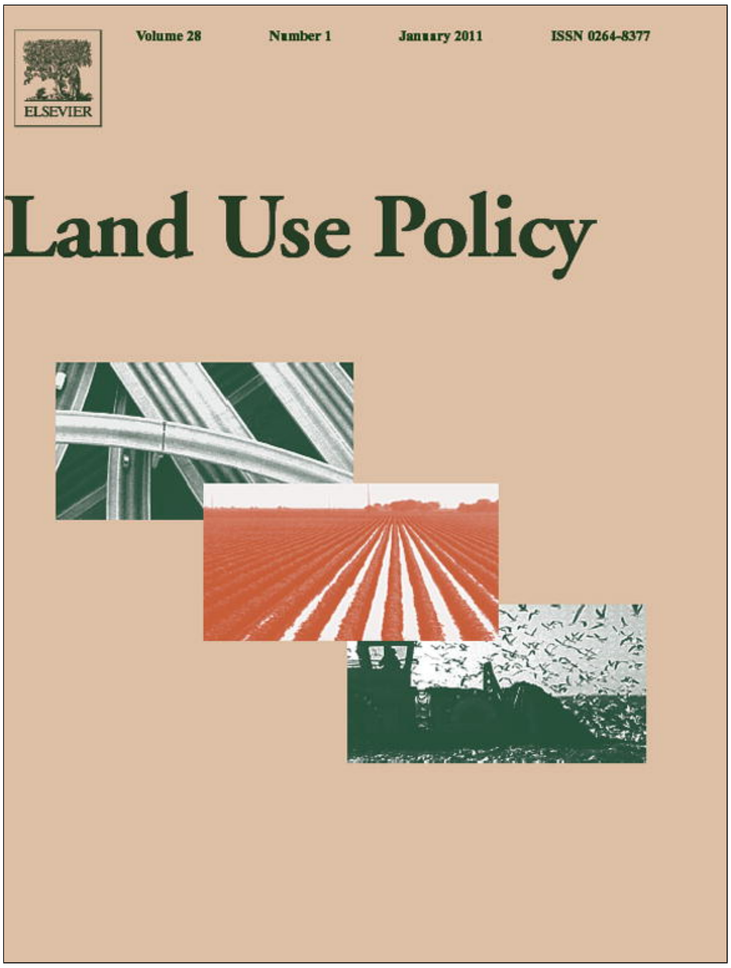
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Loss of water availability and stream biodiversity under land abandonment and climate change in a Mediterranean catchment (Olzinelles, NE Spain)

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ABSTRACT

In the north rim of the Mediterranean region, where forest cover is increasing as a result of land abandonment and temperatures are rising as a result of climate change, there is increasing interest for the effects of such changes on the runoff of water courses. This is a paramount issue for the conservation of many freshwater habitats and species. In this work we studied the effects of both an increase in forest cover after depopulation and land abandonment and an increase in temperature on the runoff of a Mediterranean catchment and on the aquatic and semi-aquatic fauna species of the stream (Olzinelles valley, NE Spain). Although in our simulation no decreasing trend in runoff is detected, the monthly runoff-rainfall ratio is now 15% lower than 30 years ago, a fact that may be attributed to a drier period rather than to the small afforestation experienced by the catchment in the last decades. Other factors such as increasing temperatures, changing rainfall patterns and increasing canopy cover are discussed. The observed decrease in the water flow has caused the disappearance of white-clawed crayfish (*Austropotamobius pallipes*), Mediterranean barbel (*Barbus meridionalis*), chub (*Squalius cephalus*), European eel (*Anguilla anguilla*), and southern water vole (*Arvicola sapidus*). Our results suggest that in a progressively warmer climate, and especially after land abandonment processes, management of Mediterranean mountain areas should be oriented towards an appropriate distribution of agrarian and forest land-covers in terms of water availability. Down to the stream scale, the pools that keep water throughout the year should be conserved and extended to enhance its potential to maintain aquatic and semi-aquatic species populations.

Introduction

Global biodiversity is changing at an unprecedented rate as a consequence of several human-induced changes in the global environment, such as land-use change and climate change (Vitousek et al., 1997; Hassan et al., 2005). Land-use change has caused declines in biodiversity through the loss, modification, and fragmentation of habitats; degradation of soil and water; and overexploitation of native species (Foley et al., 2005). Habitat destruction is, in fact, the leading cause of species extinction (Pimm and Raven, 2000). With respect to climate change, only 40 years of warmer temperatures have affected the phenology and the distribution of species of a wide range of taxonomic groups across the globe (reviews in Peñuelas and Filella, 2001; Parmesan and Yohe, 2003; Walther et al., 2002; Root et al., 2003). As some of these works point out, climate change may lead to a decoupling of species interactions and pose a serious threat to the conservation of biodiversity around the world. Although there is ample evidence of the effects of land-use change and climate change on biodiversity at a global scale, the strength of interactions among these drivers in their effects on biodiversity is virtually unknown (Sala et al., 2000), specially at regional and local scales.

Mediterranean ecosystems may experience large biodiversity loss because of their sensitivity to all drivers of biodiversity change, particularly land-use change (Sala et al., 2000). Land-use patterns in the Mediterranean basin are rapidly changing, mainly in two opposite directions for the north and the south rim: a fast increase in firewood extraction, overgrazing, encroachment of agriculture,

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and regression of forest in the south; and land abandonment with young, poorly managed and fuel-accumulating forests in the north (Puigdefábregas and Mendizabal, 1998; Terradas, 1999). Although forest recoveries offer some important environmental services, such as carbon sequestration and soil conservation (Rudel et al., 2005, 2010), it is known that land abandonment and afforestation may lead to a loss of landscape heterogeneity and have negative repercussions for biodiversity (Atauri and de Lucio, 2001), e.g. open habitat bird species (Preiss et al., 1997). Moreover, the establishment of forest cover on sparsely vegetated land or on grasslands decreases water yield from the catchment (Bosch and Hewlett, 1982; Gallart and Llorens, 2003; Jackson et al., 2005). The decrease in water yield caused by the increase in the forest cover of the catchment is added to that associated to climate variability (Gallart and Llorens, 2004).

In the Catalan region, forested area has increased in the last century (Ministerio de Medio Ambiente, 2005) as a result of land abandonment, spontaneous regeneration and afforestation works. Temperature has increased by ca. 1 °C in the last 50 years; potential evapotranspiration has increased 13 mm per decade during the period 1910–1994, while precipitation has not significantly changed (Piñol et al., 1998; Peñuelas et al., 2002). Thus, the hydrological cycle may be affected by an interaction between the increased vegetated land cover and the increased aridity.

In this work we evaluate whether this interaction can be related to changes in catchment runoff and stream biodiversity. For this purpose, we have selected the Mediterranean catchment of Olzinelles valley (Catalonia, NE Spain). In Olzinelles valley, a strong rural exodus during the twentieth century has decreased the extension of land under cultivation, favouring a forest cover expansion through spontaneous growth or plantation. Forest exploitation to obtain firewood and charcoal has been reduced due to the substitution of forest fuels by fossil fuels in the 1960s, and as a consequence forest fuel and canopy cover have increased. According to the available meteorological data from Montseny Mountains, average annual temperatures in the region have increased 1.2–1.4 °C since 1950 while the total amount of annual precipitation remained unchanged (Peñuelas and Boada, 2003). We hypothesized that these land-use and climate changes may have caused a decrease in the water runoff in the Olzinelles stream and a decline of its biodiversity. To test such hypothesis, (i) we studied the rural exodus (1924–2007), (ii) we conducted a land-cover change analysis with a Geographic Information System (1956–2002), (iii) we studied the climate trends for the study area (1977–2007), (iv) we modelled hydrological changes using the forest growth simulation model GOTILWA+; and (v) finally, we documented the presence or absence in different historical moments of those fauna species with aquatic or semi-aquatic requirements, by conducting surveys in the stream, by monitoring old surveys and by conducting interviews to local inhabitants.

Materials and methods

Study site

Olzinelles valley (province of Barcelona, NE Spain) has an area of 827.6 ha (longitude 2°29′ to 2°32′E, and latitude 41°39′ to 41°41′N) (Fig. 1). It is located in Montnegre Mountains, which are part of the Catalan Coastal mountain range, in the Mediterranean region. The mean annual temperature is 14.6 °C and the average annual rainfall is 703 mm (calculated over the last 30 years). The relief is structured in low hills (the highest reaching 558 m a.s.l.) and short streams that have formed small valleys by eroding the granitic base. At present, all the streams have an irregular regime, but the main one, named Olzinelles, used to have a permanent flow, as well as the other streams of the north face of Montnegre Mountains that flow into the Tordera River (Montserrat, 1989; Otero, 2010). Almost all the study area is covered by forest, mainly cork oak (*Quercus suber*) forest and holm oak (*Quercus ilex*) forest. There are also European alder (*Alnus glutinosa*) forests along Olzinelles stream, which present a high mortality of trees due to the recent reduction in runoff (in the field work we counted up to 91 dead alders, which means about 2 dead alders each 100 m, only in the immediate stream bed), and some monospecific plantations of *Platanus* sp. and *Pinus pinaster*. Crop fields and abandoned fields (from know on, fields) account for 3% of the valley. All the population of the valley (20 inhabitants) lives in scattered *masos*, the traditional farmhouses of the Catalan countryside. Land tenure is private in all the area and 84% of it is included in the Montnegre-Corredor Park since 1989. The valley used to belong to the municipality of Olzinelles, and since 1927 it belongs to the municipality of Sant Celoni.

Demographic data

Demographic data were provided by the Olzinelles and Sant Celoni municipality censuses (1924, 1936, 1970, 2007) and Olzinelles Parish censuses (1943, 1956, 2000), located in the City Archives of Sant Celoni and the Parish Archives of Olzinelles. A database including name and surname, year and place of birth, marital status and number of children, main economic activity and other additional information of inhabitants was created.

Cartographic sources and GIS analysis

We obtained aerial photographs of 1956 (US Army, scale 1:30,000) and orthophotos of 2002 (Institut Cartogràfic de Catalunya, scale 1:5000). By means of photointerpretation in the Geographic Information System MiraMon (Pons, 2004) and field work we created land-cover maps of both years, including the following land-cover types: forest, fields, plantations of plane trees and poplars, shrubland, houses and bare soil. Land-cover change between 1956 and 2002 was studied by overlapping both maps in the GIS.

Meteorological data

Meteorological data (temperature and precipitation) from the period 1977–2007 were provided by the meteorological station of Collsacreu (located near the study area, at 395 m a.s.l., Fig. 1). Linear regression of average annual and monthly temperature and rainfall versus the years were calculated. Trends in temperature and rainfall were evaluated using a non-parametric Kendall Tau test. Linear regression of number of days with rainfall was calculated at a yearly basis. To evaluate the changes in rainfall patterns we classified the recorded daily precipitation in 5 intervals (<1.0 mm, 1.0–9.9 mm, 10.0–29.9 mm, 30.0–49.9 mm, and ≥50 mm) and we tested whether there were significant changes in their frequency between the period 1977–1991 and 1992–2007 (one factor ANOVA for each interval). All statistical analyses were conducted using STATISTICA version 6.0 for Windows (StatSoft Inc., Tulsa, OK, USA).

Hydrological modelling: GOTILWA+

In order to assess the effect of land-use change and climate change on water runoff of Olzinelles stream, we performed a simulation test using GOTILWA+ forest model. GOTILWA+ (Gracia et al., 1999, 2005) is a process-based model that allows the performance of simulations of water use by forest under changing environmental

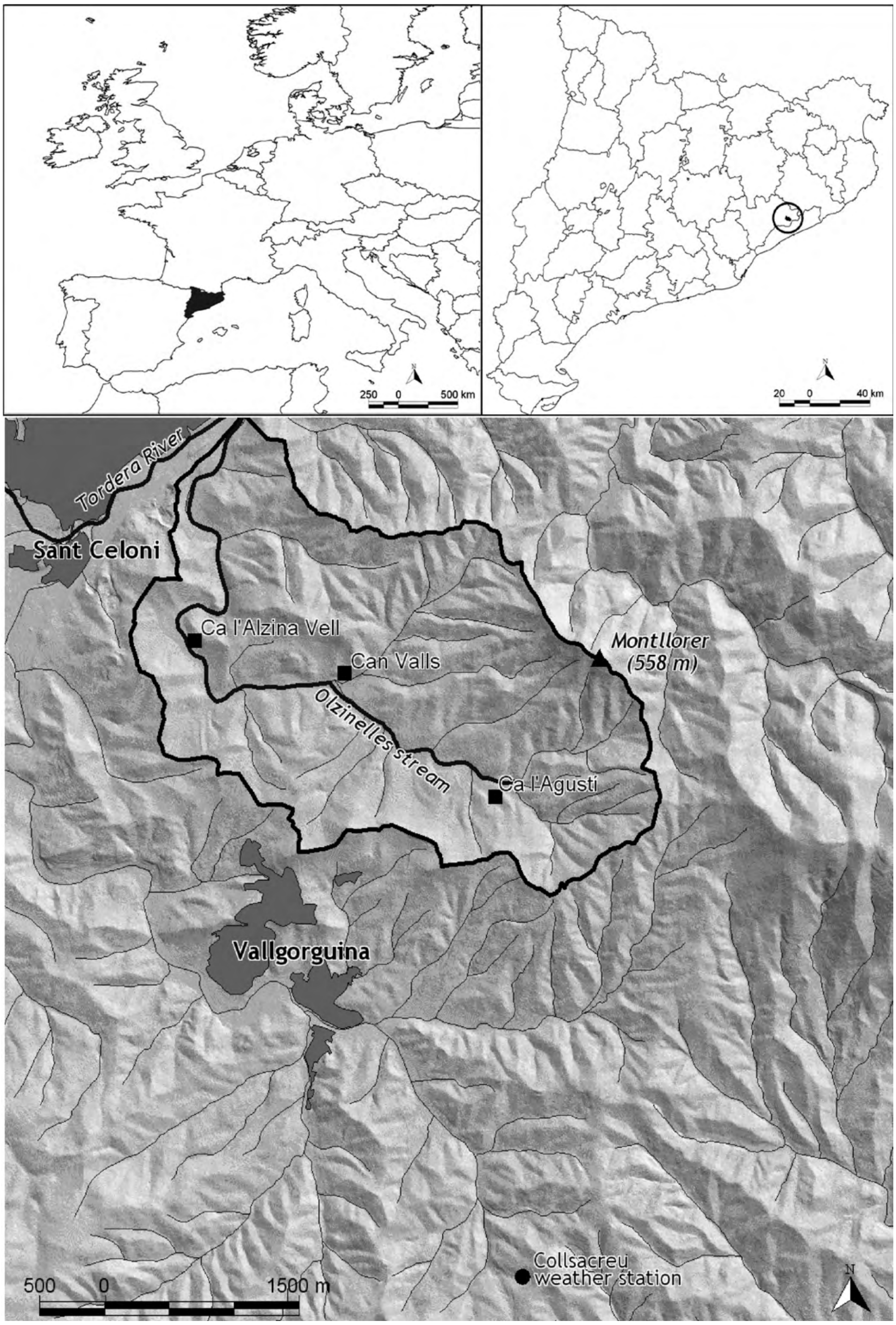

Fig. 1. Olzinelles valley is located in the county of Vallès Oriental (Barcelona province, Catalonia, Spain), and it is included in the municipality of Sant Celoni since 1927. *Source*: own elaboration.

conditions. The data of temperature and rainfall from the Collsacreu meteorological station (1977–2007), available at a monthly basis, were transformed to daily values by means of a Markovian matrix derived from a series of daily data from the same station (available from 20/11/2000 to 31/12/2007). Data on forest structure and composition was obtained from the Third National Forest Inventory, conducted throughout Catalonia in 2000–2001 by the Spanish Ministry of the Environment and the Centre for Ecological Research and Forestry Applications of the Autonomous University of Barcelona. We defined seven simulation units that corresponded to different subcatchments of Olzinelles valley. For each subcatchment we used the data of the inventory station located inside of it, which included information by tree species about volume and biomass, stand structure and ecological variables, and we assumed no forest management. For the case of fields and shrublands, we used a standard vegetation structure in all the catchment. With these vegetation and meteorological data we ran the model and we aggregated the outputs of annual/monthly runoff at catchment level taking into account the land-cover areas obtained by the photointerpretation and a constant rate of annual/monthly land-cover change inferred from the GIS analysis. Land-cover types were grouped in two categories: (1) forests (forest and plantation of plane trees and poplars), and (2) fields and shrublands. We assumed that the rainfall received by houses and surroundings was retained and did not reach the stream. Bare soil was not considered in the water balance since it represented less than 0.2% of the catchment area. To test whether the model outputs were realistic we compared them to the data gathered by different authors in Fuirosos stream, located at about 6 km NE from our study site. Trends in annual runoff were evaluated using a non-parametric Kendall Tau test. Linear regressions of monthly runoff versus monthly precipitation in two different periods were calculated. All statistical analyses were conducted using STATISTICA version 6.0 for Windows (StatSoft Inc., Tulsa, OK, USA).

Fauna information

We documented the presence or absence during the last decades of five species with aquatic or semi-aquatic requirements: freshwater white-clawed crayfish (*Austropotamobius pallipes*), Mediterranean barbel (*Barbus meridionalis*), chub (*Squalius cephalus*), European eel (*Anguilla anguilla*), and southern water vole (*Arvicola sapidus*). To do so, we looked up old surveys conducted by one of us (M.B.) during 30 years of field work, as well as some reports of the Montnegre-Corredor Park Ecological Monitoring Scheme. We also sampled the stream in order to confirm the absence of the fauna (June–July 2008). The sampling consisted in walking upriver along the entire stream bed, which was divided in three stretches to be sampled during 1 day each (the length of the stream is about 5 km), and checking exhaustively the presence of the five species. We looked especially in the roots of alders (*A. glutinosa*) and in the holes of the submerged rocks, where crayfishes and water voles could be captured thirty years ago. For the case of water vole, special attention was paid in finding the particular galleries that they excavate in the slopes of the stream. For the case of the crayfish, we confirmed the absence of the species with the data by GESMED (2008), who sampled the stream using a species-specific method. Likewise, for the case of the fish species we used the data by Aparicio et al. (1997) and URS (2007), who conducted systematic electrofishing surveys in the stream. Moreover, we conducted interviews to a sample of 11 people that used to live, work, fish or hunt in the valley. Interviews were recorded with a digital recorder, introduced to the PC and transcribed.

Results

Depopulation

Fig. 2 shows the evolution of population in Olzinelles valley, where a clear process of rural depopulation took place. The 84 inhabitants of 1924 decreased to 20 in 2007, meaning a loss of 76% of the population in 83 years. The highest depopulation rates were found between 1924 and 1943, while during the period 1943–2000 the depopulation rates were lower. The number of inhabitants per house greatly decreased in the period 1924–1943 (10.5–4.9 people per house), and reached its minimum in year 2000, with 1.8 people per house. In the last period (2000–2007), however, there was an increase in the population and in the number of inhabited houses. Between 1924 and 1970 there was a significant decrease in the number of farmers: 21 in 1924, 13 in 1936, and 7 in 1970 (the censuses registered only males as farmers, while women were registered as house workers even if they worked as farmers too). Other land managers such as estate owners and administrators also dropped: 4 in 1924, 5 in 1936, and 1 in 1970.

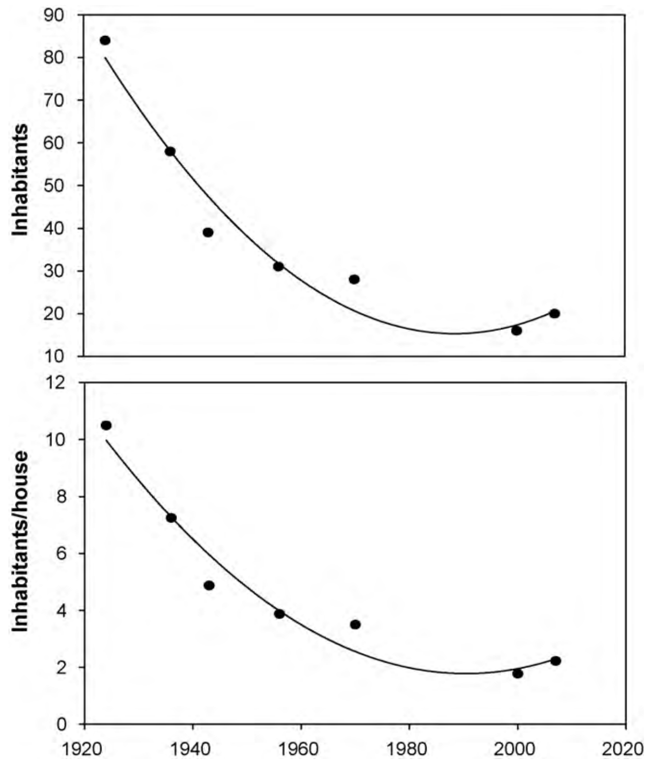

Fig. 2. Demographic evolution in Olzinelles valley. *Sources*: Olzinelles municipality census (1924), Sant Celoni municipality census (1936, 1970, 2007), and Olzinelles Parish census (1943, 1956, 2000). City Archives of Sant Celoni and Parish Archives of Olzinelles.

Decrease in agrarian cover and increase in forest cover

Depopulation and land abandonment favoured a loss of agrarian cover and an increase in forest cover, as seen in Table 1. Forest cover increased 19.5 ha (2.4% of the total catchment area), agrarian cover decreased 36.1 ha (4.4% of the total area), and plantations of plane trees and poplars increased 15.3 ha (1.8% of the total area). As shown in Fig. 3, only about a third part of the agrarian cover of 1956 was conserved (37%), while almost half of it was converted to forest, either by spontaneous growth or by coniferous plantation.

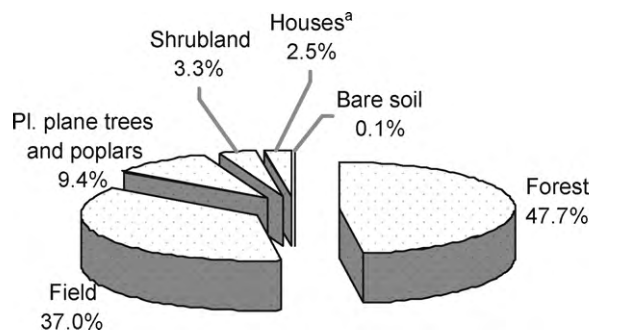

Fig. 3. Transformation of agrarian cover between 1956 and 2002. *Source*: See Table 1. Only 37.0% of the 61.5 ha of fields in 1956 has been conserved, while 47.7% has been transformed to forest and 9.4% to plantations of plane trees and poplars. [a]See note (d) from Table 1.

Table 1
Land-cover distribution and change in Olzinelles valley (1956–2002). Percentages relate to the total area of the catchment.

Land-cover	1956		2002		Δ 1956–2002	
	ha	%	ha	%	ha	%
Forest[a]	751.3	90.8	770.8	93.1	19.5	2.4
Fields[b]	61.5	7.4	25.3	3.1	−36.1	−4.4
Plantation of plane trees and poplars[c]	8.7	1.0	24.0	2.9	15.3	1.8
Shrubland	3.5	0.4	2.3	0.3	−1.2	−0.1
Houses (*masos*)[d]	1.6	0.2	3.9	0.5	2.4	0.3
Bare soil	1.1	0.1	1.3	0.2	0.2	0.0
Total area	827.6	100.0	827.6	100.0	0.0	0.0

Source: Aerial photographs of 1956 (US Army, scale 1:30,000); orthophotos of 2002 (Institut Cartogràfic de Catalunya, scale 1:5,000), GIS analysis and field work.

[a] Includes all forested area except plantations of plane trees (*Platanus* sp.) and poplars (*Populus* sp.): cork oak forest (*Q. suber*), holm oak forest (*Q. ilex*), mixed forest (holm oak and pubescent oak-*Quercus humilis*, holm oak and cork oak, holm oak and pines, cork oak and pines, etc.), riparian forest (*A. glutinosa*), coniferous plantations (*P. pinaster*, *P. radiata*), and chestnut plantations (*C. sativa*).

[b] Includes cultivated fields and fields that have been abandoned recently and still cannot be considered as shrubland nor forest. They have been grouped together because they can only be distinguished in the orthophotos of 2002 but not in the aerial photographs of 1956.

[c] It has been considered a separated category because it was possible to distinguish from the surrounding forest in both aerial photographs (this is not the case of coniferous plantations, which cannot be distinguished properly in none of them).

[d] The increase of 2.4 ha in the area occupied by houses is overestimated, since the less detailed scale of the aerial photograph of 1956 leads to an underestimation of this land cover in this year. No process of urbanization has taken place in the study area, except from the construction of one house in a former barrack hut.

In 9.4% of the former fields, owners decided to plant plane trees or poplars and in 3.3% of them spontaneous growth of shrubs took place. Another observed land-cover change is an increase in forest fuel and canopy cover. Fig. 4 shows some graphic examples of these land-cover changes.

Warming in the last decades

The data gathered at Collsacreu meteorological station shows an increase of 0.75 °C in mean annual temperature between 1977 and 2007 (calculated from the linear regression of the temperature

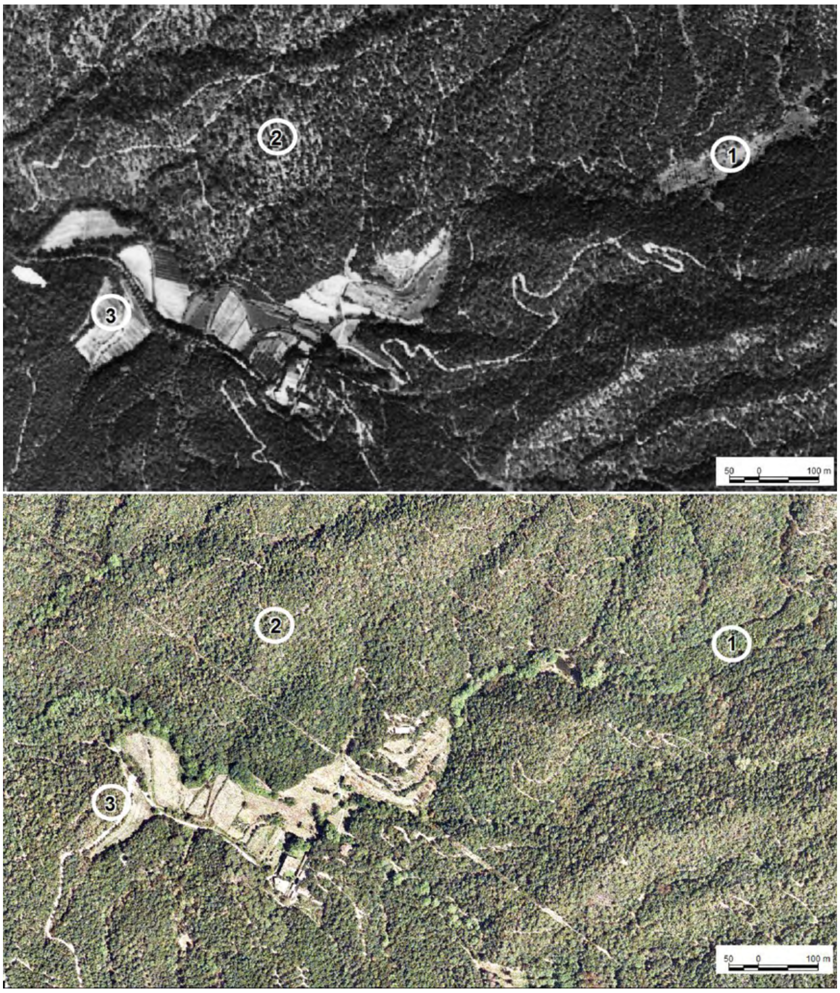

Fig. 4. View of Olzinelles valley around Ca l'Agustí in 1956 and 2002. Land-cover changes: (1) plantation of maritime pines in former fields; (2) forest densification and increase in canopy cover; (3) plantation of maritime pines and recovery of holm oak and cork oak in former fields. *Source*: See Table 1.

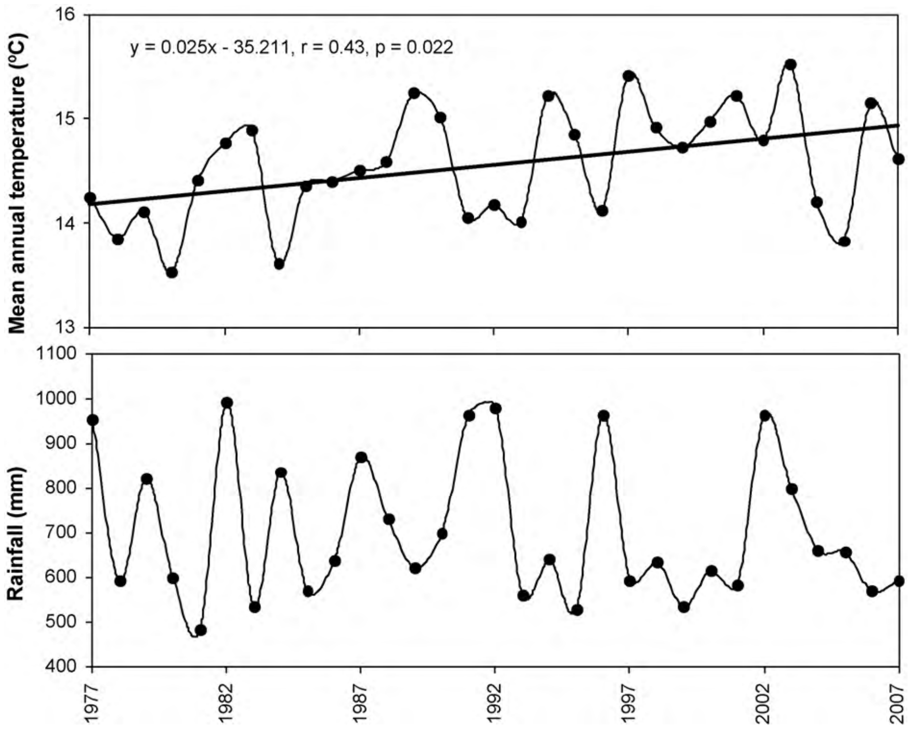

Fig. 5. Climate trends in the studied area for the period 1977–2007, measured in Collsacreu meteorological station.

change throughout this period, Fig. 5). Mean temperature increased in April (1.65 °C), May (2.89 °C) and June (3.07 °C) ($p < 0.001$ in the 3 months), while no significant trends were found in the other months. According to the meteorological data from the nearby Montseny Mountains (10 km), the main increase of the last 50 years occurred in this period (Peñuelas and Boada, 2003; Jump et al., 2006a), as it also has occurred in the whole planet (IPCC, 2007). The analysis did not reveal any significant trend in annual rainfall (Fig. 5), although September showed an increase of 57.7 mm ($p = 0.01$). Therefore, the increased temperatures and consequent increased potential evapotranspiration rates have conducted to progressively more arid conditions in the area. The number of days with rainfall decreased by 36 (calculated from the linear regression of the number of recorded days with rainfall throughout this period $y = -1.20x + 2512$, $r = 0.63$, $p < 0.001$). The second period (1992–2007) had on average 11 days less of low rainfall (<1.0 mm) than the first one (1977–1991), the differences being statistically significant at the $p < 0.001$ level. The other rainfall intervals did not show significant changes between periods.

Trends in runoff and runoff-rainfall ratio

No significant trend in runoff was detected for the period 1977–2007 (Fig. 6). Annual runoff was well correlated with rainfall ($r = 0.94$) and thus showed a high variability, ranging from 0.74 to 4.88 $hm^3\ year^{-1}$. However, the monthly runoff response to rainfall was lower in the second half of the period relative to the first one (Fig. 7). While in the period 1977–1991 the runoff-rainfall ratio (RR) was 0.82 (95% C.I. 0.77–0.87) in the period 1992–2007 it was 0.70 (95% C.I. 0.64–0.75), that is 15% lower. When not considering the changes in land-cover in the catchment area, the RR and C.I. values remained the same. The difference between monthly runoff depth and monthly precipitation increased with increasing values of rainfall, i.e. in high rainfall episodes there were lower runoffs in the latter period. The two regression lines intercepted at a rainfall value of 48.5 mm, i.e. close the mean monthly rainfall of the whole period (58.6 mm).

Loss of fauna species

White-clawed crayfish (*A. pallipes*), Mediterranean barbel (*B. meridionalis*), chub (*S. cephalus*), European eel (*A. anguilla*), and southern water vole (*A. sapidus*) were still present in Olzinelles stream in 1980 (Boada, 1990—*A. pallipes* wrongly cited as *Astacus fluviatilis*; Otero, 2006). The origin of the white-clawed crayfish in Olzinelles stream is a translocation of individuals from the Soria province by one of the land owners of the valley by the end of 19th century (Piqueras, 2009). The species was still in Olzinelles stream until, at least, 1991, although it was becoming a rare species in the area (Boada, 2000—wrongly cited as *A. fluviatilis*) and it has not been found in our last survey (June–July 2008), nor in that of 2007 (GESMED, 2008). Mediterranean barbel and European eel remained at least until 1991 in two small pools in the central part of the stream (Boada, 2000), even though it had already lost the permanent flow. From then on, the only fish species seen in the stream is an isolated individual of European eel found in 1997 after

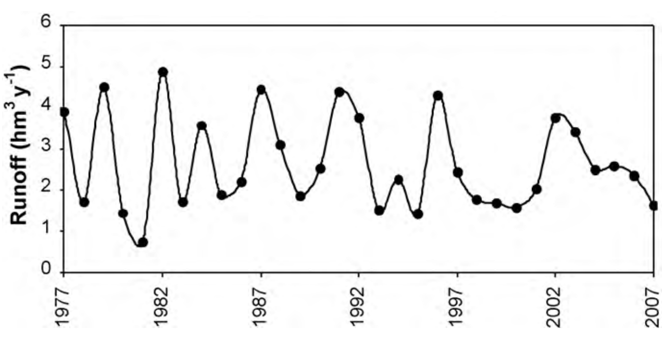

Fig. 6. Simulated water runoff of Olzinelles stream for the period 1977–2007.

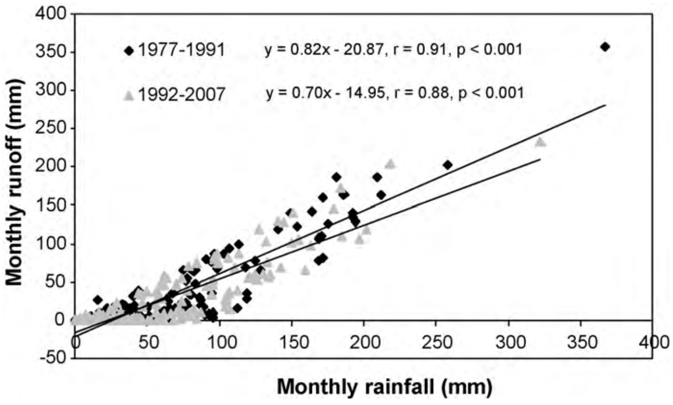

Fig. 7. Simulated monthly runoff of Olzinelles stream vs. measured monthly rainfall for the periods 1977–1991 and 1992–2007 considering that land-covers changed at a constant monthly rate inferred from the GIS analysis (see methodological approach).

going upriver from the Tordera, the main river where Olzinelles stream flows (Aparicio et al., 1997, 2001). The last survey, carried out in the same four sampling stations than in 1997, found no fish species (URS, 2007). Three introduced fish species have been found in artificial ponds of the valley: rudd (*Scardinius erythrophthalmus*), common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) (Boada, 2000; Otero, 2006). With respect to southern water vole, a semi-aquatic rodent, the last one we saw in Olzinelles stream dates back to the beginning of the eighties (observation of M.B.). The sampling in 2008 ruled out the presence of the water vole due to the absence of water in the stream and trails in the riverside.

Finally, some of the interviewed people gave us evidence of the existence and use of some of this species in the past decades. As an example, Sadurní M.V., hunter and fisher of the Montnegre Mountains born in 1926, used to fish crayfish in Olzinelles stream. Sometimes the fishers were bitten by a water vole, since the holes of both species, located under the roots of alders, often coincided. After the fishing, in some occasion they cooked rice with the crayfish and some eels captured in Olzinelles stream. Water vole also used to be captured and eaten by local people in Olzinelles and in Tordera basin.

Discussion

Depopulation and land-use changes

The decrease of population found in Olzinelles valley between 1924 and 2000 was related to the removal of people to near villages searching for better paying non-farm jobs and better life conditions. This was the case of Sant Celoni village, where a local industry based on textiles, cork, wood and milk was developing since the arrival of the railway in 1860 and the electricity in 1909 (Otero, 2010). The recovery of population in Olzinelles after 2000 may be related to the restoration of *masos* by urban people that wish to move from cities or villages to the countryside.

The agrarian area that remained in 2002, mainly located in the valley bottom, consists of flat fields where mechanization can be easily implemented. However, as the sharecroppers left their lands and the agrarian products lost profitability, some flat fields in the valley bottom were totally converted to plantations of plane trees (*Platanus* sp.), poplars (*Populus nigra*), maritime pines (*P. pinaster*) or radiata pines (*Pinus radiata*), fast growing trees planted by the land owners to be sold as wood. The steepest fields, mainly located in the northern part of the study area, have been either spontaneously colonized by oaks or converted to pine plantations. Unlike the rest of the valley, which is mainly occupied by 4 large estates with extensions ranging from 78 ha to 386 ha (meaning 90% of the valley), this area consists of numerous small plots that were mainly used as vineyards to produce small amounts of wine for self-supply. The abandonment of the vineyards (1950–1970s) was related to changes in life style brought about by the industrialization of the area and to the new interest of the small land owners to plant fast growing trees in their plots (Otero, 2010).

The expansion of forested cover detected between 1956 and 2002 represents only about 4.2% of the valley, considering forest and plantation of plane trees and poplars together (Table 1). However, the fact that the increase in forest cover took place with relatively low depopulation rates (Fig. 2) suggests that in the previous decades, when higher depopulation rates prevailed (1924–1943), the valley experienced a greater increase in forest cover. In fact, the maximum agricultural expansion in the Vallès County and in other Catalan counties dates back to the second third of the 19th century, when phylloxera plague hit French vineyards, causing Catalan wine relative prices to soar and inducing a new wave of vineyard plantation (Cussó et al., 2006; Badia-Miró et al., 2010; Olarieta et al., 2008), often in previously deforested plots.

With respect to changes in forest use, during the 1960s fossil fuels started being widely used in the region, and forest fuels lost market value. As a consequence, coppicing for firewood and charcoal, as well as shrub clearing to obtain thin firewood, decreased markedly in Montnegre Mountains. An analysis of the evolution of firewood felling in Olzinelles, studied by means of the permissions and the registers of the forest administration for the period 1956–2004, shows a sharp decline in 1964, mainly explained by the decrease in the appropriation of cork oak firewood. It is also observed that from 1962 the permissions do not register anymore the clearing of shrubs (Otero et al., 2008).

The depopulation and land-use changes that have taken place in Olzinelles valley constitute a paradigmatic example of what has occurred in many Catalan and Spanish mountain areas, as well as in other regions of Europe and the Earth (for an overall account of the depopulation of mountain areas in Spain, see Collantes, 2001, 2005; for an analysis of the demographic changes in Europe since 1870, see Martí-Henneberg, 2005). In the case of Catalonia, the industrialisation was strengthened in the second half of the nineteenth century (Garrabou et al., 2001), prompting a process of rural exodus and a concentration of population in the urban area of Barcelona since, at least, 1860. Between 1860 and 1970, Catalan rural population decreased from 788,120 (47% of the total population) to 686,994 (13%), and between 1877 and 1970 the share of agrarian working population dropped from 58% to 8% (Vidal, 1979). This process particularly affected small peasant towns and isolated houses (*masos*), especially in mountainous areas, where people tended to migrate to the plains and to the main villages. This is observed in the Catalan Pyrenees, where the abandonment of some of the hill slopes that were terraced for cultivation has promoted spontaneous afforestation (Gallart et al., 1997; Poyatos et al., 2005).

In the case of the Spanish mountains, after centuries of intense demographic pressure on the hillsides, there has also been a process of desertion particularly swift since 1950, related to the great losses of population and to the impossibility of mechanization in a large area of farmland (Collantes, 2004; Ruiz-Flaño et al., 1992). Several cases have been described in the Pyrenees, where a loss in the number of inhabitants in the mountain areas, an aging of the population, and a migration to the main cities of northern Spain have taken place in recent decades (Ruiz-Flaño et al., 1992; García-Ruiz et al., 1995; Molinillo et al., 1997). In a similar process than the one described for Olzinelles, the cultivation of cereals on steep slopes became uneconomic and many fields were abandoned, in such a manner that only the valley bottoms and perched flats remain cultivated (Molinillo et al., 1997; López-Moreno et al., 2006). Other mountainous areas of Spain have also experienced rural depopulation and forest expansion, as the Soria province, the one which has undergone the longest and most intense process of rural exodus from the sixties (Paniagua, 2008), favouring the growth of forest areas to the detriment of agriculture (Pérez and Fernández, 2006).

Trends in runoff and runoff-rainfall ratio

The water runoff simulated by GOTILWA+ model turned out to be realistic. We compared the runoff outputs with the data measured by different authors in Fuirosos (Bernal et al., 2006; Acuña et al., 2007; Bernal and Sabater, 2008; Sabater et al., 2008), a very similar stream located at about 6 km NE from Olzinelles. Both streams flow N-NO from the Montnegre hills towards the Tordera River, have comparable catchment areas (O: 8.3 km^2; F: 10.5 km^2), altitudinal gradients (O: 125–558 m; F: 95–773 m), mean annual temperature and rainfall for the period 1997–2003 (O: 15.1 °C, 675.7 mm; F: 13.8 °C, 709.6 mm), share of forested and agrarian cover (O: 96%, 3%; F: 98%, 2%), vegetation, land-use history and settlement pattern. The measured average discharge in Fuirosos from January 2001 to July 2002 (Sabater et al., 2008) was 1.7 times higher than the simulated average discharge in Olzinelles for the same time period (136 $L\,s^{-1}$ vs. 79 $L\,s^{-1}$), the difference being explained by highest catchment area, highest total rainfall and highest extreme rainfall events in January 2001, April 2002 and May 2002 in Fuirosos. Although these average values include exceptionally high discharge peaks and thus are not representative of the baseflow conditions (which in Fuirosos range from 7 $L\,s^{-1}$ in spring to 20 $L\,s^{-1}$ in winter according to Butturini et al., 2002), they show that our model outputs match with the observed fact that Olzinelles has lower runoff than Fuirosos. Moreover, the average runoff depth in Olzinelles catchment is 320 mm (2.65 hm^3/828 ha), which is similar to the value provided by Liquete et al. (2009) for the entire Tordera River basin (258 mm).

Even if the annual runoff did not show a decreasing trend (Fig. 6), the different regression slopes in Fig. 7 show that in the last 16 years the monthly runoff response to rainfall was 15% lower than in the first 15 years. These results agree with our observations on the state of the stream during the last decades indicating that around 1991 the flow of the stream shifted from (almost) permanent to irregular with long periods without runoff (Boada, 2000). The significant negative intercepts are consistent with the hydrological processes simulated in our model. The fact that rainfall is not converted into runoff until a certain threshold is reached (ca. 23 mm of monthly rainfall) is explained by rainfall interception of tree canopies and by water storage in the soil, both being considered in GOTILWA+. The intercept values are not significantly different between periods, meaning that the behaviour of the system under the threshold value of rainfall has not changed. However, the lower runoff-rainfall ratio (RR) of the last period was not reflected in the absolute trends (Fig. 6) since it occurred mostly under the highest less frequent values of monthly rainfall.

The drier conditions in the second period than in the first one (more years below the mean annual rainfall) are one of the factors accounting for the decrease in RR. During drier periods the internal water storage capacities of watersheds, mainly related to surface-near ground waters, are depleted and more water infiltrates into the grounds, thus reducing RR. This has been proven to happen in the Fuirosos stream, where the high hydraulic conductivity in the stream edge zone favours the rapid stream water infiltration in the surrounding riparian area regulating the stream runoff generation during the dry and the stream discharge periods (Butturini et al., 2002). The change in the rainfall pattern detected for our catchment should also be taken into account, since the timing and intensity of rainfall have a strong effect on interception loss by canopies (Muzylo et al., 2009). In their study of the interception processes at the event scale in a Mediterranean forest patch, Llorens et al. (1997) describe one particular interception process with a very high interception rate (49%), occurring under dry atmospheric conditions and during low intensity events when active re-evaporation from the canopies happens even during rainfall. Although as these authors show data obtained at the daily scale cannot be directly transferred to the event scale, the reported decrease in the number of days with low rainfall suggests that in our catchment the relative interception may be lower in the second period in comparison to the first one. However, increased evaporative demand and water loss by transpiration throughout the catchment due to higher temperatures could be offsetting this effect. The warming was especially intense in April, May and June, with increases in mean temperature ranging from 1.65 to 3.07 °C. The fact that these are the first 3 months after the leaf unfolding of the main deciduous species in the riverside (*A. glutinosa*, *Corylus avellana*, *Platanus* sp., *Robinia pseudoacacia*, *Castanea sativa*, *Prunus avium* and *Ulmus minor*), and that these species have advanced the leaf unfolding more than 2 weeks in the last five decades as a consequence of warming (Peñuelas et al., 2002) may be influencing the RR due to increased evapotranspiration, although these species are not included in our simulation since they represent a very low share of the catchment area.

As noted in the results section, the RR values were the same regardless of whether we considered or not the afforestation of the catchment area in the simulation. Thus afforestation does not seem to have influenced the RR. The increase in forested area, which represented 4.2% of the catchment, was probably too small to have a significant impact on water runoff, though during the first half of the 20th century, when higher afforestation rates occurred, the effect on water runoff might have been visible. In any case, the variation of vegetation structure should also be considered, since it has a strong influence on interception losses. A review by Llorens and Domingo (2007) found that there was a clear reduction in relative throughfall with increasing DBH, age, height, basal area and LAI, in other words with greater maturity of the stands and canopy closures. Although throughfall increases after thinning, it is not clear whether this leads to higher runoff. Whilst in more humid regions it is suggested that forest harvest contributes to increased peak flows, in Mediterranean forests, i.e. holm oak forests, the increased throughfall after thinning is transpired by the remaining trees at an increased individual rate (Gracia et al., 1999), without becoming stream flow. However, the throughfall increase after thinning is not proportional to the amount of biomass removed or to the increase in between-tree spacing (Llorens and Domingo, 2007), and the limit of the assumption that the overall evaporation reduces linearly in proportion to the canopy cover has to be evaluated (Muzylo et al., 2009). According to both reviews, more effort to model the interception process in very sparse forests and isolated trees should be made, and rainfall partitioning by trees and shrubs into throughfall and stemflow should be studied in more detail, especially in the rainfall range between 600 and 800 mm per year and in several species of *Quercus*. Olzinelles catchment is mainly covered by evergreen *Quercus* forests, receives about 700 mm of annual rainfall and used to have sparse forests when firewood harvesting and charcoal making were the main economic activities of farmhouses, so its dynamics of rainfall interception and partitioning fall within the gap of knowledge identified by these reviews.

The assumption of no forest management in our simulation is consistent with the decreasing trend in firewood appropriation and the biomass accumulation of the last five decades in Olzinelles. Visual comparison of aerial photographs throughout the catchment confirms that canopy cover has greatly increased (Fig. 4) as coppicing of oaks and slashing of ground vegetation decreased dramatically with rural–urban migration and land abandonment, as explained in the previous section of the discussion. According to a detailed study of management practices (Otero, 2010) we know that evergreen oak forests were coppiced every 7–10 years to obtain firewood and to make charcoal. Before felling oaks, slashing of ground vegetation was performed to obtain thin firewood, while some understorey species as *Erica arborea* and *Arbutus unedo* were uprooted and the stumps sold to manufacture wood products. Some competitor species were removed from the stands to improve the growth rate of oaks, and pines were pruned to stimulate growth before felling. Pig herds and sheep flocks grazed herbs, stems, shrubs, shoots, roots, lower branches of trees and acorns in the oaks woodland. As a result of the intensive exploitation, forest remained sparser, had less fuel load and a lower canopy cover compared to the current situation. Since we have not incorporated the variation of canopy cover in the land-cover classification nor in the hydrological model to test its role on interception, throughfall and runoff generation, we can only hypothesize that, as the mentioned reviews suggest, the increase in canopy cover experienced in Olzinelles as a result of land abandonment may had a significant effect on water discharge in the catchment. Moreover, some of the shrub species that were periodically removed from the understorey in Olzinelles (e.g. *A. unedo*) are clearly under-represented in rainfall interception and partitioning studies, although they play an important role in water balances (Llorens and Domingo, 2007; Muzylo et al., 2009).

The decrease in RR does not seem related to other factors. Water extractions for domestic and agrarian use have not increased, since both the population density and the irrigated area have decreased. Moreover, rural depopulation has led to the abandonment of some of the water infrastructures that were constructed and maintained by the inhabitants of Olzinelles in the past. A total of 5 springs and 5 ponds have been found abandoned in the valley, therefore the water appropriation for human use must be lower than in the past, at least in the catchment area itself.

In Mediterranean regions of the north rim land-use has a great influence on runoff generation (Kosmas et al., 1997) and the expansion of forests and shrublands is related to an increase of evapotranspiration and a reduction of total runoff (Puigdefábregas and Mendizabal, 1998). In mountainous areas of Spain, for example, several studies from experimental plots conclude that the growth of forest and shrubs on abandoned meadows and fields reduced the water runoff (García-Ruiz et al., 1995; Molinillo et al., 1997; Lasanta et al., 2006). In some cases, afforestation and reforestation processes in the catchments may explain up to one third of the loss of annual discharge of rivers (Beguería et al., 2003; Gallart and Llorens, 2004). The increasing use of water by new forests is added to the water used for irrigation and urbanization, and to decreasing rainfall inputs in rivers as important as Ebro (Gallart and Llorens, 2003, 2004).

Our data may serve to clarify some of these conclusions. In Mediterranean mountains historically devoted to forestry and with little agrarian area, as is the case in Olzinelles, the afforestation experienced in the last decades may be too small to have a significant influence in the runoff. Rather, decreases in water flow may be related to drier periods, longer droughts, and increased potential evapotranspiration rates, trends that are expected for the near future (IPCC, 2007). However, the great increase in forest canopies as a result of forestry abandonment, which is a generalized phenomenon in Mediterranean mountains, should be considered in more detail in further studies.

Loss of biodiversity

The disappearance of white-clawed crayfish, Mediterranean barbel, chub, European eel, and southern water vole is clearly related to the hydrological changes of the stream. No other factors seem to account for such disappearance. In Olzinelles valley there are neither industrial nor agrarian sewage that may cause water quality to deteriorate, and in the main river (Tordera) the strong industrial pollution has been reduced in recent years by the construction of sewage treatment plants and other administrative measures (Miralles, 2008). These species never had a market value in the study area, and fishing and capturing used to be occasional, so it is not expectable a negative effect in their populations for these reasons. Moreover, the human pressure on these species has surely decreased, taken into account that from 1924 to 2007 the population of the valley has dropped by 76%.

The disappearance of white-clawed crayfish in Olzinelles stream may be easily related to the loss of water flow, but also to the effect of the red swamp crayfish (*Procambarus clarkii*), one of the more widespread invasive species of crayfish in Spain, introduced in some streams of Montnegre Mountains by 1989 (Boada, 1990). However, in the last surveys in Olzinelles stream *P. clarkii* has not been found, a fact that has been related to the absence of water (own survey 2008 and GESMED, 2008).

Mediterranean barbel and chub have good populations in the entire Tordera basin (Benejam et al., 2008), while eel is less abundant due to different factors that make difficult the migration along the main river (Aparicio et al., 2001; Aparicio and Vargas, 2004). In the Fuirosos stream, Mediterranean barbel, chub and eel survive in isolated pools during dry periods, showing high spatiotemporal variability in biomass and density according to hydrological conditions (Aparicio et al., 2001; Aparicio and Vargas, 2004). This would also be the case of Olzinelles stream until, at least, 1991, when barbel and eel were found in two small pools in the central part of the stream, as noted above. But the average runoff is lower and unlike Fuirosos there are no more pools big enough to maintain stable fish populations, and only some isolated individual may go upriver from the Tordera in months with high water runoff, as the young eel found in 1997 (E. Aparicio, personal communication). The exotic fish species in Olzinelles stream (*S. erythrophthalmus*, *C. carpio* and *C. auratus*) have been found only in artificial ponds, so no negative interactions with native fish species from the stream may be expected.

In the Vallès County, southern water vole declined strongly in the last decades as a consequence of the degradation of aquatic ecosystems (Arrizabalaga and Montagud, 1989), and at present it is considered in danger in Tordera basin (Torre et al., 2008). In Olzinelles stream, the last one we saw dates back to the beginning of the eighties (observation of M.B.). Similarly to the fish species, the disappearance of the water vole seems related to the changes in the hydrological features of the stream. Although results from a study carried out in southwest Spain suggest that it is adapted to suffer the typical droughts of some Mediterranean areas (Fedriani et al., 2002), in the sampling of 2008 no galleries in the slopes of the stream or trails in the riverside were detected.

Final remarks and policy implications

The socioecological changes that have taken place in Olzinelles valley may be considered as representative of Mediterranean mountains that have experienced dramatic depopulation and land abandonment processes under current climate change, especially those mountain areas that have been historically devoted to forestry and where agriculture has been very limited in extent. It could be argued that the reported loss in biodiversity is local and does not have any effect in the conservation status of the species. But some of these species have small distribution areas and their overall population is declining. Mediterranean barbel has been considered as near threatened by the IUCN Red List and listed in the Annexes II and V of the European Union Habitats Directive (Elvira, 1995; Crivelli, 2006). The white-clawed crayfish is considered a vulnerable species by the IUCN Red List (Sket, 1996), and is listed in Annexes II and V of the European Union Habitats Directive. Southern water vole, which is only found in the Iberian Peninsula and France (Fedriani et al., 2002; Cubo et al., 2006), is considered of lower risk (near threatened) by the IUCN Red List (Amori, 1996). Moreover, the decrease of the runoff response to rainfall and the disappearance of some animal species of the stream come to add to the recently reported effects of land-use and climate changes in the species and biomes of this region (Peñuelas et al., 2002, 2007, 2008; Stefanescu et al., 2003, 2004; Peñuelas and Boada, 2003; Jump et al., 2006a,b; Bartolomé et al., 2005).

Our results suggest that conservation strategies in Mediterranean forests should take into account the use of water by forests and its role in the hydrological balance of the catchment. Management of mountain areas in a progressively warmer climate, and especially after land abandonment, should be oriented towards an appropriate distribution of agrarian and forest land-covers that guarantees water availability to maintain the stream and the riverside. The recovery of former agrarian cover in order to partially compensate the effects of climate decreasing the runoff would not have a significant effect on runoff unless large forested areas were converted into fields or pastures, something that must be carefully evaluated in terms of the opportunities and the trade-offs with other ecosystem functions and services. In this sense, the share and distribution of agrarian and forest land-covers should be optimized taking into account the conservation of open habitats and their biodiversity (Otero, 2010; Marull et al., 2010), the wildfire hazard, the economic activities of the farmhouses and the cultural dimension of landscapes. Evidences from previous studies done by some of us (e.g. Gracia et al., 1999) suggest that thinning will result in better water status of the remaining trees, but will not increase the runoff in forested catchments where potential evapotranspiration exceeds precipitation (Piñol et al., 1991). However, the great increase in canopy cover experienced in Olzinelles as a result of unmanaged growth of forests and its potential role in the rainfall interception and partitioning processes should encourage new studies to know whether traditional practices such as coppicing, slashing of ground vegetation and extensive grazing would have a positive effect on runoff. Down to the stream scale, the pools that keep water throughout the year should be conserved and extended to enhance its potential to maintain aquatic and semi-aquatic species populations.

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