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Evaluating the effects of check dams on channel geometry, bed sediment size and riparian vegetation in Mediterranean mountain torrents

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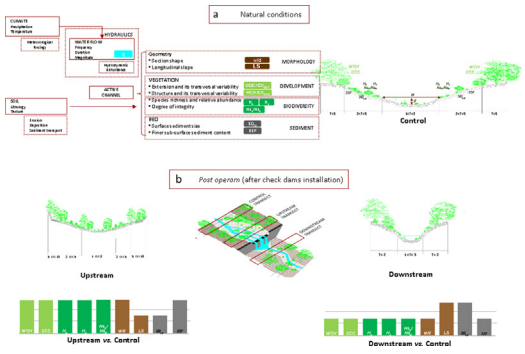
HIGHLIGHTS

- Headwaters of Mediterranean environments are very delicate ecosystems.
- Synthetic indicators identify channel and vegetation characteristics close to check dams.
- Check dams influence geometry, hydraulics, sediments and vegetation of headwaters.
- Changes in physical and vegetal parameters are more evident downstream of check dams.
- Vegetation biodiversity is slightly influenced by physical adjustments of channels.

GRAPHICAL ABSTRACT



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ABSTRACT

In mountain streams possible negative impacts of check dams on soil, water and riparian vegetation due to check dam installation can be noticed. In spite of the ample literature on the qualitative effects of engineering works on channel hydrology, morphology, sedimentary effects and riparian vegetation characteristics, quantitative evaluations of the changes induced by check dams on headwater characteristics are rare.
In order to fill this gap, this study has evaluated the effects of check dams located in headwaters of Calabria (Southern Italy) on hydrological and geomorphological processes and on the response of riparian vegetation to these actions. The analysis has compared physical and vegetation indicators in transects identified around check dams (upstream and downstream) and far from their direct influence (control transects).
Check dams were found to influence significantly unit discharge, surface and subsurface sediments (both upstream and downstream), channel shape and transverse distribution of riparian vegetation (upstream) as well as cover and structure of riparian complexes (downstream). The actions of the structures on torrent longitudinal slope and biodiversity of vegetation were less significant. The differences on bed profile slope were significant only between upstream and downstream transects. The results of the Agglomerative Hierarchical Cluster analysis confirmed the substantial similarity between upstream and control transects, thus highlighting that the construction of check dams, needed to mitigate the hydro-geological risks, has not strongly influenced the torrent functioning and ecology before check dam construction. Moreover, simple and quantitative linkages between torrent hydraulics, geomorphology and vegetation characteristics exist in the analysed headwaters; these

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relationships among physical adjustments of channels and most of the resulting characteristics of the riparian vegetation are specific for the transect locations with respect of check dams. Conversely, the biodiversity of the riparian vegetation basically eludes any quantitative relations with the physical and other vegetal characteristics of the torrent transects.

1. Introduction

Mountain streams, and particularly headwaters, are very delicate ecosystems, since they are affected by many disturbance factors, such as hydrological, geomorphological, and human impacts (Wohl, 2017; Rodrigues et al., 2017). Furthermore, across diverse hydro-climatic regions, headwaters exhibit high spatial and temporal variability, which strongly influences the river ecosystem (Marmontel et al., 2018).

Headwaters represent a natural hazard, because of the rapid increase in flow hydrographs, potential massive bedload transport and accelerated erosional processes that occur during high-magnitude flood events (Rickenmann, 1997; Galia and Škarpich, 2017). In Mediterranean zones, headwaters, in response to specific local conditions (e.g. frequent and intense rainstorms, small basins, steep slopes, Zema et al., 2014), are prone to high magnitude flash floods with high erosive power, often causing hydro-geological instability and disruption (Fortugno et al., 2017). In these contexts (such as in Southern Italy and Spain, as reported for instance by Bombino et al. (2007), and Boix-Fayos et al. (2007)) the need to control and mitigate the hydro-geological risk has often forced local administrations to fund public works over the last 60–70 years for soil conservation strategies.

Two widely applied soil conservation strategies in Mediterranean environments are reforestation and the construction of check dams in rivers and streams (Boix-Fayos et al., 2008). Check-dams (in general <5 m high, Castillo et al., 2007) are built in staircase like sequences of cemented, boulder, or wooden grade-control structures (Lenzi and Conesa-García, 2013). The main purposes of check dams are to serve as small sediment storage structures and/or to add flow resistance (reducing channel slope and increasing bed roughness), in order to stabilize the channel bed and the adjacent hillsides (Conesa-García et al., 2007).

In mountain streams, where the human impact is low, the installation of check dams modifies the natural evolutionary processes and may have noticeable influences torrent hydro-morphology and eco-hydrology. More specifically, in order to establish equilibrium conditions in the torrents, check dams decrease the longitudinal profile slope, thus slowing water and sediment movement along stream channels (Bombino et al., 2009). This action plays local effects on cross section shape, surface and subsurface sediments, which, on their turn, reflect also on structure and cover of riparian vegetation and even on its biodiversity (Bombino et al., 2014). Moreover, these effects are different between zones close to the check dams and those less disturbed (far from them) and between upstream and downstream of check dams.

However, possible negative impacts on sediment, water and vegetation due to check dam installation also in the less disturbed headwaters can be noticed. As a matter of fact, some authors state that check dams produce important negative effects like downstream scouring, which changes the stream channel, hydrological regime and morphology (e.g. Castillo et al., 2007; Boix-Fayos et al., 2007; Conesa-García and García-Lorenzo, 2009; Ramos-Diez et al., 2016b, 2017a, 2017b). Moreover, check dams are usually not paid any further attention once they are built and their role and benefits are overlooked (Bombino et al., 2008; Ramos-Diez et al., 2016b). There is, thus, a need to evaluate the efficacy of these works and the evolution of regulated channels over time, especially in those projects in which the role of check dams is questioned (Ramos-Diez et al., 2016b).

Eminent and ample literature exists, which has widely debated the effects of check dams on hydrology (e.g. Norman et al., 2016; Guyassa et al., 2017), morphology (e.g. Boix-Fayos et al., 2007; Gao et al., 2016; Fortugno et al., 2017), sedimentary effects (e.g. Ramos-Diez et al., 2016a, 2016b, 2017a, 2017b) and riparian vegetation characteristics (e.g. Bombino et al., 2006, 2008, 2009, 2014). However, as far as now, the actual impact of check dams is still not well known (Castillo et al., 2007), because their effects on physical processes and vegetation characteristics in delicate environments, such as headwaters, are not yet completely understood or, at least, have often been studied disjointedly by qualitative approach based on field observations. In other terms, we feel the lack of an objective evaluation, which should measure the torrent response to the modifications induced by check dams on hydrological regimes, morphological changes, erosion/sedimentation processes and torrent ecology. As regards this latter, in order to better understand the evolution of headwaters (considering the large number of influencing variables), more attention should be paid to the effects of control works on riparian vegetation, being one of the most important indicators of soil quality, and river health and functioning. This evaluation is necessary in order to inform the development of design criteria minimising the check dams impacts into fluvial characteristics and define the desired state after restoration, preliminary to the correct restoration project design (Henry and Amoros, 1996).

In order to accomplish this task, this study evaluates the effects played by check dams located in headwaters of Calabria (Southern Italy) on hydrological and geomorphological processes and the response of riparian vegetation to these processes. More specifically this paper: (i) analyses the differences between the indicators surveyed upstream, downstream and far from the local influence of check dams; (ii) looks for correlations between couples of indicators, able to quantify the reciprocal influence of an indicator on another; and (iii) identifies statistical similarities between such locations along the torrent. The quantitative results are explained by linkages with physical and vegetal processes acting in the studied reaches.

2. Study watersheds

The torrents of Calabria (Southern Italy) are steep, short and seasonally-flowing mountain streams with small catchments, locally known as *fiumara* (Bombino et al., 2009). These water courses have a torrential regime, whose response to the hydrological stress produces high-magnitude flash floods and erosive events (Fortugno et al., 2017).

The investigation was carried out in the mountainous reaches ("headwater") of four fiumaras (Fig. 1): Allaro (A), Torbido di Gioiosa (TG), which drain towards the south east, and Sant'Agata (SA) and Gallico (G), which drain towards the south west (Fig. 1). The four torrents rise at over 1200 m above sea level and flow through deep narrow valleys (mountain reaches) and wider floodplains downstream (valley reaches), discharging (main stream lengths from 17 to 26 km) into the Ionian (A, TG and SA) or Thyrrenian sea (G). Their watershed areas vary from 56 (G) to 161 (TG) km^2 (Table 1).

Many studies based on the "landscape ecology" approach (Allen and Hoekstra, 1992) and the "river continuum concept" (Raunkiaer, 1934), suggest a longitudinal subdivision of the river environment, from the source to the mouth, in order to take into account the spatial and functional relationships between biotic and abiotic components of the water courses. The longitudinal subdivision of the river environment