Reforestation and land use change in a drainage basin of southern Italy

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In this study, the land use change in a large basin of Calabria region (southern Italy) subjected to extensive reforestation at the end of the '50 has been carefully reconstructed and compared with the current situation. The runoff capacity of the basin was estimated using data available for the temporal periods before and after the reforestation interventions. The results show that the surface of the basin interested by former reforestation activities did not affect the runoff, probably due to a trade-off between the effects of reforestation and a concurrent increase in urbanized and degraded areas. Indeed, the hydrological response is linked to structural complexity of reforested areas, currently at an early stage of development that can be further promoted through forest management activities.

Keywords: Land Use Change, Reforestation, Runoff

Introduction

Reforestation is the entire process of forest constitution or regeneration even if no trace of the old forest remains (Pavari & Susmel 1961). The achievement of this objective is based on criteria related today to restoration ecology, which includes all those activities aiming at ecologically improving degraded, damaged or destroyed environments (SER 2004). It follows that reforestation should be treated as an input into the restoration of a natural system (Ciancio 2000), given that human intervention is the starting point of the process of forest recovery. Soil preparation, sowing or planting and early post-implantation activities are the beginning of a process whose effects become progressively evident since the early years, provided the anthropogenic activities are controlled and natural disturbances (fire, grazing) do not

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occur (Iovino 2011). Over time, forest cover modifies the microenvironment leading to microclimate changes and contributions of organic matter to the soil.

These processes are the first functional relationships between vegetation and environmental factors of the site, becoming more evident when naturalization is triggered by the presence of species characteristic of the later stages of ecological succession (Barbati 1999).

Ecosystem recovery can be considered complete when an artificial system implanted in a degraded environment acquires a set of ecological characteristics, following an evolutionary trajectory leading to an increased structural and functional complexity (SER 2004). Consequences of reforestation are of ecological, landscape and economical types. In particular, several hydrological consequences can be identified among ecological effects: protection of the soil from water erosion, increase of soil storage capacity, increase of basin lag time and corresponding decrease of ordinary peak flows (Maione 2011). In qualitative and quantitative terms, the role of reforestation on hydrological response is related to the percentage of reforested area, physiognomic types, chronological stage of the population (with reference to possible evolutionary dynamics), and dendro-auxometric characteristics of the population (Cantón et al. 2011, Sayama et al. 2011).

The above considerations become very important in relation to past and current role that reforestation plays in land management (Marland et al. 2003, Trabucco et al. 2008). Calabria is an area of particular interest for this type of investigation. In this region, after

the catastrophic floods of the last century, also due to forest destruction, specific laws were adopted aiming at a comprehensive soil conservation plan, and extended hydrological and forestry activities, including the reforestation of river hills and mountains, were carried out. The above activities affected large areas characterized by soils derived from a variety of geological formations on very steep and heavily eroded slopes. The reforestation interventions implemented from 1958 to 1970 affected overall 120 000 ha, representing about 30% of the area reforested in Italy during the same period.

In this study the land use in the Coscile basin (southern Italy) has been carefully reconstructed and compared, in order to assess the aptitude of the basin to produce runoff before and after the extended reforestation started at the end of the fifties. The runoff capacity of the basin was evaluated based on the main historical sources available for land use (CASMEZ 1957, 1968, CLC 2006).

Material and methods

Study area and data collection

The Coscile River is the most important tributary of the Crati River in the northern part of Calabria (Fig. 1). Arising from the Pollino massif, the Coscile River drains most of the northern Calabrian Apennines, flowing for about 50 km east into the Crati River near its mouth, in the plain of Sybaris.

In this paper, the Coscile Basin refers to the section of Camerata, where a runoff gauge is located corresponding to an area of 277 km^2 (at 39° 43' 00" - 39° 55' 20" N, 16° 16' 09" - 16° 16' 00" E). The Coscile River is 31 km long and its main tributary, the Garga, is about 25 km long. The basin includes most of the mountainous formations of northern Calabria. Its valley, initially, has a north-east direction, and originates from the intersection of the chains of the Apennines and Calabrian Pollino. Then the valley
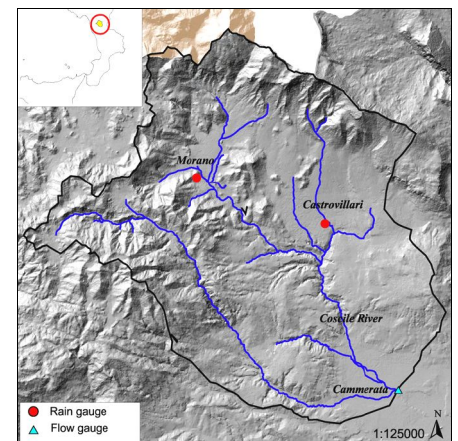

Fig. 1 - Study area: Coscile basin (southern Italy).

tends towards the east as the gradient levels into a flat plain at the confluence with the Crati River.

As regards the land use, historical data derived from the map implemented by *Cassa per il Mezzogiorno* for the Calabria region in the period 1955-67, following the special legislation n° 1177 (CASMEZ 1968), were used. CLC (2006), further supplemented with interpretation of digital orthophotos (Fig. 2), has been used for assessing current land use (APAT 2005, ISPRA 2010, 2011). Other historical data of land use have been derived from the *Piano Regolatore di*

Massima per la Calabria (CASMEZ 1957).

Archives (CASMEZ 1964) and literature (Ciancio 1970, Iovino & Menguzzato 1999) have been used to obtain information concerning to reforestation techniques at specific sites. The Calabria soil map (ARSSA 2003) provided the hydrological soil group and soil drainage condition.

Rainfall and flow data, measured at the outlet section in Camerata, were collected by the *Centro Funzionale Multirischi* for the Calabria region (CFM 2012 – http://www.cf-d.calabria.it). The dataset has been integrated with information obtained from other histo-

rical publications by the former *Servizio Idrografico e Mareografico Nazionale*, related to previous periods and/or to variables derived from the basic data. In detail, average areal annual rainfall and runoff data for the periods 1928-30, 1932-40 and 1960-69 were obtained from publication "*Dati caratteristici dei corsi d'acqua italiani*" (SIMN 1970). These historical data were integrated with information on daily rainfall and discharge obtained from the *Annali Idrologici* of SIMN for the period 1970-84.

Methods

A preliminary analysis of the historical and current land use patterns was performed to determine the percentage of reforested areas related to other land use types. The variation in the reforestation percentage was evaluated by the woodiness index (*i.e.*, the ratio between the wooded area and the total area of the basin). Areas identified as reforested areas have been verified by field surveys, which allowed a more detailed classification of reforestation, as those with Mediterranean pines (Aleppo pine - *Pinus halepensis* Mill., Umbrella pine - *Pinus pinea* L., Maritime pine - *Pinus pinaster* Aiton), with Black pine - *Pinus nigra* Arnold (Austrian black pine - *Pinus austriaca* Höss Novak) and Calabrian pine - *Pinus laricio* Poiret. In this step, the current average density of stands has been also verified.

The highly degraded forested areas were analyzed separately, by merging areas where reforested zones and natural forests have been almost entirely destroyed by repeated and intense fires and/or grazing. To ensure comparability of analogous data from CASMEZ (1968) and CLC (2006), some CLC classes of land use related to agricultural areas, wooded lands and semi-natural environments were merged (Tab. 1). Nevertheless the detailed information derived from CLC (ISPRA 2010), the analogous comparison for woodlands has been limited to their total surface due to the poor information obtained from the CASMEZ legend map.

Concerning the hydrological data of Coscile River at Camerata station, the monthly and annual values of runoff and areal rainfall have been obtained directly from SIMN. Actually, the *Annali Idrologici* indicate some uncertainties related to the runoff data of the Coscile River at the Camerata flow gauge. In particular, from 1963 to 1971, the water balance was altered by occasional water diversion upstream of the flow gauging station for irrigation from April to September. From 1936 to 1940, to take into account the same type of water diversion, the balance was adjusted by SIMN with different discharge amounts for various periods of the year (0.45 m^3 s^{-1} or 0.90 m^3 s^{-1} in different months). In addition, Coscile River was used since 1967 for hydro-electrical power production, with

Fig. 2 - Land use in the study area in 1968 (upper map) and 2006 (lower map).
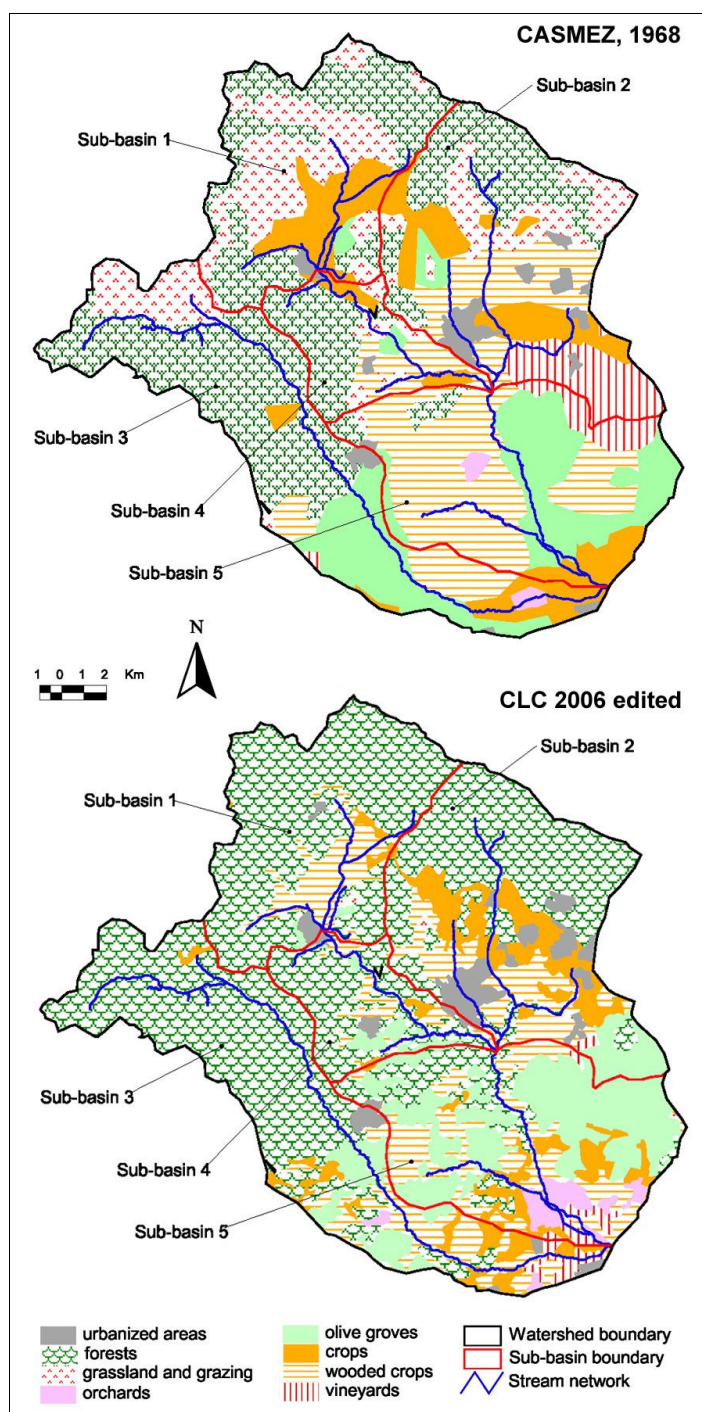
flow restitution upstream of the flow gauge. Based on these various reports, by excluding any year in which the altered balance cannot be quantitatively taken into account, the time spans 1928-40, 1960-62, 1972-84 (28 years) have been considered for further data processing. In particular, 1928-40 has been considered as "before reforestation" period, and the remaining ones as "after reforestation" period.

Land use changes have also been studied in order to assess the attitude of an area to produce runoff, that can be quantified through the synthetic parameter Curve Number (CN - USDA 1972). The procedure adopted to estimate the CN is the following:

1. identification of the hydrologic soil group. The attribution of soil infiltration values in the four classes was performed by overlaying the soil map of Calabria (ARSSA 2003) and linking each pedological class to different land uses and infiltration characteristics of the soil;
2. land use attribution;
3. identification of drainage conditions. The three classes (poor, fair, good) were derived from the soil map described above;
4. attribution of initial conditions of soil saturation. Antecedent Moisture Condition II (AMC II) was used since it refers to normal conditions (USDA 1972).

The value of the parameter CN for each category of land use was determined in both periods ("before" and "after" reforestation). To verify the possible weight of reforested areas compared to the total surface area, the average value of CN was also calculated as a weighted average for both the entire basin and five sub-basins.

Results

Dynamics of land use and reforestation

The surface of the Coscile basin in the period 1957-1968 (CASMEZ 1957, 1968), was covered by forests (30% natural forest areas and 1% reforested areas) and severely degraded areas (5%); agricultural areas were about 64% of the surface of the basin, out of which approximately 21% were wooded arable lands, while meadows and pastures covered about 15% and urbanized areas represented only 0.5%.

The woodiness index, as derived from the CLC (2006), is approximately 38%, including natural forests (26%) and reforested areas (12%); highly degraded forest areas concerned about 10%. The agricultural areas were 49% of the whole surface, including natural grassland (8%); urbanized areas represent only 3% of the total surface (Fig. 3).

As from CLC (2006), the physiognomic types are mainly beech forests, beech forest with reforestation of Black pine, and reforestation of Black and Mediterranean pine (class 4, 8, and 6 in Fig. 4, respectively). In

Tab. 1 - Correspondence of land use types between the CASMEZ map (CASMEZ 1968), integrated by the *Piano regolatore di massima per la Calabria* (CASMEZ 1957), and Corine Land Cover (CLC 2006).

CASMEZ (1957, 1968)	CORINE LAND COVER (2006)
Urbanized areas	Urbanized areas
Vineyards	Vineyards
Orchards	Orchards
Olive groves	Olive groves
Arable crops with trees	Heterogeneous agricultural areas (Annual crops associated with permanent crops + Complex cultivation patterns + Agro-forestry areas)
Arable crops	Arable crops
Pasture	Natural grassland
Forested degraded areas	Highly degraded forest areas
Forest	Forest areas
Reforestation	Reforestation

the higher areas, reforestation of Black pine was sometimes replanted within beech forests, where extensive cut was done in the past.

The comparison between the two periods shows a significant increase of urbanized areas (about 685 ha), a decrease of agricultural areas (15%) and an increase of the total
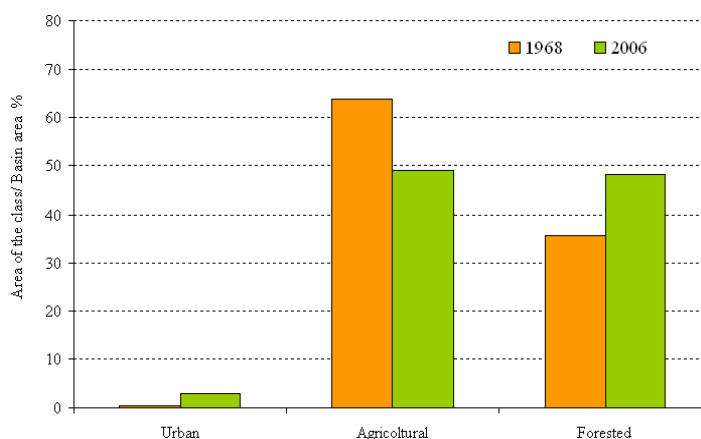

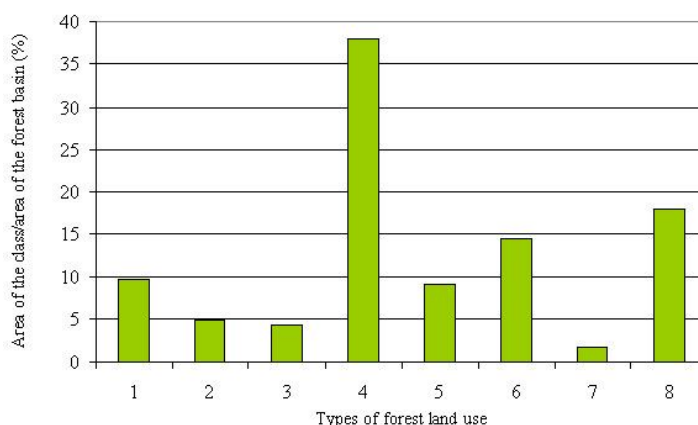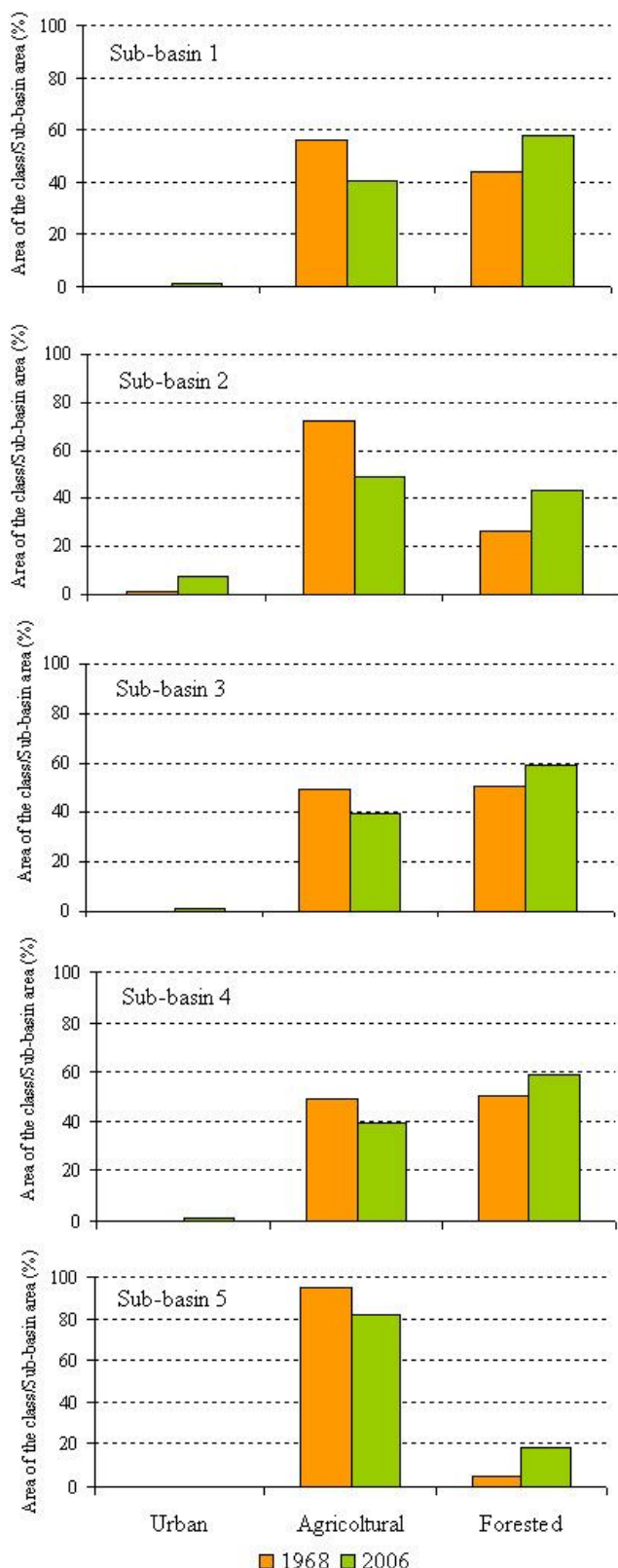**Fig. 3** - Variation of the main classes of land use in Coscile basin.

Fig. 4 - Forest land use (CLC 2006). The different physiognomic types are: (1) Forests dominated by Holm oak with scattered throughout groups of Cork oak; (2) Pure and mixed forests dominated by deciduous oaks; (3) Mesophilous hardwood forests; (4) Beech forests; (5) Forests with prevalence of hydrophytes; (6) Reforestation of Black pine and Mediterranean pine; (7) Mixed forests of conifers and broadleaves, with a prevalence of other native broadleaves; (8) Beech forests and reforestation of Black pine.

Fig. 5 - Variation of the main classes of land use at a sub-basin scale.

areas and the analysis of technical documents relating to these projects in the two periods indicate that 65% of reforested areas includes lands that had previously supported these uses. The pine reforestation, particularly Austrian black pine, Calabrian pine and in part Loricate pine (*Pinus leucodermis* Antonie), was carried out since 1957 up to 1960, while Mediterranean pine reforestation - Umbrella and Aleppo pine - was carried out in 1959 and 1960. Most of the Umbrella and Aleppo pine reforestation cover the slopes of the Vallone Fiumicello, on the left side of the Coscile River. The area reforested with these species covers about 825 hectares and 80% of this area is concentrated in a single large area of the Valle Piane sub-basin.

The planting technique included soil preparation work on terraced hill slopes 4-5 meters apart (depending on the slope), each terrace 80 cm wide. As regards the direct seeding along the terraces, 10-15 and 90-100 kg ha^{-1} of seeds was used for Aleppo and Umbrella pine, respectively. Thus, the initial densities were particularly high: in the Umbrella pine stands 6 years after sowing about 12 000 up to more than 21 000 plants ha^{-1} were still surviving; while for the Aleppo pine stands 48 000 to 96 000 plants ha^{-1} were detected (Ciancio 1970). Early on, density was reduced by thinning and, in later years, with moderate thinning. Also, self-thinning took place in several areas, so that in the early 1980s the above stands approached current density values, ranging from 1 400 to 1 900 trees ha^{-1}, still quite high in relation to the stand age.

Austrian black pine had been used in reforestation in the range 800-900 m a.s.l. up to 1300-1500 m; Calabrian pine has been used where substrate conditions were suitable; on limited areas with well-preserved soils, Atlas cedar and Douglas fir were also used. These reforestation activities currently cover large areas of the middle and upper basin of the Garga River and other smaller streams, all right tributaries of the Coscile River, as well as the very steep slopes of the hydrographic left side of the Vallone Fiumicello basin. The total reforested area is 2125 ha and is mainly concentrated in one large area on the crest of the Coscile and Garga River, with areas of smaller size spread in the other sub-basins (Fig. 6).

The most widely used soil preparation technique has been terraced hillslopes along the contour lines; following the slope, in some areas the distance between terraces was 4-5 m. Within two terraces, segments of terraces 2 m long and 3 m distant from each other were made. Each terrace was 40-80 cm wide with a 20% upstream counter slope. On average, each hectare was involved with about 2800-3300 m of terraces and segments of terraces; the plants along the terrace were

forest area (12%), out of which 11% due to reforestation. On the other hand, very degraded forest areas were slightly increasing (5%).

Land use dynamic is confirmed at sub-basin scale reproducing a similar trend as to the entire basin (Fig. 5).

The increase of areas affected by reforestation was over 3 000 hectares. Indeed, the comparison of natural grassland and pasture
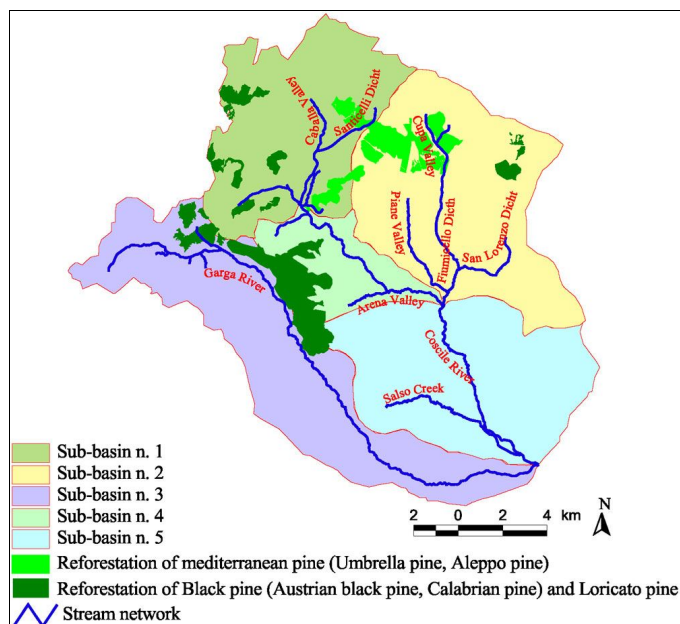
Fig. 6 - Reforestation areas in the Coscile sub-basins.

Fig. 7 - Soil preparation work for terraced hillslopes of Coscile basin (by CASMEZ 1964).
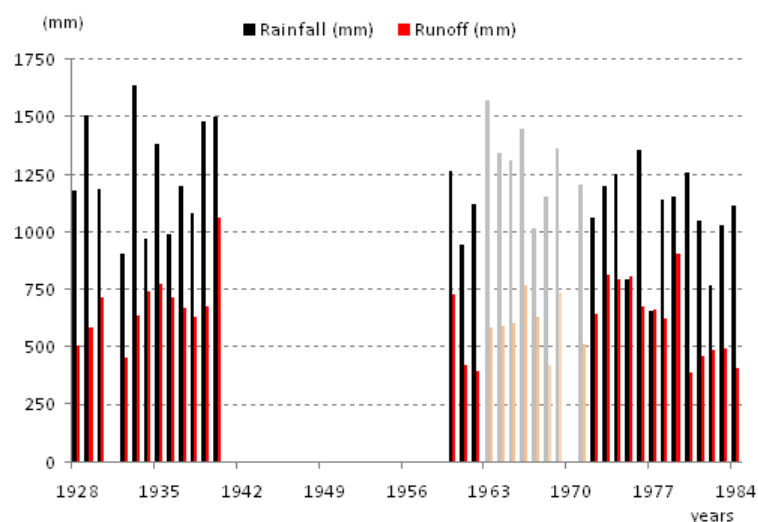

Fig. 8 - Annual distribution of rainfall and runoff for the Coscile basin at Camerata gauge.
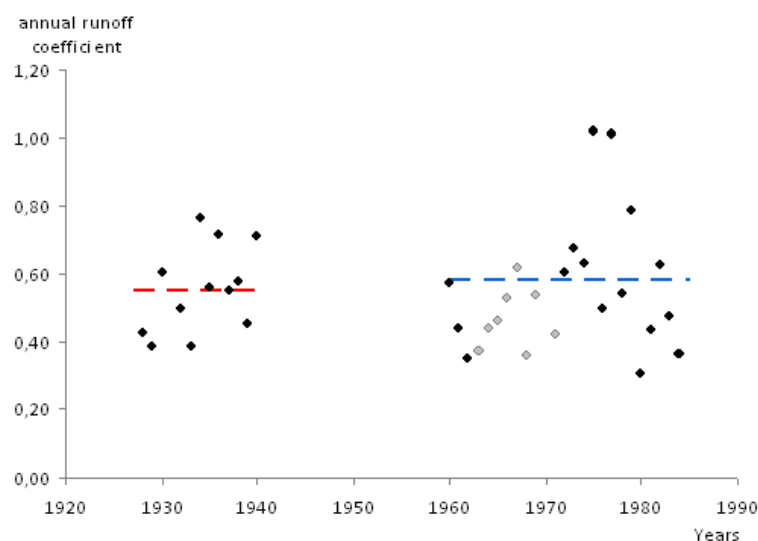

Fig. 9 - Runoff coefficients for the Coscile basin at Camerata gauge. Dashed red line represents the mean value for period 1924-40, while the dashed blue line represents the mean value for period 1960-84, not considering grey points. For more details, see text.
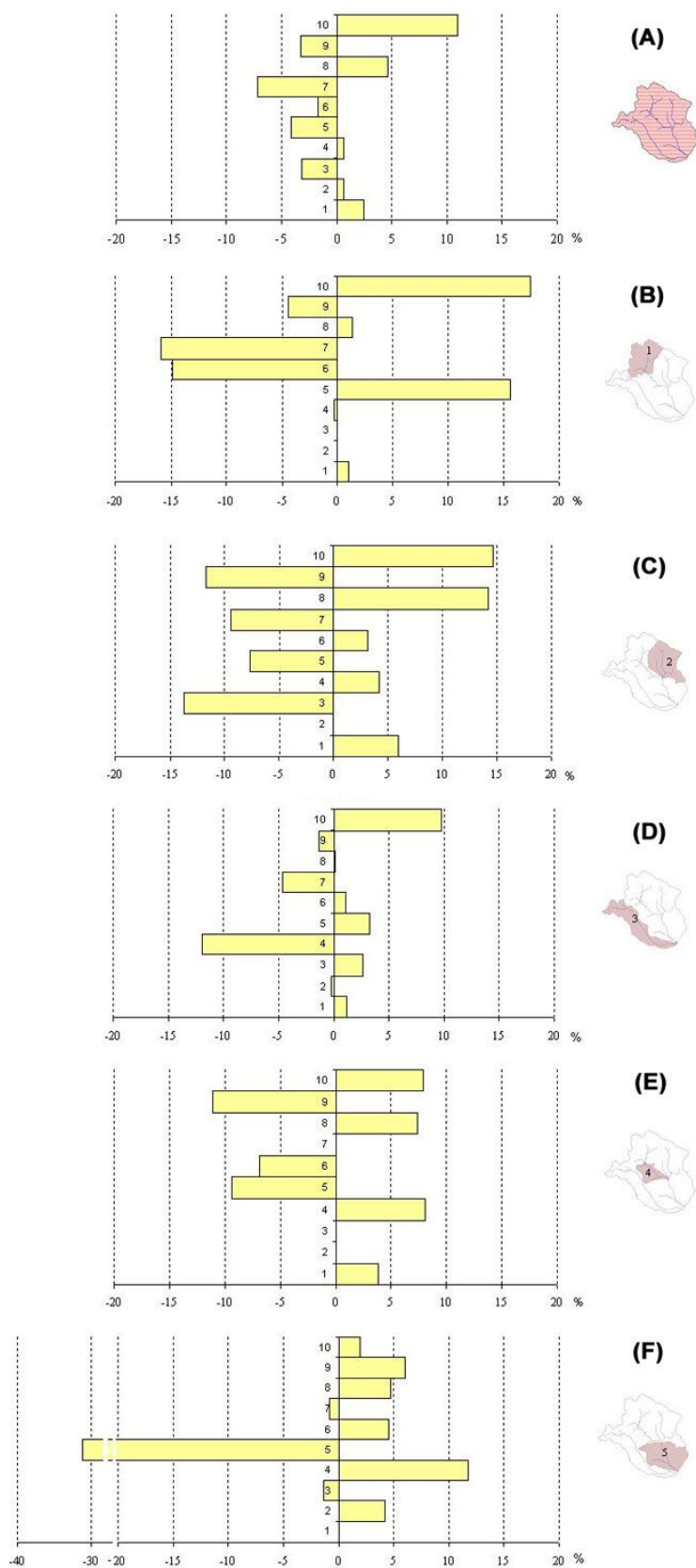
Fig. 10 - Change of land use from 1968 to 2006 in Coscile basin and for the different sub-basins of Coscile watershed. (1): urbanized areas; (2): orchards; (3): vineyards; (4): olive groves; (5): heterogeneous agricultural areas; (6): Arable crops; (7): natural grassland; (8): highly degraded forest areas; (9): forest; (10): reforestation.

spaced about 70-80 cm apart (Fig. 7).

On average, the initial density was 2500-3000 plants ha^{-1}, decreased to about 2000 plants ha^{-1} in the early '80s. Current density varies between 1000-1500 plants ha^{-1}, up to 1700 plants ha^{-1} where thinning operations were ineffective and losses from self-thinning were negligible.

Hydrological analysis

As regards the analysis of the hydrological data, the temporal distribution of the annual values of rainfall and runoff for the Coscile basin at Camerata gauge is shown in Fig. 8. The behavior of annual runoff coefficients (Fig. 9) reveals similar mean values for the periods considered (Tab. 2), both before and after reforestation. Analogously, CN parameter estimated for the whole basin in the two time spans considered did not show any substantial differences, being its value about 54 before and after land use changes (Tab. 3). These values can probably be due to the opposing effects caused by the substantial increase in reforested area (11%) which was counterbalanced by the increase of both degraded wooded areas and urbanized areas, as well as the decrease of extent of forestland (Fig. 10a). The disaggregated analysis of the CN value for each sub-basin (Tab. 3) shows an increase in the CN by an average of 4.8 units only in sub-basin 2 from 1968 to 2006. This situation stems from an increase in the surface area of highly degraded forests (+14.3%) and urbanized areas (+6%), although the reforestation account for 14.7% of the area within the sub-basin (1080 ha - Fig. 10c). The only sub-basin in which a marked negative variation of the CN value (5.9) occurs is the sub-basin 5, which is located in the valley, where 81% of the entire sub-basin is committed to agricultural uses. The decrease of 32% of heterogeneous agricultural areas (CN=72) is mitigated by increases in the surfaces of all other land uses, including forests and reforestation accounting for 8% (Fig. 10f).

As for the other three sub-basins the variation of the CN are very small. In sub-basin 1 a slight decrease of the CN has been obtained, due to an substantial increase in reforested area (17.4%), little variation of the very degraded forest areas and urban areas (+1.4% and +1.1%, respectively) and a 16% increase in heterogeneous agricultural areas. Conversely, a strong decrease of both natural grasslands (16%) and arable crops (15%) was detected (Fig. 10b).

In sub-basins 3 and 4 (Fig. 10d, Fig. 10e) no substantial changes of the CN values were detected, although a conspicuous increase in reforested areas was found (10% and 8%, respectively). In sub-basin 3, an increase in surface reforested and a concurrent reduction of natural grasslands, olive groves and forests were observed.

Tab. 2 - Values of CN parameter related to the different land uses in the Coscile basin.

Land use	CN	Area - 1968 (ha)	Area - 2006 (ha)
Urbanized areas	98	135	820
Vineyards	45	1283	406
Orchards	45	158	347
Olive groves	45	3281	3452
Heterogeneous agricultural areas (Annual crops associated with permanent crops + Complex cultivation patterns + Agro-forestry areas)	72	5789	4636
Arable crops	72	3085	2603
Natural grasslands	50	4155	2162
Highly degraded forest areas	77	1420	2731
Forest	38	8197	7295
Reforestation	35	290	3340

Tab. 3 - Mean values of CN for each sub-basin and the whole basin.

Sub-basin	Area (ha)	CN 1968	CN 2006	ΔCN (1968-2006)
1	5781	50.9	49.9	-1
2	7361	57.1	61.9	4.8
3	7437	48.5	49.3	0.8
4	2318	53.2	53.3	0.1
5	4895	66.1	55.2	-5.9
Whole basin	27794	54.1	54.1	0

In sub-basin 4, increased reforestation is balanced by both the reduction in the forested area and the heterogeneous agricultural areas, besides the increase in highly degraded forest areas and urbanized areas.

Discussion

The link between waters and forests are yet a subject of discussion (Andréassian 2004, Cosandey et al. 2005). Sun et al. (2006), using small experimental reference basins, highlight how reforestation efforts result in a reduced runoff coefficient. This reduction may also depend on the type of species used. Farley et al. (2005) compared the effect of both eucalyptus and pine reforestation, where a runoff reduction by 75% and 40% has been observed, respectively. In this case, the authors attributed the recorded differences to the different growth patterns of the species used. Analogous studies on larger basins (with areas of about 1000 km^2) show how the degree of reduction strongly depends on reforestation characteristics and specific hydrological conditions (van Dijk & Keenan 2007). Buttle (2011) suggests that reforestation reduces several metrics of peak streamflow at the Ganaraska River basin, Canada. By analyzing a 267 km^2 basin with about 12% of the basin forested with pine and red oak, the author detected a decrease in annual runoff of about 100 mm, a decrease of peak daily flow and an increase in annual minimum flow.

In this study, the effects of reforestation on runoff reduction are not obvious, though they can be masked by various causes: the concurrently increased urbanized areas, the relatively large size of the basin, the limited extent of reforested area and the uncomplete development and evolution of the reforested stands. In fact, plantations have likely increased the soil infiltration rate and the evapo transpiration losses in Coscile basin, though the runoff decrease was partially counterbalanced by an increase in runoff from very degraded lands and urbanized areas. Moreover, the effects of reforestation can be considered as opposed to those due the forest destruction, but are more gradual and not immediately recognizable. In a first phase the techniques of preparation of the soil, including terracing, affect the water balance and soil erosion. Subsequently, plant growth provides soil protection as canopy cover approaches to full closure, and finally a gradual improvement of soil physical and chemical properties (including hydrological features) takes place, as organic matter accelerates the renaturation processes (Iovino 2003). Indeed, the reforestation carried out in the '50 in the Coscile Basin are currently in a stage of soil improvement, with renaturalization processes occurring only in part, due to the high stand density.

Conclusions

A historical analysis on land use changes, with particular reference to reforestation following decades of abandonment and exploitation, has been performed in a large basin (277 km^2) of southern Italy characterized by intense degradation on very steep slopes. In the scientific literature, studies on reforested basins are fewer than those devoted to deforested basins, since the effects of deforestation are more rapidly appreciable than those due to the reforestation.

The investigation carried out in the Coscile basin suffered the above difficulty in detecting the effects of reforestation on the hydrological behaviour of a large basin. In fact, a 11% spatial increase of reforested areas in a basin of 277 km^2 has not modified runoff coefficient and CN parameter, the latter evaluated both at a sub-basin and basin scale. Our results could be the consequence of a trade-off between increases of reforested areas, degraded areas urbanized areas. It is worth to be noticed that these results depends on characteristics of the specific reforested area, in that the time periods analyzed refers to the monospecific pine reforestation experiencing only variations in density in relation to age. However, in future the hydrological response may change as a result of the increased structural complexity of reforestation, according to an evolutionary dynamics that can be supported through forest management.

Notes

The authors contributed to this paper in equal measure.

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