neighbors to grow out and so the interception increased and runoff decreased.

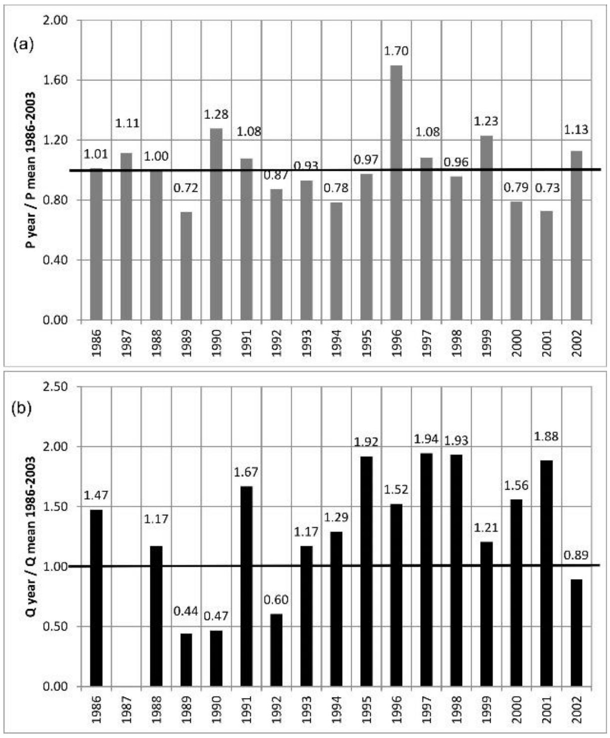

Fig. 5: Ratio between the annual rainfall (a) and runoff (b) and the mean annual values in the whole observation period

In order to better analyse the effect of the thinning on the cumulated runoff vales, the moving averages of the annual rainfall sum and of the annual runoff sum have been evaluated and compared in Figure 6. While a horizontal curve can be observed for the rainfall, a different behavior before and after the thinning has been detected for the runoff values.

In fact, the runoff curve is horizontal or about horizontal before the thinning while rise after the thinning, which, as said before, can probably be due to lesser interception losses.

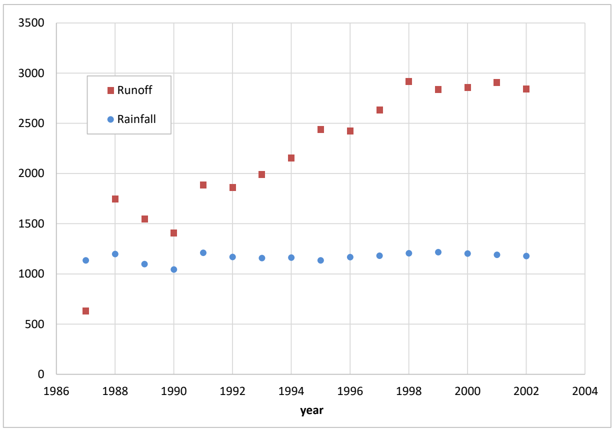

Fig. 6: Moving averages of the annual rainfall sum and of the annual runoff sum

The comparison of the mean monthly runoff values before and after the thinning showed a significant increase in December, January and February, while in November and March a decrease in the runoff has been revealed (Fig. 7). At monthly scale, the silvicultural thinning appears to affect the winter period to a greater extent than the other periods; yet, although in the summer period low runoff values have been measured, the increase in runoff after the thinning in summer is similar to the one detected in winter, with runoff values 2 or 3 times higher than the pre-thinning period (Fig. 7).

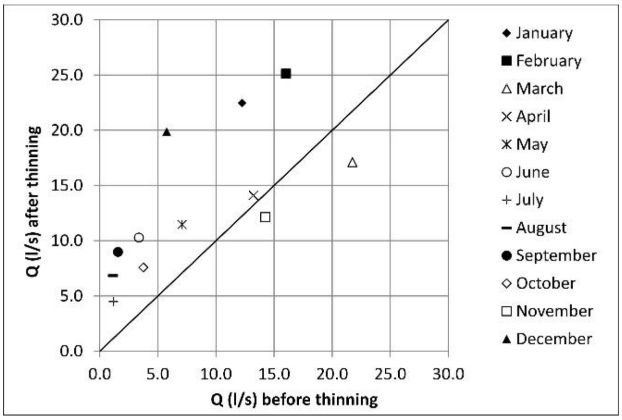

Fig. 7: Comparison of the mean monthly runoff values before and after the thinning

Finally, in order to evidence the possible change points in the data, the Mann-Whitney (MW) test has been applied. This test is an adaptation of the rank-based Mann-Whitney test that allows to identify the time at which the shift occurs. The MW test indicated that 1994, the first year after the thinning, was the most probable year of variation in the mean annual runoff values thus confirming a statistical significant change in the runoff data after the thinning.

At stand scale, analyzing 62 recorded events, mean interception in the thinned plot represented 47% of precipitation, while it was 55% in the control plot. Stemflow was very limited, representing 0.52% of precipitation in thinned plot and 0.59% in control plot. Forest cover reduction did not substantially alter components of stand water balance. Percentage difference between two plots (control plot and thinned plot) was not significant and stemflow represented a minimum part of incoming precipitation. These interception values are higher than those reported in other studies (Levia & Frost 2003).

Ongoing research

In May 2003, a tower for the measurement of fluxes with the Eddy covariance technique was installed in a plantation of 44-year old Laricio pines, in Cozzarella - Don Bruno location. Subsequently, the Bonis watershed was included as an associated site to the CarboEurope flux network and long-term continuous flux measurements of scalars such as CO_2 and water vapor started to be made on a routine basis.

In particular, all the data about carbon fluxes exchanged between atmosphere and vegetation (net ecosystem exchange, gross primary productivity) and functional relationships between plants and environmental parameters like soil water content and radiation, are collected and analyzed to estimate the net carbon exchange of the pine forest and its role in the water cycle of the watershed (see for details Marino et al 2005). As a result, the continuous monitoring of CO_2 and H_2O fluxes between canopy and atmosphere allowed the assessment of daily, seasonal and annual fluxes and the evaluation of variations over the years. Also the monitoring of meteorological parameters and their influence on canopy physiology is constantly carried out. It was observed that the maximum instantaneous values of carbon absorption (NEE, net ecosystem exchange) were usually recorded in July (21-24 μmol CO_2 m^{-2}·s^{-1}), whereas in January the CO_2 uptake was the lowest of the year (about 14 μmol CO_2 m^{-2}·s^{-1}). Nighttime respiration fluxes were similar in July-August (3-4 μmol CO_2 m^{-2}·s^{-1}), with higher values in autumn and secondly in spring seasons, due to higher precipitation and consequently higher water soil content.

As in other Mediterranean environment, during the summer season, when temperature and radiation are very high, respiration is recorded as decreasing, responding to limiting soil moisture levels. The same happens for transpiration processes. Together with radiation, temperature and soil water content, the variation in VPD (vapor deficit pressure) also influences transpiration and respiration. In summer, when VPD increases, transpiration and respiration decrease, also because of the closure of stomata for water conservation behavior. Soil water availability and atmospheric evaporative demand prove to be important and concurrent factors in determining adaptive responses by the ecosystem. The pine forest in the Bonis watershed can be considered a carbon sink practically all year round, with a total annual uptake of 1130 g C m^{-2} (estimated through interpolation method) and 1230 g C m^{-2} (estimated through average day method) (Marino et al 2005). However ongoing climate change can influence the sink capacity, since the increase in temperature and the contemporary decrease in precipitation during the summer season can lead to a lower carbon uptake.

Conclusion

In this work, the effects of forest thinning in a headwater basin draining a Calabrian (southern Italy) pine forest, at catchment scale on runoff generation, have been investigated.

The rainfall dataset, obtained from three mechanical rain gauges (with a tipping bucket) 20 minute-span interval, has been preliminary analyzed through the application of a well-known homogenization procedure in order to detect inhomogeneities in the data. Only the data from the outlet rain gauge emerged as homogenous and were used in the analysis. Specifically, rainfall data before and after the thinning were compared with the runoff data measured at the catchment outlet using a gauging structure, comprising a concrete-lined channel and a mechanical stage recorder, equipped with a Thomson weir at the end of the structure.

The main effect of the thinning on the hydrological behavior of the studied basin consisted of an increase in daily and monthly runoff, probably as a result of lesser interception losses. In fact, from the comparison of the hydrological data (rainfall and runoff) collected before and after the thinning, an increase (more than 50%) in the runoff in the basin after the forest thinning emerged, while no significant differences in rainfall have been detected.

The effect of thinning at the end of the measurement period (1986-2002) looks similar to that at the beginning, a fact which can be explained considering that the canopy of the existing trees was getting more space to grow out after the thinning of their neighbors, so that the interception increased and the runoff decreased.

The effect of the thinning on the cumulated runoff values have also been analyzed by comparing the moving averages of the annual rainfall sum and of the annual runoff sum. As a result, a horizontal curve can be observed for the rainfall; instead a different behavior before and after the thinning has been detected for the runoff values: while the curve which is horizontal or about horizontal before the thinning, it rises after the thinning. This result has been confirmed through the application of the Mann-Whitney test, which allows the identification of shift in hydrological series. In fact, 1994, the first year after the thinning, emerged as the most probable year of significance variation in the mean annual runoff values.

The comparison of the mean monthly runoff values before and after the thinning showed a significant increase in the winter period, even though the increase in runoff after the thinning in summer is similar to the one detected in winter, with runoff values 2 or 3 times higher than the pre-thinning period.

At stand scale, 62 events have been analyzed, evidencing that forest cover reduction did not substantially alter the components of stand water balance.

In addition to the hydrological analysis, in this paper ongoing research (started in 2003) focused on the estimation of the net carbon exchange of the pine forest, and its role in the water cycle of the watershed has been presented. As a result, the pine forest in the Bonis watershed can be considered a carbon sink practically all year round.

The results of this study have demonstrated that the silvicultural interventions affected the runoff response, thus evidencing that an appropriate forest management can have a key role in water management. Therefore, the hydrological processes in this mountainous area need further investigation. In fact, a scientifically sound knowledge of such hydrological processes could facilitate the modification of forest management in order to successfully combine water and wood production.

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