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Land-use changes in a small watershed in the Mediterranean landscape (SE Spain): environmental implications of a shift towards subtropical crops

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Resource use and watershed management have become an increasingly important issue, stressing the need to find appropriate management approaches for improving agricultural landscapes. We analysed land-use changes from 1978 to 2007 in a representative watershed of Almuñécar (SE Spain). In 1978 the watershed consisted of 64.2% almond, 24.7% fallow land, 6.7% vineyard, 1.9% olive and 2.5% other uses. In 2007 much of the traditional orchards had disappeared, leaving only 17% almond and 0.6% vineyard. Not less than 29.8% had become shrubland and another 24.6% abandoned cropland. However, much of the land is now under subtropical crops: 19.2% avocado (*Persea americana* M.), 3.9% mango (*Mangifera indica* L.), 2.4% loquat (*Eriobotrya japonica* L.) and 1.1% cherimoya (*Annona cherimola* M.). This intensively irrigated agriculture with subtropical trees on terraces could exacerbate watershed degradation and could become a core problem with implications for sustainable resource use. The abandonment of traditional terraces with rainfed crops has led to the re-emergence of spontaneous native vegetation, promoting a denser plant cover and subsequent decrease in erosion. Therefore, highlighting the need for implementing sustainable conservation practices is crucial as part of future agricultural support.

Keywords: land-use type; subtropical crops; terraces; land-use change

1. Introduction

Land-use changes are fundamental in the current global change phenomena being directly related to food security, human health, urbanisation, biodiversity, transboundary migration, environmental refugees, water and soil quality and runoff and sedimentation rates (Shriar 2002; Rounsevell, Berry, and Harrison 2006; Durán, Rodríguez, Flanagan, García, and Muriel 2011a). Over the millennia, land-use changes have transformed the ecosystems of the Mediterranean Basin being subject to the vagaries and complexities of social, political, economic and even cultural and religious factors (Grove 1996; Margaris, Koutsidou, and Giourga 1996). Moreover, industrialisation and pressure from tourism during the twentieth century have led to major socio-economic changes in rural areas, based on the

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abandonment of marginal terraced hillside land in favour of cash crop cultivation through better soils in the plains, providing far higher net outputs (Puigdefábregas and Mendizábal 1998).

In this sense, traditional elements of the Mediterranean landscape provide habitats for organisms and thus maintain biodiversity. These elements include hedgerows, irrigation ditches, rough pastures, ponds and terraces. Terracing, an agricultural technique for collecting water and reducing soil erosion, has an ancient history of transforming landscapes into stepped agroecosystems in the Mediterranean Basin, as well as in many mountainous regions of the world (Sandor, Gersper, and Hawley 1990; Xing and Lin 1991; Treacy and Denevan 1994; Beach and Dunning 1995). The main purpose of these structures in the past and also at present has been to increase the usefulness of steep slopes. In addition, they also may be used to boost the agricultural potential of slopes that could be cultivated without levelling. Throughout the Mediterranean region, and also in the traditional dryland farming in SE Andalusia (S Spain), soils on sloping land and cultivated for thousands of years have been gradually degraded by soil erosion. Currently, terracing continues, sometimes with heavy financial investment, resulting in pronounced alterations in the soil profile. The new structures commonly found in the study area are a reverse-sloped bench terrace type with a toe drain measuring 160–170 m long, with a platform of 2–3 m wide and the talus 3–5 m high.

Approximately since the 1950s, as a consequence of the rural exodus, many Spanish rural regions have undergone changes in their landscape structure due to the abandonment of agricultural activities, and in some cases due to the proliferation of other economic activities, such as tourism. Particularly, on the coast of Granada (SE Spain), as in other areas along the Mediterranean Coast, human impact has been historically very strong (Fernández, Martín, Ortega, and Ales 1992). The economy of the Granada Coast has been based on tourism, mainly since the 1970s. Particularly, in Almuñécar, during 2001, according to the official population census (IEA 2001), only 7.2% of the active population was employed in agriculture and fishing, whereas 55.5% was involved in tourism and services. However, in the late 1980s, intensive irrigated agricultural systems were established with tropical and subtropical crops in the mountainous areas near the coast in newly constructed machinery-made terraces. These structures are being used to cultivate avocado (*Persea americana* Mill.), mango (*Mangifera indica* L.), loquat (*Eriobotrya japonica* L.), cherimoya (*Annona cherimola* Mill.), litchi (*Litchi chinensis* Sonn.) and others (Durán, Martínez, Aguilar, and Franco 2003; Durán, Rodríguez, Franco, and Martín 2006b). The new terraces have profoundly transformed the traditional landscape of this area, since old terraces were cut by hand and built of stone. The current terrace construction uses heavy machinery and high economic investment approximately amounting to €3300 ha^{-1} (PMCS 2011).

Here, we analyse land-use types in the agricultural landscape from 1978 to 2007. Particularly, we focus on the influence of land-use changes on a pilot watershed located in Almuñécar (SE Spain), which typifies adjacent watersheds in the study area and furthermore highlights the need for adopting sustainable environmental policies in many areas of the Mediterranean Basin.

2. Study area and methods

The study area consists of a small agricultural watershed located approximately 57 km south of the city of Granada and some 1.7 km north of the city of Almuñécar (SE Spain) (Figure 1). The watershed area is 343 ha and ranges in altitude between 80 and 720 m. The

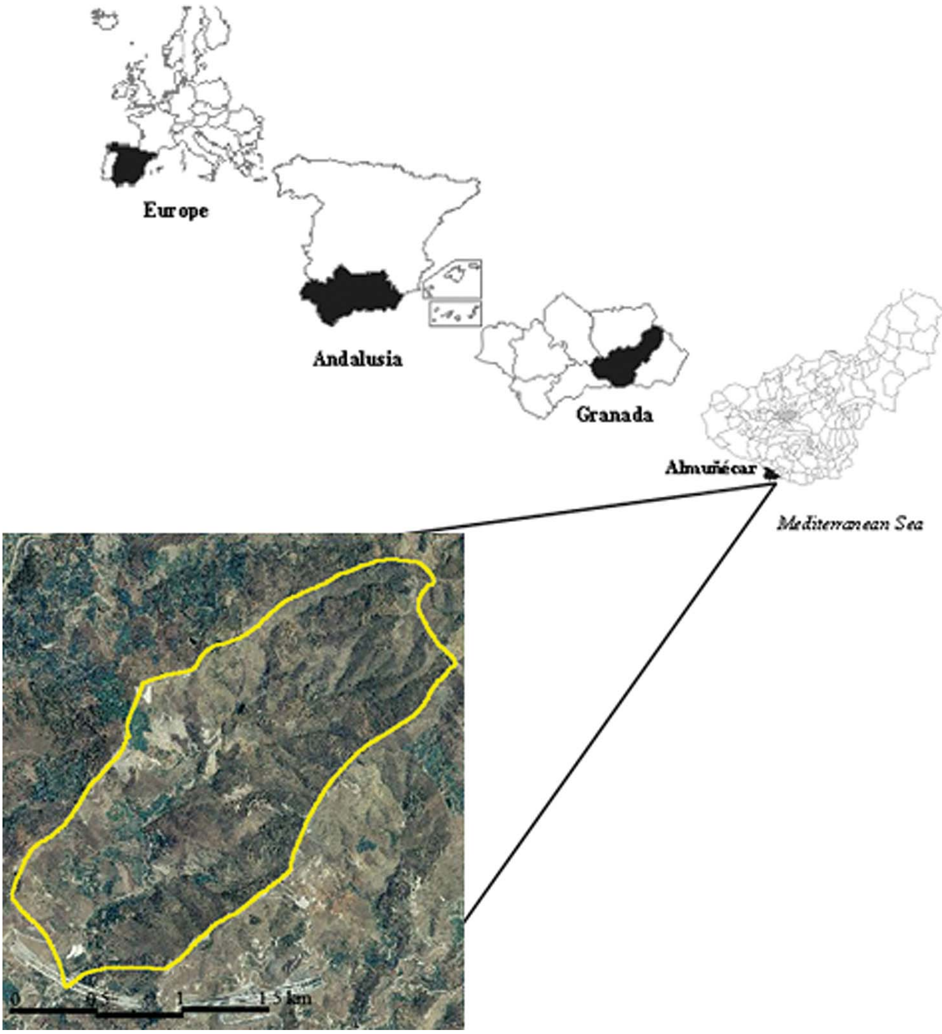

Figure 1. Location of the watershed in SE Spain.

topography is mountainous with an average slope exceeding 50%, showing features similar to those found in other Mediterranean mountain zones (Figure 2). Local temperatures are subtropical to semi-hot within the Mediterranean subtropical climatic category (Elías and Ruiz 1977). The average annual rainfall in the study zone is 449.0 mm. During the summer the watershed had only base flow, peaking in December–January, the months of heaviest rainfall. Despite scattered light rains, runoff is lowest during July and August, because the watershed storage becomes depleted and the rainfall has to satisfy the evaporation, transpiration and soil storage demands before generating runoff. The proximity to the sea and to the Penibetic mountain system in the north reduces the influence of the northern winds, which result in a unique microclimate in Europe suitable for subtropical farming and greenhouses.

The soils, formed from weathered slates, have a low degree of development. The main soil types are Eutric Regosols (FAO 1998), occupying around 80% of the study area;

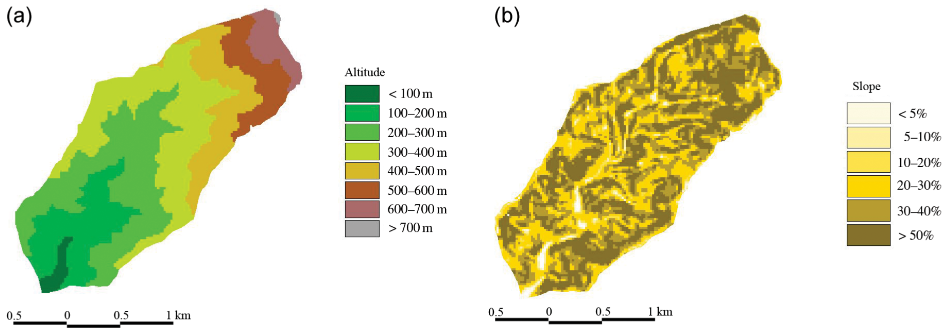

Figure 2. (a) Altitude and (b) slope maps of the studied watershed.

the texture of these soils is dominated by sand (>650 g kg^{-1}), with a low clay content (<150 g kg^{-1}), gravels being frequent in depth; the pH is close to neutrality; the cation exchange capacity is low (frequently <10 $cmol^{+}$ kg^{-1}); and the organic matter is generally below 15 g kg^{-1} (Aguilar, Simón, Fernández, Gil, and Marañas 1986). Other soil types are less abundant in the area. The Eutric Leptosols (FAO 1998) occupy around 15% of the study area, and are directly related to the slopes steeper than 50%; the thickness is generally less than 10 cm being related to the areas where erosion occurs. Finally, the Eutric Fluvisols (FAO 1998) appear in about 5% of the area being restricted to seasonal watercourses. The accumulation of material eroded from the slopes generates soils with depths greater than 60 cm but with a very high content of gravels and stones.

Details of land cover dynamics in the watershed over the period between 1978 and 2007 were interpreted from diverse site information (land-use maps of 1:50,000 for 1978 and of 1:10,000 for 2007 and aerial photographs) and field observations. In particular, the analysis of topographical maps and aerial photographs (1978 and 2007) delineated the different land-use types, contour line, farm houses, greenhouses and waterbodies within the watershed.

The older map was used to identify the changes that have occurred in relation to the current state. All land was classified into the following land-use types: olives, almonds, vineyards, fallow, abandoned cropland, shrub land and subtropical crops (e.g. mango, cherimoya, loquat and avocado). We evaluated the changes in land-use types from 1978 to 2007 to determine the extent of the landscape changes and we undertook some field observations and consulted the local government to determine how these changes had occurred.

3. Results

3.1. Traditional Mediterranean land-use types

The land-use type maps for 1978 and 2007 are shown in Figure 3. In 1978 the major land-use type was almond orchards, with 64.2% of the watershed area, followed by 24.7% of fallow cereal-growing land and 6.7% of vineyard. In 2007 the percentages for almond and vineyard were reduced to only 17% and 0.6%, respectively, whereas olive and fallow cereal-growing land had disappeared altogether (Table 1). Rainfed crops such as olive, almond and vineyard expanded rapidly during the 1970s on marginal land in many semi-arid environments, as pointed out by many other authors (Faulkner, Ruiz, Zukowskyj, and Downward 2003; Tubuleih, Bruggeman, and Turkelboom 2004). Abandonment of olive

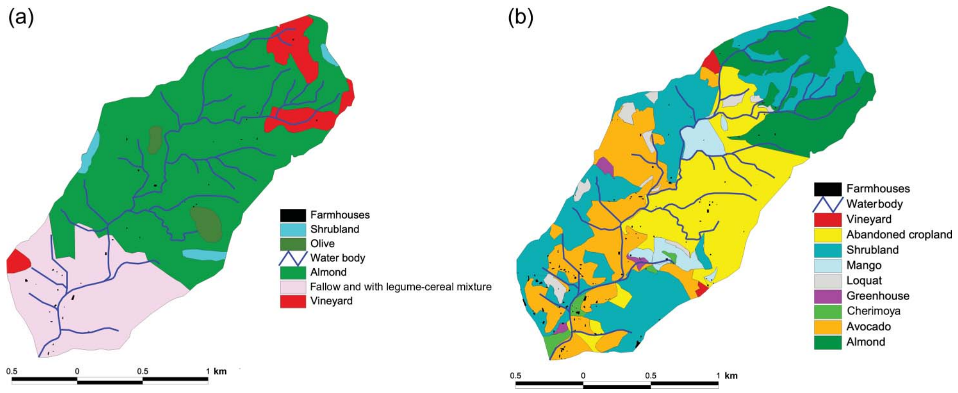

Figure 3. Land-use type dynamics for watershed from (a) 1978 to (b) 2007 in the study area.

Table 1. Land-use types in the watershed from 1978 to 2007.

	1978		2007	
Land-use type	(ha)	(%)	(ha)	(%)
Almond	220.6	64.2	58.3	17.0
Fallow land with legume–cereal mixture	85.0	24.7	–	0.0
Vineyard	22.9	6.7	2.0	0.6
Olive	6.5	1.9	–	0.0
Avocado	–	–	66.1	19.2
Cherimoya	–	–	3.9	1.1
Loquat	–	–	8.2	2.4
Mango	–	–	13.5	3.9
Shrubland	6.7	1.9	102.5	29.8
Abandoned cropland	–	–	84.5	24.6
Greenhouse	–	–	2.4	0.7
Farm house	0.5	0.2	1.2	0.3
Waterbody	1.5	0.4	1.2	0.3
Total	343.7	100.0	343.7	100.0

cultivation in our study area was due to the more profitable new irrigated crops, and also due to several factors affecting olive cultivation in general – that is, the competition with other regions having a comparative advantage that influences their economic sustainability. Another major reason is the dependence on the governmental economic policy, concretely on production subsidies, as well as on other regional measures such as aid to depressed areas and agro-environmental subsidies (Duarte, Jones, and Fleskens 2008).

On the other hand, in 1978, an important part of the study area was dedicated to fallow land in rotation with a legume–cereal mixture (24.7% of the total area; Table 1). This was part of the predominant agriculture; the use of synthetic inputs not being necessary to recover soil fertility, but leaving the land free from cultivation for some time. This agricultural system can also be considered to be a traditional Spanish rural activity with food production for local use.

3.2. Shrub land

The shrub land area increased from 6.7 ha in 1978 to 102.5 ha in 2007, due to abandonment of almond orchards within the watershed. This land-use type consists of a patchy matorral of medium height with *Stipa tenacissima, Genista umbellata* subsp. *equisetiformis, Rosmarinus officinalis* and *Anthyllis cytisoides* as dominant species from the *Asparago-Ramnetum oleoidis* association, which results from the degradation of a denser and taller forest of the association *Olea ceratonium* (Rivas and Rivas 1971). Other species within the watershed include *Pinus halepensis*, *Juniperus phoenicea*, *Ononis tridentata*, *Thymus vulgaris*, *Papaver rhoeas*, *Convolvulus* sp., *Malva sylvestris*, *Reseda phyteuma*, *Anacyclus* sp., *Sinapis arvensis*, *Medicago* sp., *Chrozophora* sp., *Taraxacum officinale*, *Chenopodium* sp., *Poa annua*, *Bromus* sp. and so on. Thus, the progressive recolonisation of native vegetation took place in the watershed in those areas where farmers abandoned cultivation basically due to the migration of young generations from rural areas to the main cities seeking economic opportunities.

3.3. Subtropical crops

According to the results of this study, new tree crops established within the watershed occupy 26.6% of the area. Part of the traditional rainfed cultivation of almonds and fallow areas was converted to irrigation and the entire olive area was turned into subtropical orchards (91.7 ha). In addition, in recent years these new irrigated crops were established mainly on new orchard terraces. The most extended subtropical crop was avocado, grown on 66.1 ha, representing 19.2% of the area (Table 1). This could be explained by its high internal rate of return which according to PMCS (2011) amounts to 14.9%, compared with 12.5%, 10.7% and 10.4% for mango, loquat and cherimoya, respectively. The cultivation of avocado on the coast of Granada was started in the early 1960s and expanded vigorously during the 1980s. Currently, there are more than 2800 ha on the coast of Granada, with an annual expansion rate of 40 ha. About 60% of the avocado produced on the Granada Coast is exported to the European market, since this fruit is more appreciated than those coming from overseas, which usually lose quality due to the transport time. The main cultivars in the watershed studied are 'Hass' (with 75% of the total area) followed by 'Fuerte', 'Bacon', 'Reed' and 'Pinkerton'.

The primary problem of avocado cultivation on terraces, as for the rest of the crops in the area, is the excessive cost of energy required for pumping irrigation water to high levels. Other problems of avocado cultivation in the study area include the spider mite (*Oligonychus perseae*) and iron chlorosis that negatively affects its production. This spider cannot be treated chemically, although on the coast of Granada and Málaga some 3500 ha are already affected by this mite. Finally, another problem is the large size of the trees due to the high application rates of N fertilizers on terraces, which reduces the number of fruits in relation to canopy, slows down the manual harvest of the crop and leads to a high risk of nitrogen pollution of waterbodies (Durán, Martínez, and Aguilar 2004a, Durán, Rodríguez, and Franco in revision).

A new subtropical crop, cherimoya, not yet found in the watershed in 1978, by 2007 covered an area of 3.9 ha (Table 1). This exotic fruit has a strongly expanding European market (Lüdders 2002). Globally, Spain is the first cherimoya producer in the world, with about 3600 ha (and total production of 35,000 t), followed by Peru (1800 ha) and Chile (1200 ha) (Van Damme and Scheldeman 1999). In the watershed, as in the rest of Granada Coast, the chief cultivars are 'Fino de Jete' and 'Campas'. These crops were brought by Andalusian emigrants, when they returned from the United States in the sixteenth to eighteenth centuries. However, the crop began to be cultivated at the beginning of the nineteenth century, most specimens being a cross between the varieties brought from the United States and those grown in Río Verde valley (Almuñécar). Today, most cherimoya orchards on the Granada Coast are located in flat areas, and 90% of this fruit is consumed in Spain and the remaining 10% is exported to European Union (EU) countries (Durán *et al.* 2006b).

Loquat is another key crop on the coast of Granada. According to the results of this study, there are 8.2 ha in the studied watershed in 2007 (Table 1). Unknown to the Western world until the eighteenth century, the easy adaptation of loquat to the Mediterranean climate has led to its rapid expansion throughout the Mediterranean Basin. China is the world's largest producer of loquat, with more than 314,000 t, and Spain is the second world producer of this fruit, accounting for 84% of exports worldwide (Caballero and Fernández 2004). In the watershed studied the most common cultivars are 'Golden Nugget', 'Algerie' and 'Tanaka', which are considered the most marketable cultivars (Martínez, Badenes, and Llácer 2000). This crop needs intensive field labour because of the pruning, and inflorescence and fruit thinning are made by hand. The trees are usually planted in a single row on terraces with platforms of 3–4 m wide that hinder the mechanisation of loquat plantations as it does for other subtropical species within the watershed.

Mango is also an emerging crop in the study watershed, not existing in 1978. Table 1 shows the area dedicated to this crop in the watershed of 13.5 ha in 2007, with a strong increasing trend of mango cultivation in this marginal area (Durán *et al.* 2003; Durán, Rodríguez, and Franco 2006a). In this context, the world production of mangoes is estimated to be over 28.5 million tonnes per year, grown commercially in more than 90 countries. Asia produces 77% of the world production, the United States 13% and Africa 9%. In 2005, global exports reached 912,853 t for a total of 543.10 million USD (FAOSTAT 2007). Europe imported about 134,258 t of mangoes in 2008 whereas this amount increased slightly in comparison with 125,424 tonnes in 2006 (USAID-TAPP 2010). In Spain, cultivation is feasible primarily in the provinces of Granada and Málaga, with some 900 ha of mango orchards soon to exceed a production of 6000 t yr^{-1}, most being Florida cultivars. Within the watershed, as in the adjacent watersheds, the most extensively produced commercial cultivar is cv. Osteen (Durán *et al.* 2003).

3.4. Abandoned cropland and greenhouses

Another important land-use change in our watershed is the increase of abandoned cropland, which represents some 25% of the current state (Table 1). In recent past, the entire land was cultivated mainly with the purpose of self-sufficient agriculture and also to produce wood as an energy source. However, the abandonment of marginal agricultural landscapes has been a widespread phenomenon in European Mediterranean areas since the second half of the past century (Margaris *et al.* 1996; Puigdefábregas and Mendizábal 1998). Likewise, agricultural land abandonment promotes widespread changes in the composition and spatial arrangement of the plant communities (Barbero, Bonin, Loisel, and Quézel 1990), increasing the risk of severe wildfires (Vallejo, Aronson, Pausas, and Cortina 2005). The ancient terraces (bench type with handmade stone walls), occupied mostly by almond orchards, have been progressively abandoned. These structures protected the soil and preserved the natural vegetation. Nowadays, the taluses of new orchard terraces occupied by subtropical crops are totally unprotected by vegetation because local farmers usually leave bare soil, promoting a progressive collapse mainly due to soil erosion (Durán, Aguilar, Martínez, and Franco 2005). In this context, it has been demonstrated that abandonment of traditional extensive cultivation in the Mediterranean Basin has different impacts on soil–sediment losses according to the slope gradient, as pointed out by Koulouri and Giourga (2007). In the watershed, abandoned old terraces are gradually restored by native spontaneous vegetation, protecting soil from erosion.

Currently, there are 2.4 ha of greenhouses within the watershed that did not yet exist in 1978 (Figure 3). These structures are basically low-cost, unheated plastic-covered frames and with soil-grown crops. However, this activity involves a high consumption of energy and agricultural materials (e.g. fertilizers, pesticides, herbicides) that can eventually pollute both surface and groundwater systems. In this context, the study area has been classified as 'vulnerable' according to the DG (2002) due to the diffuse pollution caused by fertilizers. After the 1990s, this growth slowed down due to the stabilisation of market prices and the emergence of pests that affected production (Matarán 2005).

3.5. Implications for the environment

The intensification of irrigated agriculture in the watershed has led to the use of chemical products in order to maximise production. Particularly this type of agriculture, based mainly on subtropical crops, relies on the use of chemical fertilizers, herbicides, fungicides, insecticides, plant growth regulators and so on. Table 2 summarises the water and fertilizer application rates for subtropical crops present in the watershed. On an average, avocado is the crop with the highest fertilizer requirements, while loquat and mango require more water due to the higher number of trees per hectare (400–600 trees). The cultivation of subtropical crops in the watershed has increased water consumption, usually coinciding with the dry season and with the highest water demand for tourism. Meanwhile, farmers often apply higher nutrient rates (NPK) than required by the crops, and such excesses represent potential environmental pollution, requiring a detailed assessment of nutrient balances (Durán *et al.* 2004a). Consequently, high fertilizer application in subtropical intensive agriculture is often one of the main sources of nutrient leaching to the environment, associated with a reduced quality of groundwater and surface water (Durán *et al.* in revision). Thus, there is an urgent need to improve the water use efficiency, and consequently, the rational use of natural resources. Conversion of sloping land into terraced land for cultivating subtropical crops could deteriorate soil properties, especially reducing soil organic matter and changing the distribution and stability of soil aggregates, above all in bare soil areas (taluses) (Durán *et al.* 2005). According to Durán *et al.* (2011c), the taluses of new orchard terraces with subtropical crops that are totally unprotected by vegetation urgently need the implementation of plant covers in order to control erosion and to conserve the terrace structure. In addition, plant cover in this type of environment promotes the atmospheric carbon sequestration and recycles the nutrients (Rodríguez, Durán, Martín, and Franco 2009). Thus, the increased production in this fragile high-altitude ecosystem makes it urgent to implement agro-environmental strategies in order to mitigate this impact.

Another important consequence of the intensification of agriculture in the area is the overexploitation of the Río Verde aquifer existing in the watershed. Due to the scarcity of fresh surface water resources during drought years the water supply is usually covered by the exploitation of aquifers, leading sometimes to marine intrusion processes which increase groundwater salinity (Calvache and Pulido 1996), and therefore, affecting the irrigation wells and plantations that use this water for irrigation (Durán, Martínez, and Aguilar 2004b). In this context, at least 45% of all water pumped from aquifers each year is extracted without regard to legal constraints (WWF 2006), and the same situation is reflected in our watershed.

Table 2. Average water consumption and the use of nutrients for irrigated subtropical crops within the watershed.

Crop	Water consumption 0–5 years trees	Water consumption 5–10 years trees	Water consumption Mature trees	Nutrient use Nitrogen	Nutrient use Phosphorus	Nutrient use Potassium
		($m^3\ ha^{-1}\ yr^{-1}$)			($kg\ ha^{-1}$)	
Mango	482	2892	2903	165	49	140
Cherimoya	268	1608	2150	145	24	103
Avocado	240	1440	2400	287	150	275
Loquat	446	2223	2969	200	120	160

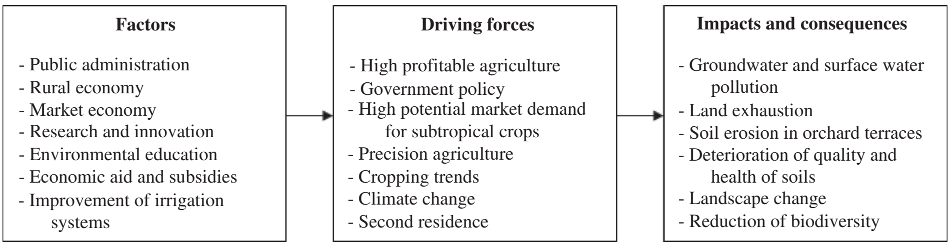

Figure 4. Factors, driving forces and impact in the study area.

Land-use changes are caused by a number of natural and human driving forces (Meyer and Turner 1994). Whereas natural forces such as climate change are felt only over a long period of time, the effects of human activities are immediate and often radical and detrimental. In this context, the status of land cover and its dynamics have both local and regional environmental implications, because the consequences of degradation do not have clear boundaries. Particularly in our study area, the main driving force which significantly affects land use is highly profitable agriculture, which has reshaped the landscape (Figure 4).

4. Conclusion

This study highlights the impact of human activity regarding land use and the urgent need to apply conservation practices in an agricultural mountain watershed in the Mediterranean region. Therefore, on the basis of the results of this study and based on the current land-use types, we conclude the following:

(1) In the watershed studied, as well as in adjacent watersheds in the coastal area of Granada, the main driving force affecting the land-use types is agriculture, mainly based on subtropical crops.
(2) These driving forces exert heavy pressures on the environment because of the intense use of natural resources (soil and water). It is necessary to promote and improve the equilibrium between water demand and water availability by better land-use planning, and by research on water requirements of the different existing subtropical crops in the area (Durán, Rodríguez, and Franco 2011b).

(3) After the abandonment of traditional (stone) terraces in 1978 occupied by almonds and olives, new orchard terraces were built for subtropical crops, enhancing soil degradation (water erosion, soil nutrient losses, carbon losses and so on). The establishment of subtropical crops on terraced hillsides requires planned sustainable agricultural measures based on the analysis of water and nutrient balances in order to avoid water waste and to preserve groundwater from pollution by fertilizers (Durán *et al*. 2011c, in revision).

(4) In this watershed, as in many other agricultural systems in the Mediterranean Basin, land-use changes are correlated with socio-economic forces. Given the increasing trend in the cultivation of subtropical crops on terraces in the coming years along the coast of Granada, in future research, priority should be given to the adoption and implementation of environmental planning strategies for sustainable land use.

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