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ORIGINAL PAPER

Evaluation of the post-fire erosion and flood control works in the area of Cassandra (Chalkidiki, North Greece)

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Abstract We quantified morphological and hydrographical characteristics of two drainage basins (Chanioti and N. Skioni) on Cassandra peninsula of Chalkidiki (North Greece), and evaluated the effectiveness of post-fire flood and erosion control works. The drainage basins were chosen because of their severe damage by fire, post-fire potential for erosion and flood due to the steep relief, and the importance of the area for residential and tourism development. The first measures taken in the area after the fire were salvage cutting of burned trees, a total ban on grazing, and construction of three types of works, log erosion barriers (LEBs), log check dams and contour branch barriers. Almost all necessary post-fire works were completed in both catchments but many construction failures were recorded. Approximately 75 % of the LEBs and 45 % of the contour branch barriers functioned properly, while the remainder failed. Nearly 80 % of the log dams were sedimented to 0–20 % of the dam height, 14.3 % were 20–40 % filled and 5.9 % collapsed. Despite these failures, peak discharge declined by 10.5 % in Chanioti and 20.4 % in N. Skioni catchment. The main reasons for works failures were the rush of construction and the limited supervision of workers, which resulted in floods during the years that followed.

Keywords Erosion · Catchment · Contour branch barrier · Flood · Log erosion barrier · Post-fire management

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Introduction

Wildfire is a natural process in many conifer-dominated ecosystems. After fire, both total runoff and peak flow can increase dramatically in burned watersheds, causing flooding, debris flows, and high rates of soil loss and sedimentation (Robichaud et al. 2008b). Commonly used flood and erosion control measures are log erosion barriers, log check dams and contour branch barriers, while there are several hillslope treatments such as broadcast seeding, mulching, contour trenching, terrace construction, scarification, slash spreading, and installation of straw wattles, silt fences, geotextiles, and sand bags.

During the last 20 years in Greece these flood and erosion control works have been constructed in burned drainage basins but, in many cases, the efficiency of these works has been criticized. Faults arise from ineffectiveness of works due to inadequate supervision of construction and consequently inadequate implementation of the construction rules (Baloutsos et al. 2007).

An intense forest fire occurred on Cassandra peninsula in August 2006 that burned 5,500 ha of forest and crops, while the catchments of Chanioti and N. Skioni were totally burned (Fig. 1).

Sediments, ash, burned logs and branches were transported by overland flow during the first rainfalls after the

Fig. 1 Part of burnt area of N. Skioni drainage basin

fire to two downstream settlements. This caused problems including the destruction of parts of roads. The most significant problem was the contamination and fouling of the sea and the beaches of the area, which resulted in cancellation of several tourist bookings for that summer. The financial losses resulting from the cancelled reservations proved to be serious for the local community.

Pine forest, olive trees and crops were destroyed, leaving the soil unprotected and, therefore, increasing runoff and soil erosion. Fire might also have changed some physical properties of the forest soils, such as moisture content, structure, leaching potential, absorption capacity and water penetration, mainly due to the fact that the soil organic matter, the basic factor of particle aggregation, was destroyed. Additionally, a hydrophobic layer of soil was observed after the fire at many locations in the study area. This possibly resulted from phenol constituents that melted from the fire, moved to deeper soil horizons and created clusters, condensing the soil. This water repellent layer usually leads to increased runoff and soil erosion (Mataix-Solera et al. 2013). Researchers have described post-fire soil water repellency and its dependence on soil type, fire severity and vegetation type. Tessler et al. (2008) reported that pre-fire vegetation type is an important factor affecting water repellency persistence values, and that sites with pre-fire *Pinus. halepensis* cover showed the highest levels of water repellency. Lewis et al. (2008) also reported strong water repellency after fire, while Robichaud (2000) calculated hydraulic conductivity values that provide important input parameters for use in erosion prediction models. As Beatty and Smith (2010) reported, water repellent soils can contribute, except for the development and propagation of unstable wetting fronts and preferential flow paths, increased and more rapid aquifer contamination, increased soil degradation (i.e. erosion and rill formation), enhanced overland flow, reduced soil–water redistribution, also to reduced productivity and seed germination.

Erosion, apart from large amounts of soil, also removes a significant part of soil nutrients, leaving an arid and poor substrate. Due to the threat of the above factors, the need for immediate construction of post-fire erosion and flood control measures in the study area was imperative.

After the fire of August 2006, the forest service immediately started the flood-prevent and erosion-control works construction to protect the area from the impending autumn rainfalls. The main post-fire works were salvage cutting of all burned trees, contour felling of trees to serve as log erosion barriers (LEBs), and construction of log check dams and contour branch barriers. Many studies have evaluated post-fire measures of this type in areas worldwide that suffer from wildfires, providing important information about the construction and utility of these measures. Robichaud et al. (2008a) conducted a study after an extended fire in western Montana in 2000 to determine the effectiveness of erosion barriers including contour-felled logs, straw wattle, and hand-dug contour trench in mitigating post-fire runoff and erosion. Fox (2011) compared the efficiency of two erosion control methods, log debris dams (LDDs) and a sedimentation basin, immediately after a major forest fire in southeast France in 2003. Wohlgemuth et al. (2001) studied two watersheds after fire in the San Jacinto Mountains of southern California to quantify post-fire hydrologic and erosion response, and to assess the performance of LEBs. Wagenbrenner et al. (2006) evaluated the effectiveness of three common post-fire rehabilitation treatments in burned areas along the Colorado Front Range, quantifying the installation quality of several contour-felling treatments, and assessing their effects on runoff and sediment yields. Raftoyannis and Spanos (2005) evaluated the effectiveness of log and branch barriers in Greece as post-fire rehabilitation treatments after a severe fire in a *Pinus brutia* Ten. forest near Thessaloniki.

The main objectives of the current research were: (1) to quantify the post-fire morphological and hydrographical characteristics of two drainage basins (Chanioti and N. Skioni); (2) record the performance of the constructed post-fire flood prevent and erosion control works and evaluate their effectiveness; and (3) account for failures in works construction. The two drainage basins were selected as our study area because of their nearly total destruction by fire, the potential erosion threat emerging from the steep topographic relief and the importance of the area for residential and tourism development. We aimed to describe a representative case of post-fire catchment management in Greece and compile knowledge and experience on post-fire management in environments of similar conditions. Our conclusions are applicable to other Mediterranean areas where frequent wildfires and residential development coexist, and post-fire flood and erosion control works are both urgent and necessary.

Materials and methods

Our data were obtained not only from field survey, but also from study of topographic, geologic, and vegetation maps. The study area was visited four times: November 2006, February 2007, April 2007 and June 2007, to record hydrological data and to document works, and to measure the effectiveness of works and the progress of natural revegetation. Catchment morphology and hydrological characteristics were described using a topographical map of the area at 1:50,000 scale, and digitization was carried out using the software of ArcGIS® of ESRI, Inc, Redlands, CA, USA. The main torrential factors that were determined and evaluated for the two drainage basins of Chanioti and N. Skioni streams were relief, climate, vegetation and geological substrate. For determination of relief, we used maps of the Hellenic Military Geographical Service (H.M.G.S. 1971) at 1:50,000 scale. Meteorological data were obtained from the Institute of Forest Research, which is responsible for the Meteorological Station at Cassandria (Chalkidiki) and refer to the period 1978–1997, and from the Meteorological Station at Sani for 2006–2010. Field survey and a map produced by the Institute of Geological and Mineral Exploration (I.G.M.E. 1993) were used for study of the geological substrate of the drainage basins. We used CORINE (2000) for study of vegetation of the two catchments. The effectiveness of constructed erosion and flood control works was examined, recorded, and illustrated. Before visiting the burn area, representative sites in the study area were chosen and mapped for monitoring of works, while factors including slope, elevation, geology, stream class, and work type were taken into consideration in that choice. Peak discharge, recorded in September 2006, was measured using the flood-water traces method, based on the geometrical features of cross-sections of the two main streams, the slope and the roughness of the torrent-bed, and by applying the Manning–Strickler equation (Kotoulas 2001). For the determination of maximum expected discharge (Q_{max}) the analytical equations of Giandotti and Turazza and also the rational method were used (Kotoulas 2001). In these analytical equations, one rainfall amount was used for both catchments to enhance comparability of results. Additionally, in the Turazza equations and the Rational Method, we used the mean value of the runoff coefficient (c) for both catchments, based on the analysis of the torrential factors of vegetation, geology and relief, before and after the fire. Maximum sediment discharge (G_{max}) was estimated using the equation of Stiny-Herheulidze, that is widely used in Greece, especially in lack of sediment measures (Kotoulas 2001; Maris et al. 2004; Water in Core 2011).

Study area

Cassandra is a peninsula, on the southwest side of Chalkidiki prefecture (north Greece), while in the east one can see the other two peninsulas of Chalkidiki, Sithonia and Athos (Fig. 2). This area is semi-mountainous and is covered mainly by farmland and pine forest. Chanioti settlement is located at the middle of the east coast of Cassandra, while N. Skioni settlement is located on the west coast of the peninsula.

The study area consisted of two drainage basins, Chanioti stream and N. Skioni, which are of approximately the same width. The stream of Chanioti flows eastwards and drains to the sea, passing through Chanioti settlement. N. Skioni stream flows southwestward, passing through N. Skioni settlement to the sea.

The floodplains of both streams had been supported intense residential and tourism developments. Particularly, parts of the streams that flow through villages were used as roads, while the width of the two streams was significantly constricted by channelization works.

Fire destruction of the dense pine forest highlighted the fact that the area was vulnerable to flood and erosion. The impacts of extreme rainfalls during autumn and winter, the erodible soil and the steep relief were multiplied after the fire, causing increased runoff and reduced water time concentration ($t_{c'}$). The design of flood control works had to account for large increases in runoff to protect the two settlements. Below, we present analysis of basic torrential factors and describe the effect of each of these on the watershed.

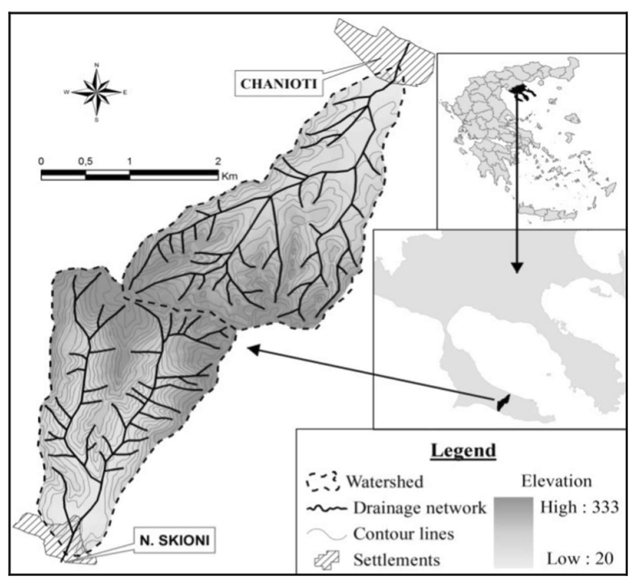

Fig. 2 The study area including the catchments of Chanioti and N. Skioni settlements and their drainage network

Morphological and hydrographical characteristics

The area of Chanioti and N. Skioni catchments was 5.05 and 4.48 km^2, respectively. The minimum elevations (H_{min}) in the catchments were 15 m in Chanioti and 8 m in N. Skioni, while the maximum elevation (H_{max}) for both catchments was 333 m. Mean elevation (H_{med}) was 168 m in the Chanioti catchment and 158 m in the N. Skioni catchment. The length of the mainstream was 4.62 km in the Chanioti catchment and 4.13 km in the N. Skioni catchment. The slopes of Chanioti and N. Skioni mainstreams were 6.51 and 7.79 %, respectively, while the mean slope of Chanioti catchment was 30.76 % and the mean slope of N. Skioni catchment was 38.81 %.

The two catchments were small and were classified as hilly and semi-mountainous areas (Table 1). The steep relief of the area in combination with fire destruction of the vegetation had potential to generate flood and erosion events of great intensity. The mean slopes of the torrents (6.51 and 7.79 %) were steep, and caused severe rill and gully erosion. This emphasized the urgency and necessity of the construction of post-fire erosion and flood control works.

Climate

Annual temperature and precipitation data are shown in Table 2. The annual pattern of air temperature peaked in July and was at its minimum in January.

According to Köppen climate classification, the climate of the area is defined to be Csa, corresponding to Mediterranean climate or mean temperature climate type with a dry and warm summer. Precipitation is brief but intense with maximum precipitation volume (rainfall) in winter and minimum in summer. Maximum 24-h rainfall was 150 mm and maximum rainfall intensity was 35.2 mm/h, which promoted intense erosion and floods. This history of frequent, intense rainfall events in this area, generated the need for erosion and flood control works construction after the fire.

Land uses

The pre-fire study area was covered by shrubs of evergreen hardwood species, dense pine (*P. halepensis* L.) forest and croplands (Fig. 3). Land uses and areas of coverage for each catchment are listed in Table 3.

Vegetation is a basic factor that affects the available water mainly through the vegetation canopy and in softwood species tend to retain 30–40 % of total precipitation, while hardwoods retain 10–15 %. All this amount of water, which would be retained by vegetation, now flows superficially increasing the maximum discharge of the main streams of the two catchments.

Geological substrate

The geological substrate of the two catchments (Fig. 4) consisted mainly of the following geological formations. There is a system of colourful marl and conglomerates. Marls are situated between limestone and split-clay and consists of $CaCO_3$ (35–65 %) and clay (65–35 %). Conglomerates are approximately of between 70 and 250 mm diameter with rounded edges. There were also yellow–brown sands with the diameter within the range of 0.2 and 2 mm and alluvial depositions.

The geology of the area consisted mainly of rocks that are vulnerable to water erosion. The sediments that were produced were small due to the nature of the rocks, a fact that should be taken into consideration during the design of the post-fire works to prevent sediment transport. The distribution of geological formations in the two catchments is displayed in Table 4.

Results and discussion

Evaluation of the post-fire flood and erosion control works efficiency

The fire caused total destruction of the vegetation, leaving the soil unprotected from intense rainfalls. The first post-fire measures were the salvage cutting of burned trees, a ban on grazing and the construction of three types of works, LEBs, log check dams and contour branch barriers. The material for the construction of these works was burned trees and shrubs. These works were accomplished before the end of September 2006, just before the start of autumn rainfalls.

Table 1 Morphological and hydrographical characteristics of Chanioti and N. Skioni catchments

Drainage basin	Morphological characteristics					Hydrographical characteristics	
	Area (km^2)	Min. altitude (m)	Max. altitude (m)	Mean altitude (m)	Mean slope (%)	Main stream length (km)	Mean main stream slope (%)
Chanioti	5.0503	15	333	168	30.76	4.6297	6.51
N. Skioni	4.4896	8	333	158	38.81	4.138	7.79

Evaluation of LEBs

LEBs functioned better than contour branch barriers. Behind the logs, large amounts of small sediments accumulated and herbaceous plants colonized this material (Fig. 5a), contributing to stabilization of the soil. Construction and placement failures of LEBs were also recorded. Crooked logs were placed without the necessary preliminary process of digging trenches to avoid gaps between the logs and soil (Fig. 5b). This failure enable water to flow beneath the log, causing soil erosion and sediment transport that was not controlled by the next downstream LEB line. Because of the erodible nature of the rocks and the steep relief of the area, logs used for LEBs should have been of diameters >20 cm to hold large quantities of sediment. In places with steeper slopes, more LEBs should have been constructed per unit of stream length. Approximately 75 % of LEBs were efficient at holding large amounts of sediment (Fig. 5a), while the remaining 25 % failed.

Table 2 Precipitation height (mm) and air-temperatures (°C), (1978–1997)

Month	Mean monthly precipitation (mm)	Mean monthly air temperature (°C)
Jan.	60	7.4
Feb.	62	7.9
Mar.	53	10.1
Apr.	41	13.9
May	30	19
Jun.	23	24
Jul.	20	26.1
Aug.	21	25.6
Sept.	24	21.9
Oct.	78	17.4
Nov.	86	12.2
Dec.	92	9
Mean	590	16.2

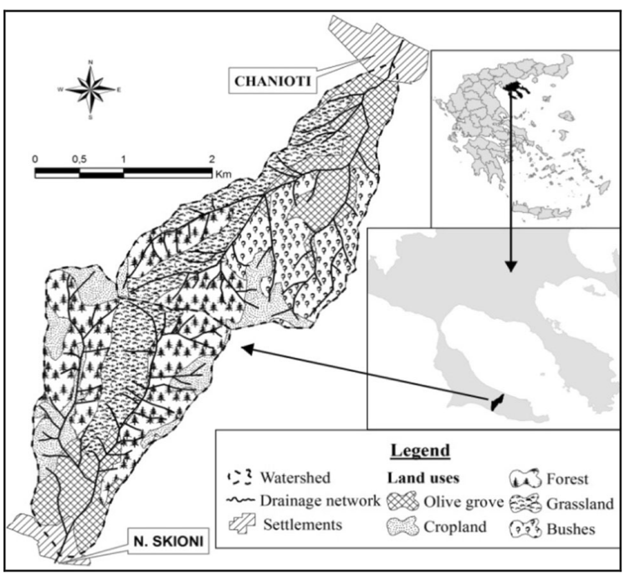

Fig. 3 Land uses of Chanioti and N. Skioni catchments

Evaluation of contour branch barriers

Contour branch barriers were constructed of burned tree branches. The branch barriers were constructed parallel along contour lines in streams of 1st and 2nd order to hold the fine material transferred by runoff.

Sediments did not accumulate behind most of the branch barriers, indicating poor function. The branches were not tightly compacted and some branch barriers consisted only of a few branches (Fig. 6b). Furthermore, branch barriers were placed on the ground but not in trenches needed to stabilize the barriers and to ensure close contact between branches and the ground to block transfer of sediments. If all these factors had been taken into account, these works would have functioned more successfully. In places where contour branch barriers were constructed properly, they retained fine-grained sediments (Fig. 6a). Approximately 45 % of the contour branch barriers functioned properly and held fine-grained material, whereas the remaining 55 % were of low efficiency.

Evaluation of log check dams

Log-dams were constructed of burned logs in the 1st and 2nd order streams. The logs were placed one atop the other, until the desired height was achieved. Dams were stabilized by poles inserted into the ground, upstream and downstream of the wooden log-dam. Poles were tied together

Table 3 Land uses, the area they cover and the respective percentages

Land uses	Chanioti catchment		N. Skioni catchment	
	Area (km^2)	(%)	Area (km^2)	(%)
Crop lands	1.0590	20.96	1.17	26.07
Bushes evergreen—hardwood species	2.3441	46.42	1.9374	43.15
Forest (*Pinus halepensis* L.)	1.6472	32.62	1.3822	30.78
Total	5.0503	100	4.4896	100

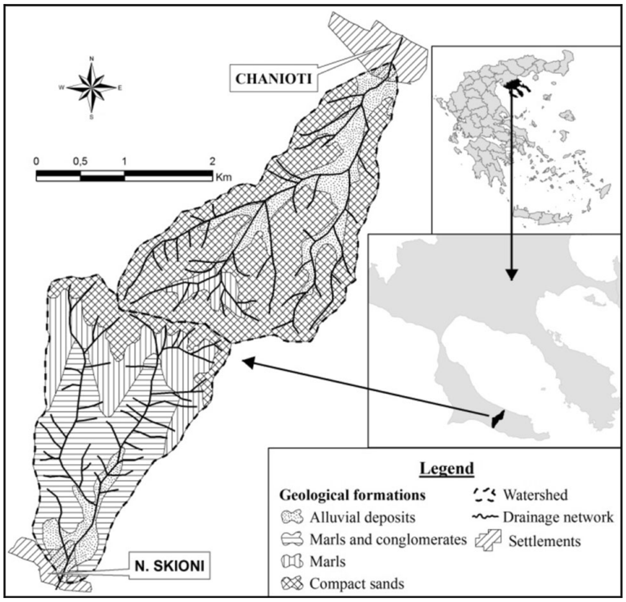

Fig. 4 Geological formations of Chanioti and N. Skioni catchments

with wire passing between the logs. These works were constructed across the streams to decrease stream flow velocity and prevent the downstream transfer of sediments.

Failures were detected in the construction of log check-dams. The main causes of malfunctions were the improper placement of logs and the use of crooked logs, that created gaps in the body of the dams (Fig. 7). As a result, only limited amounts of sediments accumulated behind the dams (Fig. 8a). Stabilization of the log dams was accomplished only using poles, without the construction of foundations at the sides or the bottoms of the log dams, increasing the risk of collapse of the dams (Fig. 8b) and undermining of the sides of dams.

Spillways were not constructed at the crests of log dams for overflow of high-volume discharge. Thus there was no protection against side erosion by the streams. Also, there were no measures to prevent the undermining of the log dam foundations. Accumulation of sediments behind the log dams was limited, indicating that the dams were inefficient at holding materials that passed through the settlements and creating problems for the local population and their tourism infrastructure. Nearly 80 % of the log dams were filled with sediments to 0–20 % of the dam height, while 14.3 % of dams were filled to 20–40 % of the dam height and 5.9 % collapsed.

Given the slope of the drainage basins, there were reaches where branch barriers, log-bundles and log-dams should have been constructed in closer distances to achieve more efficient protection. Nearly all prescribed flood and erosion control works were completed but several construction failures were recorded. The main reason for insufficient planning, inadequate supervision, and improper

Table 4 Geological formations of Chanioti and N. Skioni catchments

Geological formations	Chanioti catchment		N. Skioni catchment	
	Area (km^2)	(%)	Area (km^2)	(%)
System of colourful marls and conglomerates	–	–	2.13	47.45
Series of white marls	0.25	4.87	1.22	27.11
Sand	3.72	73.62	0.78	17.39
Alluvial depositions	1.09	21.51	0.36	8.05
Total	5.05	100	4.49	100

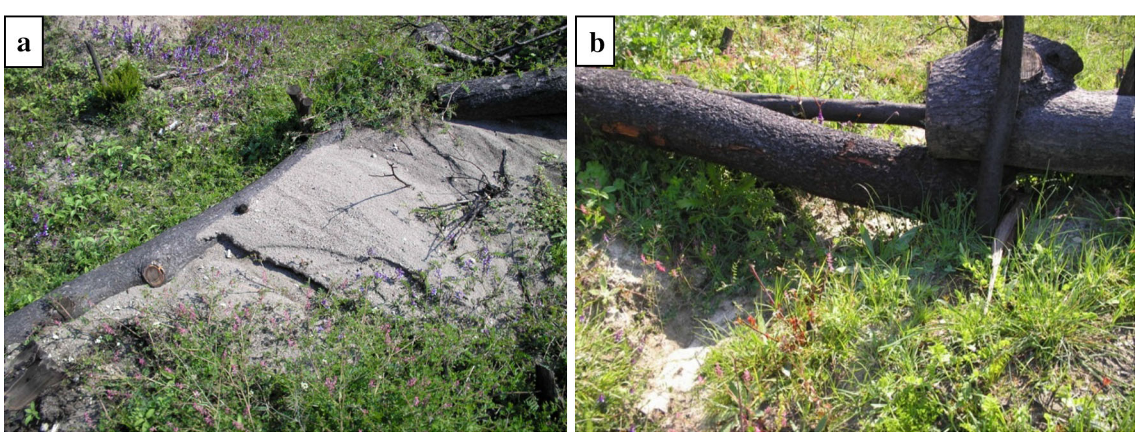

Fig. 5 Representative examples of effective (**a**) and ineffective (**b**) LEBs in the study area

Fig. 6 Representative examples of effective (**a**) and ineffective (**b**) contour branch barriers in the study area

construction of the flood and erosion control works was the post-fire rush to complete the works.

The forests in the two watersheds were totally burned and the destruction of the area was vast. Even if most of the post-fire protection works and treatments had been accomplished successfully, complete protection of the communities could not be ensured. Generally, the main aim of the works was not to retain all sediments, but primarily to control and regulate stream flow velocity, and secondarily to decrease the amount of sediments and minimize damages to the two settlements. Given these issues, the construction of the works was necessary and had a positive effect on reducing of peak discharge, sediment yield and the damages to infrastructures, which undoubtedly would have been even more severe if these treatments and works had not been implemented.

During the months that followed the works construction, September, October and November, intense rainfall occurred and the works that had been constructed properly were filled with sediments by November. During the next months no significant changes were recorded. In contrast, the works that were not constructed properly did not work efficiently and did not trap sediments or retained the same amount of trapped sediments regardless of stream flow volumes. Similar results have been recorded for other protection works. Fox (2011) evaluated the efficiency of sediment trapping methods after a Mediterranean forest fire and found that log dams did not trap predicted amounts of sediment, mainly due to the presence of gaps in the dams, and only the half of the dams were filled with sediments. Wagenbrenner et al. (2006) and Robichaud et al. (2008a, 2008b) reported that post-fire works reduced surface runoff and sediment transport after moderate rainfall events but after intense rainfall events the works did not work efficiently.

Fig. 7 Gaps between the logs of the log-dams and the resultant absence of sediments

The effects of post-fire work on maximum discharge and sediment transfer

One month after the August 2006 fire, 35.2 mm of rainfall was recorded in one event (Tables 5 and 6) Peak discharge recorded for the Chanioti catchment (34.54 m^3/s) was approximately 10.5 % lower than the expected average maximum discharge (38 m^3/s). In the N. Skioni catchment, peak discharge (27.21 m^3/s) was approximately 20.4 % lower than the average expected maximum discharge (34 m^3/s). Expected maximum discharge rates are mean values generated by the three equations of Turazza, the rational method (for burned untreated watersheds) and Giandotti. After the construction of the works, maximum sediment discharge (G_{max}) was 11 and 25 % lower in Chanioti and N. Skioni catchments, respectively (Table 7). We assume that the decrease in maximum water discharge and sediment transfer resulted from construction of flood-erosion control works. The reduction by 20.4 % in peak discharge and 25 % in sediment discharge in the N. Skioni catchment could be attributed to more efficient works

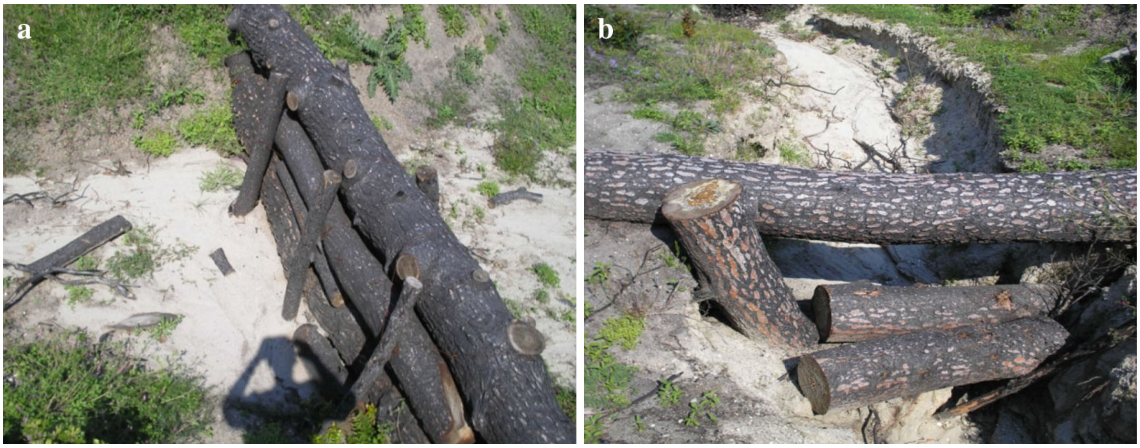

Fig. 8 Representative examples of relatively effective (**a**) and ineffective (**b**) log check dams in the study area

Table 5 Estimation of peak discharge in Chanioti and N. Skioni watersheds using the water-trace method

Cross-section data	Symbol	Chanioti	N. Skioni
Rainfall	Depth (mm/h)	35.2	35.2
Average velocity of water	u (m/s)	6.84	6.06
Watered area	F (m^2)	19.92	12.58
Watered perimeter	U (m)	8.95	12.22
Hydraulic radius	R (m)	1.22	1.03
Water depth	(m)	1.65	1.31
Coarseness coefficient	K	60	60
Mean slope of mainstream	J (%)	1	1
Time concentration (Giandotti)	$t_{c'}$ (h)	1.61	1.5
Peak discharge (burned, treated area)	Q (m^3/s)	34.54	27.21

Table 6 Estimation of expected maximum discharge for unburned, burned-untreated and burned-treated watersheds

Equation and treat	Symbol	Watershed	
		Chanioti	N. Skioni
Peak discharge burned, treated area	Q_{max} (m^3/s)	34.54	27.21
Max discharge (Giandotti) burned, untreated area	Q_{max} (m^3/s)	33.76	31.09
Max discharge (Turazza) unburned	Q_{max} (m^3/s)	15.67	13.71
Max discharge (Turazza) burned, untreated area	Q_{max} (m^3/s)	41.86	36.57
Max discharge (rational method) unburned	Q_{max} (m^3/s)	14.82	13.18
Max discharge (rational method) burned, untreated area	Q_{max} (m^3/s)	39.53	35.14

construction compared to that in the Chanioti catchment: more severe damage occurred in the settlement of Chanioti.

Natural revegetation after the August 2006 fire met expectations. Three months after the fire (November 2006), evergreen hardwood species (*Arbutus unedo*, *Quercus coccifera*, *Pistacia lentiscus* and others) had reached heights of 40–45 cm. In shady places, many seedlings of *P. halepensis* L. were recorded. The grazing prohibition after the fire undoubtedly contributed to natural revegetation and the ecosystem protection. Nevertheless, natural revegetation did not prevent floods the months that followed, mainly because the new seedlings and their root systems were too small role to impede flows of water or sediments. Therefore, the construction of the works was of great importance for the protection of the area. In Mediterranean ecosystems, fires cause serious erosion and flood problems mainly during the first 6–9 months after the fire, because natural revegetation mechanisms start working quite soon,

Table 7 Estimation of the maximum sediment discharge for burned untreated and burned treated area

	Chanioti	N. Skioni
G_{max} (m^3/s), burned, untreated area	9.13	8.15
G_{max} (m^3/s), burned, treated area	8.22	6.47

especially in the case of pine forest. Therefore, replanting of the burned forest area is not necessary. In time repair of the anti-erosion and anti-flood works that failed would have been very useful and would prevent the destruction extent, but repairing of works in such a vast area like the study area would be cost ineffective. Consequently, government should establish a central plan, following the rules of forest science, using only trained working teams, using properly the infrastructure and the respective tools to respond in the best way to similar urgent situations.

Conclusions

Almost all planned post-fire works were completed but many construction failures were recorded. Generally, the works did not perform as expected due mainly to the rush to complete construction and the limited supervision of the workers by the forest service. Using three different models to estimate and compare expected maximum discharge volumes with calculated peak discharge volumes due to the first rainfall event after completion of planned works, we conclude that the treatments reduced peak discharge in Chanioti and N. Skioni watersheds by approximately 10.5 and 20.4 %, respectively. Additionally, a reduce of 11 and 25 % in maximum sediment discharge was estimated in Chanioti and N. Skioni catchments, respectively, due to the treatments. The following intense rainfall events caused significant problems to the two settlements in these catchments because the control measures did not perform as planned. Nevertheless, the natural revegetation of the burned area progressed as expected in the first months after the August 2006 fire. The sedimentation and flood phenomena that were recorded immediately after the fire and during the next months, could have been more effectively prevented controlled if the planned works had been completed on schedule and properly constructed.

The following issues should be considered in similar cases of post-fire rehabilitation: mitigation measures should be properly planned, forest workers should receive adequate training, works construction should be supervised by trained and experienced scientific personnel.

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