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Spatial dynamics of land cover change in a Euro-Mediterranean catchment (1950–2008)

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The Euro-Mediterranean area has experienced widespread land cover change since 1950, but few studies of land cover change explicitly explore spatial constraints on land cover change patterns. The main objective of this study was to analyze the spatial dynamics of land cover change from 1950 to 2008 in a French Mediterranean catchment. Aerial photographs (1950, 1982, and 2008) were screen digitized, and surfaces were classified into five categories: forest, vineyard, grassland, urban, and suburban. Land cover changes were concentrated mainly in the alluvial plain. Although forest remained the dominant land cover in the catchment (>85.0%), it underwent significant swapping with vineyard and grassland. Vineyard decreased (34% of initial loss) while grassland increased (43% of initial). Urban and suburban areas remained minor in the catchment (0.2% in 1950 and 3.0% in 2008), but showed a dramatic relative increase (about 20×). Changes occurred mainly at low altitudes and slopes. Vineyard located near streams was converted mainly to grassland. Built areas were dependent on roads and former built areas for expansion but expanded little near streams due to flooding risks. The rate of change was greater during the latter part of the study (1982–2008) than in the earlier phase (1950–1982).

Keywords: land cover change; urban expansion; vineyard conversion; topographic drivers; distance drivers

1. Introduction

Land cover changes represent major human alterations of the Earth's land surface (Lambin et al., 2001), and land cover conversion processes in Europe have accelerated since the Second World War (Antrop, 2005; Geri, Amici, & Rocchini, 2010; Serra, Pons, & Saurí, 2008). Land cover change has occurred through the interaction of environmental and socioeconomic characteristics, including population growth, urban sprawl, industrial development, and political and environmental policies. In addition, rapid expansion of tourism during the last six decades has caused important socioeconomic changes (Dunjó, Pardini, & Gispert, 2003) driving land cover alterations in Euro-Mediterranean areas (Geri, Amici, & Rocchini, 2011). Land cover changes affect biodiversity and ecosystems, food security, human health, urbanization, and global climate change (Falcucci, Maiorano, & Boitani, 2007; Geri et al., 2011; Sala et al., 2000). They can also be responsible for environmental change, water pollution, and soil degradation (Dunjó et al., 2003).

Several studies have described land cover changes in the Mediterranean area. Mediterranean countries from Spain to Greece experienced strong urban growth from

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the 1970s onwards, and a moderate growth rate is projected to continue (Benoit & Comeau, 2005). Serra et al. (2008) reveal that about 34% of Spanish Mediterranean coastal areas were urbanized between 1989 and 1999. In France's Provence Alpes Côte d'Azur region (SE France), about 40% of shorelines were built in 2006 (IFEN, 2012). Migration from other European countries tends to concentrate in the Mediterranean coastline area (Brunetta & Rotondi, 1996), since the quality of life in Mediterranean cities seems to be greater than average in European countries (Cori, 1999). Aging population in Europe has a typical migration trend towards the Mediterranean coastal zone (Van Eetvelde & Antrop, 2004). In addition, internal migration also favors coastal areas, increasing urban pressure and land cover changes in these areas (IFEN, 2009). For example, Van Eetvelde and Antrop (2004) analyzed the characteristics and mechanisms of land cover change in southern France (Tavernes) and identified a pattern where arable land decreased in foothills while urban areas expanded near the coast. They also found that residential and secondary houses occupied traditional terraced foot slopes.

Traditional Mediterranean agriculture was comprised mainly of vineyards, olive trees, and wheat grown in the nearby hinterland, often on terraces. Serra et al. (2008) reported that vineyards and olive trees decreased in mountainous areas and transitional subregions, resulting in land abandonment and increased shrub land area. Vineyard area decreased near roads and urban areas due to urban sprawl and industrialization in moderately mountainous to flat valley areas in Peyne, France (Sluiter & de Jong, 2007). Under these conditions, farmland is sacrificed to urban expansion (Martínez-Fernández, Esteve-Selma, Baños-González, Carreño, & Moreno, 2013). Nainggolan et al. (2012) identified several biophysical and socioeconomic factors (demography, markets, and subsidies on agriculture) responsible for the change in Torrealvilla catchment of South-eastern Spain: population decreased in 1960–1980 due to migration from villages to the coastal area, and rain fed agricultural, the main landscape feature in 1940–1960, was abandoned. However, in 1980–2005, intensification of agriculture occurred on flat to gentle slopes and near main roads due to subsidies for agriculture and the European highway infrastructure. Other authors have found that land cover change affected the overall environment, resulting in deforestation (Kepner, Rubio, Mouat, & Pedrazzini, 2003), land abandonment (Serra et al., 2008), and increased runoff and soil erosion in Portugal and Greece (Koulouri & Giourga, 2007; Nunes, de Almeida, & Coelho, 2011).

From a spatial point of view, Falcucci et al. (2007) describe three common major land cover changes in the Mediterranean area of Italy: the expansion of tourism that promotes rapid urbanization along the coastline, spatial concentration of agriculture on alluvial plains and low lands (except in the coastal area), and abandonment of agricultural terraced land in mountainous steep slopes resulting in their transformation to forest. According to Geri et al. (2011) and Nunes et al. (2011), four general trends of land cover change took place during the last decades in the coastal Mediterranean area. First, dry farming and forest land cover decreased in alluvial coastal plains while reforestation occurred in hilly areas. Second, urbanization occurred rapidly in most of the coastal plains where the tourism industry flourished. Third, population growth and socioeconomic development caused agricultural intensification that increased irrigated crops. Fourth, the development of infrastructure, communication networks, and technological advances resulted in socio-economic development that was the main reason of agricultural land abandonment on marginal lands.

Most of the studies on land cover change in the Mediterranean area highlight a particular issue or describe an individual land cover change such as forest, agriculture, or urban expansion (Calvo-Iglesias, Fra-Paleo, & Diaz-Varela, 2009; Pelorosso, Leone, &

Boccia, 2009), and few studies take into account all these changes concurrently. In addition, spatial patterns of land cover change and identification of driver variables influencing change are sometimes taken into consideration, but they tend to focus mainly on altitude or slope (Geri et al., 2010; Serra et al., 2008), and few authors (Sluiter & de Jong, 2007) take distance variables into account. Urban population growth and expansion of tourism occurred more in the French Mediterranean coastal area than on average for European Mediterranean coasts in the last decades (Blue Plan Papers, 2001). This resulted in significant land cover change in this region, but very few studies describing land cover change in the area can be found. Fox et al. (2012) analyzed the impact of land cover change on total runoff between 1950 and 2003 in the upper part of the study catchment. They noted a small increase in runoff due to a complex pattern of land cover change, but much of the lower alluvial plain, where most changes occurred was ignored, and spatial controls on these changes were not examined.

The first objective of this study is to quantify land cover change patterns in terms of gains, losses, total change and swapping in a Mediterranean catchment with a strong vineyard activity in proximity to a coastal area well known for its tourism. The second objective is to quantify the impacts of topographic and distance variables on land cover change for each land cover category.

2. Methods

2.1. The study area

The Giscle watershed has a surface area of about 235 km² and is situated in the Var department of SE France near the Gulf of St. Tropez (outlet coordinates 43°16'30"N, 6°34'24"E). It is characterized by a Mediterranean climate with hot dry summers that extend from June to August, and cooler rainier winters. Average temperatures range between 22°C and 26°C in summer and 5°C to 10°C in winter. The mean annual rainfall is about 900 mm, and the main rainy seasons are from October to January and then in April (Fox et al., 2012). The study area includes two topographic units: the hilly upper part of the catchment (roughly 70% of the catchment) is made up of metamorphic rocks, mostly schist and gneiss, while the lower part of the catchment, located near the gulf, is a gently sloping alluvial plain (Fox et al., 2012).

The western (upper) part of the watershed is mostly forest (pine and oaks), and the topography of the area is uneven with the highest elevation at about 650 m. Vineyard and moderate to dense urban areas are the dominant land cover types of the lower part of the catchment. The region became a major tourist destination of Mediterranean France in the second half of the twentieth century, with the 'Côte d'Azur' development, and this generated a strong growth in urbanization. Three main municipalities are located within the catchment: Cogolin, Grimaud, and La Môle. Cogolin and Grimaud are situated in the eastern part of the catchment, about 5 km from the Mediterranean coast. They represent the main populated areas with total populations of around 11,000 and 4000, respectively (INSEE, 2011). La Môle is a small urban area with a total population of around 950 (INSEE, 2011). The total population of the catchment increases by several times (perhaps as many as 10) in the summer due to tourism and secondary homes. Unlike many Mediterranean coastal areas, the sea front is confined by the gulf and topography, and land cover change is restricted to the inner near coastal area.

2.2. Data description and land cover classification

Land cover maps were screen digitized from acquired (Institut Géographique National) digital orthorectified aerial photographs (1950 and 1982 were panchromatic; 2008 was color), using ArcGIS (ESRI, 2012). Initial spatial resolution for all aerial photographs was 0.5 m, and this was reduced to 1 m to facilitate data manipulation. The aerial photographs of 1950 were the first high-quality post-Second World War photos available when the area was still strongly rural; an intermediate date (1982) was selected between 1950 and the most recent 2008 photographs. Aerial photographs of 1982 may represent land cover conditions at the beginning of rapid urban sprawl (Baccaini & Semécurbe, 2009; Salvati, Sateriano, & Bajocco, 2013).

Surfaces were classified into five categories based on visual interpretation: forest, prairie or grassland, vineyard, urban and suburban areas. High-density urban, industrial, and commercial areas were classified as urban, and moderate- to low-density built areas were classified as suburban. Urban and suburban areas were distinguished by the density of buildings and other infrastructures as described below. Isolated housing was ignored. To avoid creating a small isolated category, the Verne water dam (built in 1989–1991) was ignored and left as forest; its surface area is negligible compared to total forest cover. Similarly, a small recreational port built on the sea at the outlet of the catchment was ignored. After digitization, land cover maps were imported into IDRISI (Eastman, 2012). Main roads and stream networks were then digitized from the aerial photographs of 2008. Main roads were about the same in aerial photographs of 1982 and 2008, so this layer did not change over time. Cell size of all digitized maps was changed to 25 m to make land cover layers compatible with the 25 m digital elevation model (DEM) used for the creation of topographic and distance variables.

Land cover layers were identified visually. Most of the forest areas found in the aerial photographs were evergreen and were clearly identified by their deep gray color in the black-and-white aerial photographs (1950 and 1982) and deep green color in color aerial photographs (2008). Vineyards were differentiated by their blocky, geometric shapes and linear texture created by the rows of planted vines. Unmanaged or abandoned agricultural areas, new shrub lands with small and scattered trees, and pasture land for sheep and horses were all classified as grassland, even though some of it could more appropriately be called shrubland. Densely to moderately built areas, including residential, commercial, and industrial areas, were identified as urban. Urban areas were distinguished from suburban by the density of buildings and absence of trees and open area. Suburban area is essentially low-density residential housing. Some small denser communities were considered suburban areas. The presence of trees and open spaces were common in the suburban area. Land cover classification was facilitated by numerous field visits

2.3. Cross-tabulation analysis in 1950–1982, 1982–2008, and 1950–2008

Land cover change was quantified using the cross-tabulation matrix of the CROSSTAB module and the change analysis module of the land change modeler (LCM) of IDRISI Selva (version 17.02 (Eastman, 2012)). The cross-tabulation matrix is a fundamental process in land cover change analysis (Pontius, Shusas, & McEachern, 2004) to show land cover changes between two images of different dates. Persistence and pixel numbers of each category from earlier to later classified images are displayed through images and tables. After creating land cover maps of 1950, 1982, and 2008, land cover changes in three temporal periods were investigated: 1950–1982, 1982–2008, and 1950–2008. Cross-

tabulation of 1950–1982 represents the historical land cover change shortly after the Second World War; 1982–2008 represents more recent changes in land cover from the beginning of the urban sprawl period. The net 58 year change is provided by the 1950–2008 analysis. The land cover change determining method proposed by Pontius et al. (2004) was applied for all temporal periods to quantify persistence, gains, losses, total change (addition of gains and losses), net change, and swapping (exchanges between land cover classes, equal to the difference between total change and absolute net change).

2.4. Spatial dynamics

To describe spatial dynamics in land cover change, surfaces were simplified into four categories: forest, vineyard, grassland, and built area. Urban and suburban areas were combined into built area due to their small individual coverage compared to other land cover categories. Although data were available for all time periods cited above, maps of losses and gains for individual categories were simplified to show the spatial pattern of net 1950–2008 change since spatial patterns did not vary significantly between 1950–1982 and 1982–1950. Histograms were used to display quantitative losses and gains of each land cover class as a function of topographic (altitude and slope) and distance (from streams, roads, built area, and the sea) variables for the 1950–1982 and 1982–2008 periods. However, since this analysis alone generated 36 figures, only summary figures of total change will be presented here and gains and losses will be described in the text. Altitude and slope were obtained from a 25 m DEM. Only main roads (created by screen digitization) were taken into consideration, and smaller roads and dirt paths were ignored. Main stream channels were also digitized manually due to errors in the automatic tracing of the hydrologic network from the 25 m DEM: in the plain, where topography is nearly flat, errors of up to 300 m could be observed between the modeled and actual channels. Finally, for changes in land cover occurring in 1950–1982, distance from built area in 1950 was used. For changes taking place in 1982–2008, distance from built area in 1982 was calculated.

3. Results

The steps in describing the results are the following: overall trends in land cover change over the study period, detailed analysis of land cover change patterns for three periods (1950–1982, 1982–2008, and 1950–2008) using CROSSTAB, spatial trends of land cover change, and topographic and distance controls on land cover change.

3.1. Areal trends in land cover change

Figure 1a–c shows land cover maps digitized from the air photos, and Table 1 provides the corresponding surface areas and changes in surface area for each category and time period. Forest remained by far the dominant land cover in the catchment (Figure 1a–c), accounting for more than 85% of land cover at all times (Table 1). Forest cover decreased by only 34 ha in 1950–1982, represents a change of only about 0.2% of its catchment cover. This increased slightly to 0.7% loss in catchment cover in 1982–2008. Vineyard was the second dominant land cover and it too declined from about 2457–2183 ha (a loss of 274 ha, almost 11% of the catchment area) between 1950 and 1982 (Table 1). This trend accelerated in 1982–2008 to reduce vineyard area to about 1616 ha (almost 26% lost). Over the 1950–2008 period, vineyard lost more than a third (34.2%) of its initial

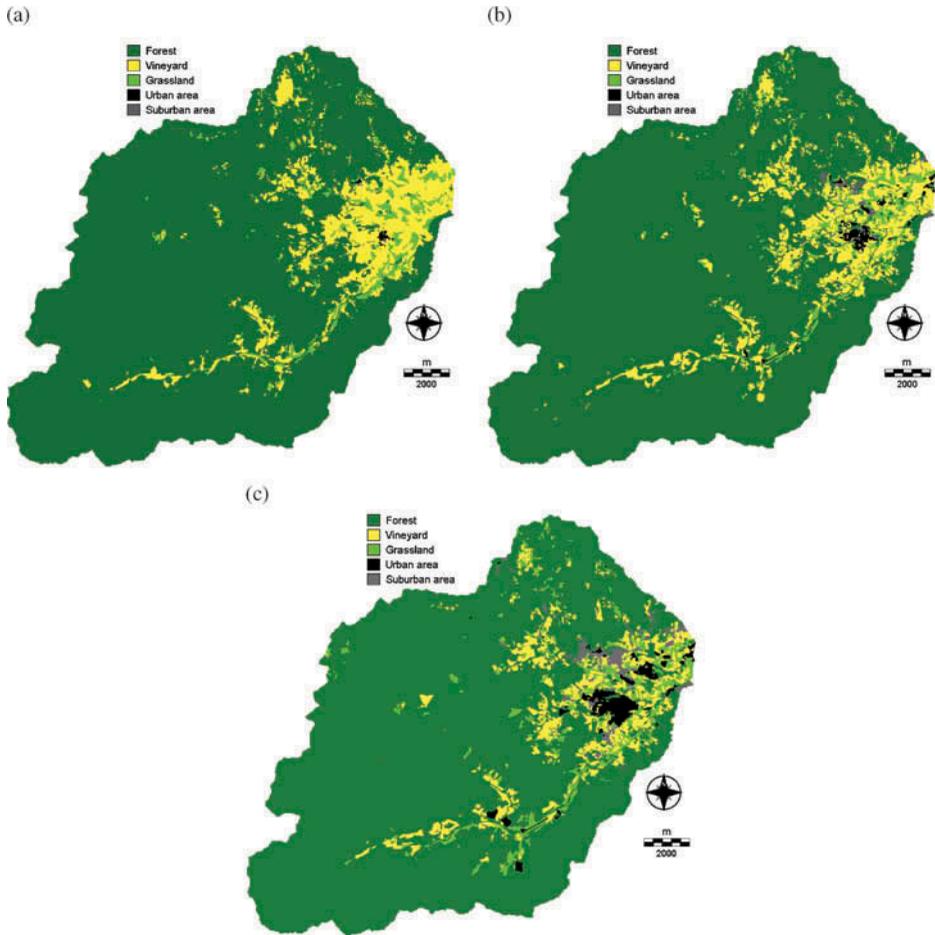


Figure 1. (a) Land cover map of 1950. (b) Land cover map of 1982. (c) Land cover map of 2008.

Table 1. Surface area of land cover types for 1950, 1982, and 2008, and changes in area for 1950–1982, 1982–2008, and 1950–2008.

Land cover type	Surface area in ha (% of catchment)			Change in surface area in ha (% of initial cover)		
	1950	1982	2008	1950–1982	1982–2008	1950–2008
Forest	20,267 (86.1)	20,233 (85.9)	20,091 (85.3)	-34 (-0.2)	-142 (-0.7)	-176 (-0.9)
Vineyard	2457 (10.4)	2183 (9.3)	1616 (6.9)	-274 (-11.2)	-566 (-25.9)	-840 (-34.2)
Grassland	794 (3.4)	879 (3.7)	1140 (4.8)	84 (10.6)	261 (29.7)	345 (43.5)
Urban	19 (0.1)	140 (0.6)	387 (1.7)	121 (645.0)	247 (176.2)	368 (1957.8)
Suburban	13 (0.1)	115 (0.5)	316 (1.3)	102 (787.0)	200 (173.8)	303 (2328.3)

cover. Grassland was the third dominant cover in 1950, though its surface area amounted to less than a third of vineyard. Contrary to forest and vineyard, grassland increased significantly during the study period, showing an overall 43.5% increase between 1950

Table 2. Cross-tabulation of land cover in 1950 (columns) and in 1982 (rows). Values are in ha, persistence (diagonal) is also expressed in % of total area in initial year (1950).

	Forest	Vineyard	Grassland	Urban	Suburban	Total
Forest	19,777 (97.6)	270	186	0	0	20,336
Vineyard	337	1660 (67.5)	186	0	0	2183
Grassland	105	394	379 (47.7)	0	0	879
Urban	12	83	22	19 (100.0)	5	140
Suburban	36	50	21	0	8 (59.1)	115
Total	20,267	2457	794	19	13	23,565

and 2008. These first three land cover categories covered 97% (in 2008) of the catchment (Table 1). Rapid changes occurred in built area (both urban and suburban), which increased steadily to over 700 ha in 2008 from below 50 ha in 1950 (Table 1). Moreover, urban and suburban areas each covered only 0.1% of the catchment in 1950, and they increased to about 1.7% and 1.3% of the catchment in 2008, respectively.

As can be seen in Figure 1a–c, most of the changes occurred in the eastern part of the catchment. This area corresponds to the alluvial plain where altitudes and slopes are gentler. For the vegetation land covers (forest, vineyard, and grassed areas), the rate of change, expressed as % of initial cover, was greater in 1982–2008 than in 1950–1982 (Table 1). Calculated on an annual basis, the difference would be even greater since the latter period showed greater change in a shorter time, 26 years versus 32 for the initial period. Although the contrary appears to be true for urban and suburban categories, where % change was greater in 1950–1982 than in 1982–2008, it should be noted that the latter period experienced greater absolute change, and small absolute differences in 1950–1982 generate an artificially large % change due to the very small initial area. The built categories showed the greatest % change of all land cover types during the 1950–2008 study period with an increase of more than 2000% each.

3.1.1. Cross-tabulation analysis 1950–1982

Cross-tabulation for 1950–1982 (Table 2) was used to explain persistence, losses, and gains in land cover. In Table 2, columns display time 1 (1950) and rows display time 2 (1982). Persistence represents the amount of unchanged land cover between 1950 and 1982; this is highlighted in bold in diagonal, and values are presented in both ha, and % of initial (1950) area in parentheses. As for % change, persistence is often correlated with initial land cover, where extensive land covers tend to have greater persistence (Pontius et al., 2004). The sum of each column shows total area in 1950 for each land cover type. The sum of each row shows total area in 1982. The cross section of each column–row shows the area converted from one land cover to another between 1950 and 1982. For example, 337 ha were converted from forest to vineyard between 1950 and 1982; in terms of losses/gains, this therefore corresponds to a loss of 337 ha of forest to vineyard and, of course, a gain of 337 ha of vineyard from forest.

Forest had the greatest persistence (97.6%), and most of its loss was conversion to vineyard. Vineyard, on the other hand, had moderate persistence (67.5%), and its greatest loss was conversion to grassland. In this initial period (1950–1982), the dominant trends among the vegetated land covers are a conversion from vineyard to grassed areas (394 ha) and forest to vineyard (337 ha). This apparent compensation in vineyard loss is only

partial since there is also considerable loss of vineyard to forest (270 ha). Among the different land cover types, swapping is greatest for forest and vineyard. Although grassland gained in surface area, it had low persistence (47.7%) and greater susceptibility to change, showing high losses to both forest and vineyard as well as significant gains from these two land cover types, especially from vineyard (394 ha). The urban category reflects an 'end state' which cannot easily evolve into another land cover type, though suburban can evolve into urban. Both urban and suburban gained from all vegetated land cover types. The greatest gains in the built categories were from vineyard. Therefore, although all land cover types contributed to the growth of urban and suburban areas, the major trend was expansion of built area on vineyard.

Forest, vineyard, and grassland experienced the most significant gains and losses (Tables 1 and 2). Among these, vineyard underwent the greatest total change within the catchment, even though its initial surface area in 1950 was only about 12% that of forest (2457 ha vs. 20,267 ha). It also exhibited the highest rate of swapping, demonstrating extensive exchanges with other land cover types, especially forest and grassland. Of the five land cover types, vineyard was the most active, gaining and losing the most area and exchanging the most land with other land covers. Built areas had low total change, but especially very low swapping since these land covers gain from others but do not lose in exchange.

3.1.2. Cross-tabulation analysis 1982–2008

As can be seen in Table 3, trends during 1950–1982 continued in 1982–2008. Forest area decreased slightly but maintained high persistence (97.0%) due to its high surface area. A large area of vineyard continued to convert to grassland (457 ha), but during this period the compensating effect of forest to vineyard was weaker than in 1950–1982 (169 ha vs. 337 ha), and vineyard persistence decreased (61.5%). The conversion of forest to grassland was greater in 1982–2008 than in 1950–1982 (279 ha vs. 105 ha). As in 1950–1982, urban expansion occurred mainly at the expense of vineyard. However, during the latter period, suburban growth took place on forest cover before vineyard. Grassed area showed the lowest persistence (46.0%) as significant areas converted to forest and vineyard.

During 1982–2008, grassland surpassed vineyard in both total change and swapping, even though it still accounted for only 4.8% of the catchment in 2008 (Table 1). The significance of grassland dynamics will be discussed below. Total change in 1982–2008 was greater than in 1950–1982 for all categories except vineyard, though vineyard had the greatest net change (–2.4% of catchment area). This was particularly true of urban and suburban areas for which total change in 1982–2008 was more than double the values for

Table 3. Cross-tabulation of land cover in 1982 (columns) and in 2008 (rows). Values are in ha, persistence (diagonal) is also expressed in % of total area in initial year (1982).

	Forest	Vineyard	Grassland	Urban	Suburban	Total
Forest	19,636 (97.0)	215	240	0	0	20,091
Vineyard	179	1344 (61.5)	104	0	0	1617
Grassland	279	457	404 (46.0)	0	0	1140
Urban	51	105	63	140 (100.0)	27	387
Suburban	99	62	67	0	88 (76.4)	316
Total	20,233	2183	879	140	115	23,550

1950–1982. Overall, the 1982–2008 period experienced more land cover change than in 1950–1982 (16.5% of catchment compared to 14.5%).

3.1.3. Cross-tabulation analysis 1950–2008

Table 4 shows the results of almost 60 years (1950–2008) of land cover change in the catchment. Forest remained the dominant category by far and had high persistence (96.1%), but large areas of forest were converted to vineyard (358 ha) and grassland (247 ha). These losses were only partially compensated by gains from grassland (216 ha) and vineyard (39 ha). Vineyard is the land cover type that contributed most to all others, and more particularly to grassland (577 ha). The majority of urban and suburban expansion occurred on vineyard, though significant suburban growth was also at the cost of forest. Overall, three land cover types showed low persistence: vineyard (45.2%), grassland (39.7%), and suburban (40.9%), where the low persistence of suburban can be explained by its conversion to urban.

The greatest land cover change between 1950 and 2008 was experienced by vineyard which lost an equivalent of 3.5% of the catchment area or 34.2% of its initial area (or 840 ha out of an initial 2457 ha, Table 1) in the 58 year time frame. This, however, was not a simple loss in land but corresponds to a complex pattern of exchanges with other land cover types since vineyard has a swapping value of 4.3% (greatest swapping was for forest, 5.2%). Major swapping trends were a net gain in vineyard from forest of 319 ha and a net loss in vineyard to grassland of 431 ha, so grassland progressed significantly within this context of land cover swapping. Total and net change were smallest for urban and suburban land covers, but these values are high for land covers which had very low initial values (Table 1). Urban and suburban area increased by about more than 20 times in 1950–2008.

3.2. Spatial dynamics influencing land cover change

The spatial dynamics of land cover change will be investigated in two steps. In the first, land cover change maps will be used to highlight specific locations. In the second, the impact of spatial variables (altitude, slope, and distance from roads, streams, sea, and built area) will be presented. As described in the methods, urban and suburban are grouped together into a single ‘built’ category. Histograms showing total change will be described first, and then significant gains and losses will be detailed; however, histograms showing gains and losses are not included here due to the very large number of figures involved.

Table 4. Cross-tabulation of land cover 1950 (columns) and land cover 2008 (rows) (ha).

Land cover type	Forest	Vineyard	Grassland	Urban	Suburban	Total
Forest	19,477 (96.1)	39	216	0	0	20,091
Vineyard	358	1111 (45.2)	146	0	0	1617
Grassland	247	577	316 (39.7)	0	0	1140
Urban	69	228	64	19 (100)	8	387
Suburban	118	143	50	0	5 (40.9)	316
Total	20,267	2457	794	19	13	23,550

3.2.1. General spatial trends

Although the rates of change between 1950–1982 and 1982–2008 were different, spatial patterns for losses and gains were similar, so only the net 58 year (1950–2008) differences are shown here. Gains and losses for each land cover type are shown in Figure 2a–d; low altitudes are portrayed in white while higher values are in black to enable better visualization of gains and losses. Losses and gains in forest (Figure 2a) indicate that much of the lost land was in foothills in proximity to the alluvial plain (white patch in eastern part of catchment). Area lost was almost twice the area gained. Gains in forest occurred mainly in the south-eastern portion of the alluvial plain.

Whether in terms of percent of initial area (Table 1), absolute area (Table 1), or percent of catchment area, vineyard was the major loser of all land cover types. Lost area clearly outstrips gains and was concentrated almost entirely in the alluvial plain (Figure 2b). Only about half the land lost was compensated by gains elsewhere, and these tend to be found outside the eastern alluvial plain area, either in nearby foothills or on alluvial soil to the extreme SW of the catchment.

In terms of absolute area and percent of catchment (Table 1), grassland gained the most land, just ahead of urban areas. There is no strong spatial pattern to the gains and

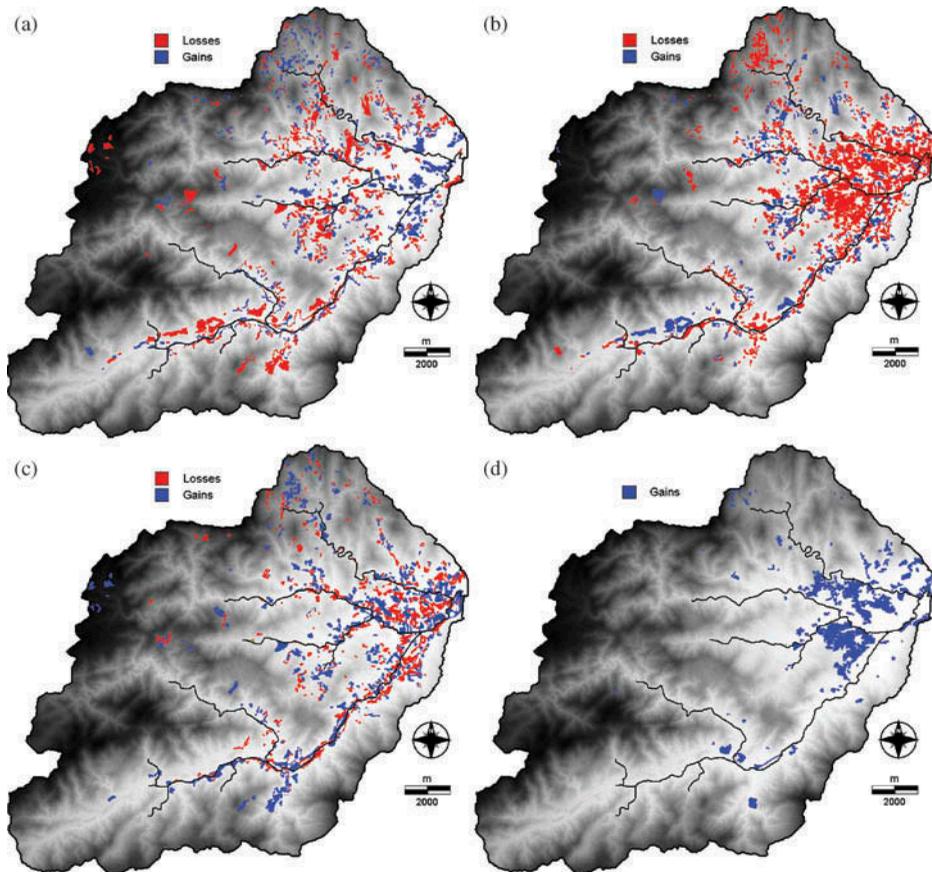


Figure 2. (a) Forest change in 1950–2008. (b) Vineyard change in 1950–2008. (c) Grassland change in 1950–2008. (d) Built area change in 1950–2008.

losses in grassland (Figure 2c) with gains and losses both occurring in the alluvial plain. There is a weak tendency for grassland losses to be absent from higher altitudes (Figure 2c).

The combined gains in urban and suburban covers outstrip individual gains and losses of all other land covers (Table 1). Built area expansion (Figure 2d) occurred almost exclusively in the alluvial plain, and much of it was in close proximity to the core city centers of Grimaud and especially Cogolin (Figure 1a–c).

3.2.2. Altitude

The impact of altitude on total change for each land cover type is shown in Figure 3a (1950–1982) and 3(b) (1982–2008), respectively, where it can be seen that total change in all land cover types decays exponentially with increasing altitude. The decrease in change with increasing altitude is the least pronounced for forest, for which about 30% of total change occurs in the 0–25 m range in both time periods. For the other land cover types, the 0–25 m range accounts for about 50% to 65% of total change according to the specific cover and time period. Grassland has the highest percentage of total change in the 0–25 m for both periods: 64.4% and 58.4% for 1950–1982 and 1982–2008, respectively.

The relationship between gains and losses in forest cover and altitude over time is complex. In both time periods, gains outstrip losses in the lowest altitude range (0–25 m); this corresponds to the overall increase in forest noted in Figure 2a in the SE portion of the alluvial plain. At greater altitudes, losses are greater than gains, and in intermediate altitudes (50–100 m), lost forest area tends to be greater in 1982–2008 than in 1950–1982. Unlike the other land cover types, losses in forest cover tend to increase slightly at the highest altitudes (greater than about 200 m). This loss tends to benefit grassland and then vineyard most.

Vineyard changes tend to be the opposite of forest trends noted above. For both time periods, the 0–25 m altitude experienced significant loss in vineyard cover. Although gains at greater altitudes (≥ 25 m) compensate a small part of the losses in vineyard in

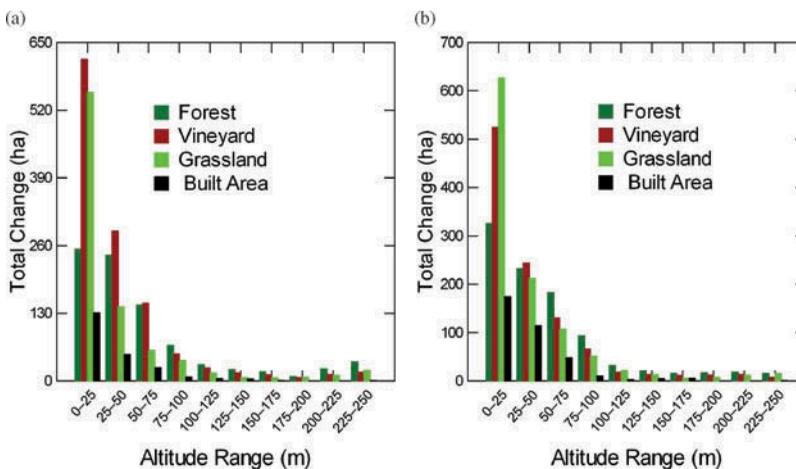


Figure 3. (a) Land cover changes in 1950–1982 with altitude (m). (b) Land cover changes in 1982–2008 with altitude (m).

1950–1982, this is no longer true in 1982–2008 where losses remain significantly greater than gains in the 25–50 m range.

Grassland gains and losses with altitude are quite different from both forest and vineyard. In 1950–1982, gains are slightly greater than losses for all altitude ranges. Although the trend remains the same in 1982–2008, the gap between gains and losses is greater. Finally, built area increases at all altitudes and more particularly in the lower range, as for the other land cover types. The 1982–2008/1950–1982 gain ratio is substantially greater in the intermediate altitude range (25–75 m) than in the 0–25 m range, indicating that higher altitudes were preferentially built in the later time period.

3.2.3. Slope

Slope and altitude are correlated in the catchment as higher altitudes tend to have steeper slopes. Changes in land cover as a function of slope (Figure 4a and b) are therefore similar to the trends with altitude, and only noteworthy differences will be highlighted here. Overall trends are sensitive to the choice of range and in this case, there is an intermediate range (5%–15%) where values in two categories (5%–10% and 10%–15%) remain constant (Figure 4a and b); there seem to be no significant exceptions to this trend. Roughly 30% of changes in forest occur on slopes less than 5%, and this value ranges from about 50%–60% for the other land covers. For slopes less than 10%, these values increase to about 50% (forest) and 60%–70% (others), respectively. Changes in land cover for the 0–25 m altitudes (Figure 3a and b) correspond closely to values for the 0%–5% slope range (Figure 4a and b). Unlike altitude, where forest cover loss increased at higher altitudes, there is no increase in land cover loss on steepest slopes. Thus, the loss experienced at higher altitudes probably corresponds to level ground or topslope convexities with low slope inclinations.

3.2.4. Distance from streams

Total change in the vegetation covers (forest, vineyard, and grassland) all decrease exponentially with distance from streams (Figure 5a and b). In the initial period (1950–

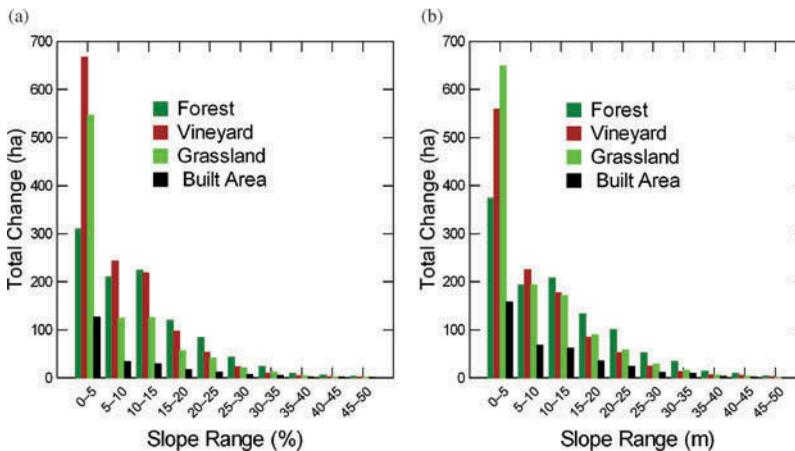


Figure 4. (a) Land cover changes in 1950–1982 with slope (%). (b) Land cover changes in 1982–2008 with slope (%).

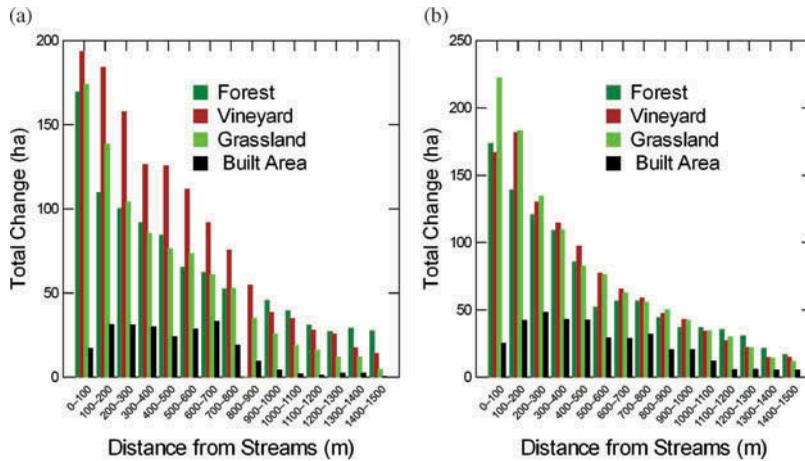


Figure 5. (a) Land cover changes in 1950–1982 with distance from stream. (b) Land cover changes in 1982–2008 with distance from stream.

1982), the greatest total change near streams concerns vineyards most, and this continues on into intermediate distances of up to about 900 m (Figure 5a). In the latter period (1982–2008), grassland experiences the greatest total change near streams, but there is little difference with vineyard or forest beyond about 100 m and 200 m, respectively (Figure 5b). The relationship between total change in built area and distance from stream (Figure 5a and b) is unlike any other so far: very little change close to the stream, moderate change at intermediate distances (roughly 100–800 m), and then little change again at greater distances.

In 1950–1982, forest gains more than twice the surface lost close to streams, but this trend is reversed in 1982–2008. For all other distances and in both periods, forest generally loses more land than it gains. In the initial period (1950–1982), lost land tends to peak at about 200–300 m from streams whereas it is greatest close to streams in 1982–2008 and decreases with distance. Vineyard loses more land than it gains at all times and distances, except for the 1950–1982 period when gains are slightly greater than losses at distances greater than about 800 m. At intermediate distances in 1950–1982 (100–400 m), the difference between losses and gains is progressively minimized by greater gains, but this no longer holds in the 1982–2008 period.

Gains and losses in grassland are the general opposite of those noted for forest, though the gains in grassland cannot be accounted for entirely by forest and significant areas of vineyard must have contributed to grassland growth close to streams. The greatest gains in grassland close to streams (<400 m) occur in 1982–2008. Before then, gains and losses are roughly equivalent except at intermediate distances (400–600 m) where gains are greater than losses. In the latter period (1982–2008), gains become greater than losses again at distances beyond about 1000 m.

Built area gains relatively little land immediately next to streams (<100 m). Gains in built area are then relatively stable between distances of 100–700 m and 100–800 m for 1950–1982 and 1982–2008, respectively. For almost all distances, gains in 1982–2008 were greater than in 1950–1982, with the exception of roughly equivalent values in the 500–700 m range.

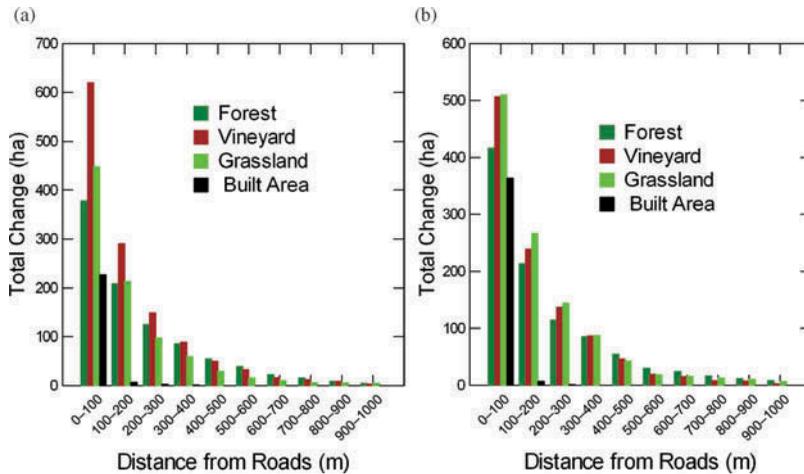


Figure 6. (a) Land cover changes in 1950–1982 with distance from road. (b) Land cover changes in 1982–2008 with distance from road.

3.2.5. Distance from roads

Total change in land cover with distance from roads (Figure 6a and b) follows the decaying exponential trend of most variables taken into consideration. Roughly 40%–50% of total change in forest, vineyard, and grassland occurred within 100 m of a road. This value was greater than 95% for built area. In 1950–1982, vineyard was most affected close to roads (0–100 m), but in 1982–2008, vineyard and grassland were approximately equal.

For both time periods and almost all distance ranges, loss in forest cover was greater than gains, and the greatest overall difference was in the 0–100 m range in 1982–2008. Vineyard trends are similar to forest but greatly exaggerated. Losses outweigh gains significantly close to roads (0–100 m), but differences are small beyond this distance. Grassland gains are greater than losses at all distances, though the land gained and lost decreases with distance from roads. Major gains are registered more particularly in the 0–100 m range for 1950–1982 and in the 100–300 m range for 1982–2008. Built area clearly distinguishes itself from the other land cover types since almost all of its gain occurs within 100 m of a main road.

3.2.6. Distance from built area

The relationship between total land cover change and distance from built area (Figure 7a and b) is strongly time dependent. In 1950–1982 (Figure 7a), there is little evolution in land cover change with distance from built area despite a tendency for the vegetation covers (forest, vineyard, grassland) to show greater change at intermediate distances (300–1300 m) and built area to change more close to earlier built area (0–100 m). In 1982–2008, the pattern is totally different (Figure 7b). For vineyard and grassland, total change first increases with distance from built area, peaks at about 100–200 m, and then decreases with further distance from built area. Total change in forest cover is roughly constant between 0 and 300 m before decreasing with greater distances. Built area change is greatest within 0–100 m, where more than 50% of total change takes place in 1982–2008. For comparison, the value for the other land cover types in this distance range is

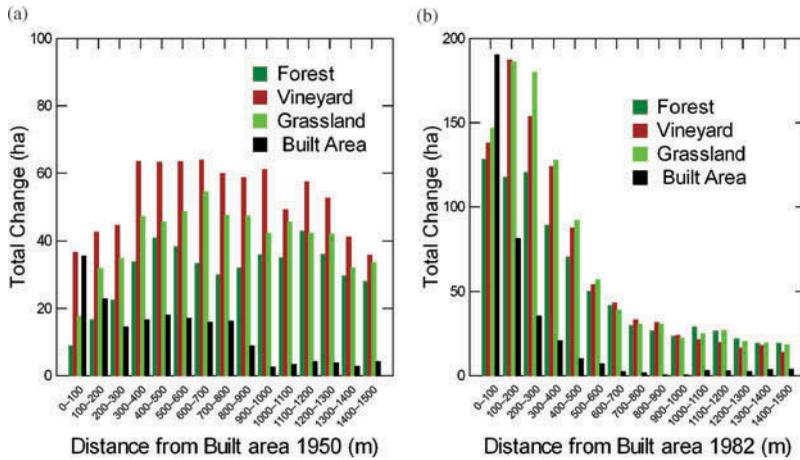


Figure 7. (a) Land cover changes in 1950–1982 with distance from built area 1950. (b) Land cover changes in 1982–2008 with distance from built area 1982.

approximately 15%. It should be noted that built area was limited to only 32 ha in 1950 and expanded to almost 270 ha in 1982 (Table 1); built area expansion was particularly important in the 1982–2008 period (Table 1).

Gains and losses in forest vary with time: in 1950–1982, gains and losses are relatively small and tend to occur far from built area. In 1982–2008, forest land is lost close to built area (within 200 m) and gained at intermediate distances (200–500 m). Vineyard clearly loses significant area near built area. The trend is particularly strong in 1982–2008 within about 300 m to 400 m from built area. In this range, losses are 3 to 10 times greater than gains. Although total changes are similar for vineyard and grassland (Figure 7b), the relationship with distance from built area is quite different: in grassland, losses and gains are better balanced in the estimation of total change. In the 0–100 m range, grassland experiences a net loss, but beyond this distance, grassland gains are generally greater than losses, even though losses can remain substantial, especially in the 100–400 m range. Where vineyard systematically lost area, grassland both lost and gained land. Built area expansion in 1982–2008 occurred close to former built area. Almost 75% of the land gained in 1982–2008 was located within 200 m of 1982 built land.

3.2.7. Distance from sea

Trends for changes in land cover with distance from the sea (Figure 8a and b) are distinct from all other patterns examined thus far. Before examining these, it should be noted that the catchment sea front is restricted to a narrow band near the outlet into the Gulf of St Tropez. Total change in vineyard, grassland, and built area covers tends to be greatest at about 3–5 km from the sea front in 1950–1982 (Figure 8a). This distance corresponds roughly to the center of the alluvial plain and is close to the city cores of Cogolin and Grimaud. Changes in forest cover peak at a greater distance (about 7–9 km) and this corresponds roughly to a secondary peak in change for vineyard and grassland. This distance is situated near the foothills peripheral to the alluvial plain. Finally, there appears to be a third smaller peak in change around 10–12 km and this corresponds roughly to the area near the town of La Môle in the western part of the catchment. Trends for 1982–2008

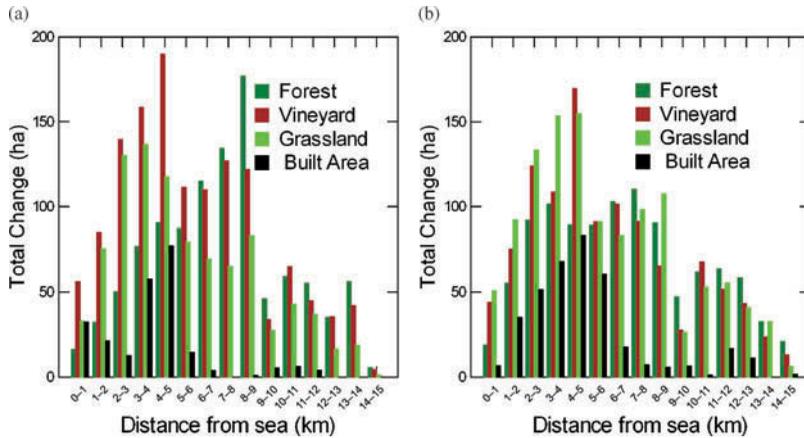


Figure 8. (a) Land cover changes in 1950–1982 with distance from sea. (b) Land cover changes in 1982–2008 with distance from sea.

(Figure 8b) are generally similar to 1950–1982 (Figure 8a), but changes in forest are concentrated within closer distances to the sea, vineyard changes are less great at intermediate distances (5–9 km), grassland peaks are greater at both near (3–5 km) and intermediate (7–9 km) distances, and built area changes are significantly greater in the 1–4 km range especially.

Forest gains and losses are sensitive to distance from the sea. Gains outweigh losses close to the sea (within about 2–3 km for both periods and 3–4 km for 1950–1982), but losses are generally greater beyond about 5 km. The greatest difference in gain–loss occurs at about 7–9 km. Vineyard losses and gains are strikingly simple. Losses outstrip gains at all distances up to 6 km, and gains outweigh losses at all distances beyond 6 km. Peak lost land is situated about 3–5 km from the sea, and the peak gained land occurs at a distance of around 6–9 km. Grassland trends are more complex and vary less systematically as a function of either time period or distance. Three approximate distance peaks can be identified. The first is in the 2–5 km range; here, grassland gains more land than it loses in 1950–1982, but the trend is reversed in 1982–2008. The second is in the 7–9 km range; gains are greater than losses for both time periods. The third is in the 10–13 km range where land gained is also greater than lost. Finally, the major peak in gained land for built area is about 3–5 km from the sea in 1950–1982 and 2–6 km in 1982–2008. For the initial 1950–1982 period, significant gains were made close to the seafront but these do not persist in 1982–2008. Finally, built area shows growth in the distant (11–13 km) range in the latter period.

4. Discussion

The results above detail land cover changes for the 235 km² Giscle catchment over two time periods and describe spatial patterns and topographic/distance variables influencing these changes. The spatial and temporal dimensions create a complex pattern of change that will be simplified in the discussion to highlight the major findings of the study. Before this, it should be noted that the topographic and distance variables are often correlated, but may have distinct impacts. Altitude and slope are correlated and both reflect a greater distance from the sea; in addition, slope influences building costs as it is

cheaper to build on flat land than steep slopes. Distance from the sea also reflects the impact of built area, as described in the results. The major cities of Ste Maxime and St Tropez are located on either side of the Gulf of St Tropez, so distance from the sea also represents distance from larger urban centers, seafront tourism, and major road and rail transportation networks. Behind all these variables are economic considerations that are impossible to isolate and quantify here.

Perhaps the most frequently cited land cover transition in Mediterranean regions in the scientific literature is the abandonment of agricultural practices on marginal land and its conversion to forest (Falcucci et al., 2007; Geri et al., 2010; Parcerisas et al., 2012; Pelorosso et al., 2009; Serra et al., 2008). This was not observed in this catchment. On the contrary, marginal lands on steeper slopes were converted from forest to vineyard, as can be seen in Figure 9 showing vineyard terraces on foothills above the alluvial plain. A forest fire in the catchment in 2003 (Fox, Berolo, Carrega, & Darboux, 2006) revealed extensive terracing on steep slopes, but marginal subsistence farming was probably abandoned in the region before 1950, as was the case elsewhere in Mediterranean France (Sluiter & de Jong, 2007). The Maures mountains ('Massif des Maures') are highly prone to forest fires and this clearly explains the prevalence of cork oak (*Quercus suber*) as the dominant tree species in the catchment. The thick bark of cork oak protects the heart of the tree from intense heat, and most trees survive even high severity fires. Exceptions are the very young or old trees, and trees which have recently been harvested for their cork bark. Pine (*Pinus pinaster*) trees, on the other hand, are systematically killed by high severity fires. With regard to vineyards, large areas in the plain were converted to grassland, built area, and some forest. This was compensated in part (but only partially since the net result is a 28% loss in vineyard cover between 1950 and 2008) by planting on steeper slopes in proximity to the plain. These fields therefore find themselves at the interface between the extensive forest on one side and the plain on the other. During the large fires of 2003, vineyards served as effective fire breaks; as forest fires penetrated into the vineyard, the lack of combustible vegetation extinguished the fire after the first few vine rows were burned or dried out.

A second common trend cited is the intensification of agriculture on plains (Falcucci et al., 2007; Geri et al., 2010; Van Eetvelde & Antrop, 2004). The term 'intensification' is ambiguous as it can imply either the clearing of land to plant crops or an increase in



Figure 9. Clearing and terracing of foothills for vineyard.

mechanization in crop production. The latter is true here; wine producers are more mechanized and most harvest grapes mechanically and no longer manually in the catchment, as has been the trend elsewhere in southern France (Sluiter & de Jong, 2007). However, the first interpretation of land clearing does not hold since vineyard experienced the greatest loss (−34.2% of initial cover, Table 1) in the alluvial plain of all land cover types. Much of this was to built area as urban centers expanded onto adjoining land. The tendency for cities to grow onto agricultural land is common throughout the world and the Mediterranean area (Serra et al., 2008; Sluiter & de Jong, 2007), but the conversion of vineyard to grassland in conjunction with urban expansion is less common (Falcucci et al., 2007; Serra et al., 2008). In this case, abandoned vineyard fields generally belonged to owners who did not produce their own wine but brought their grapes to a winemaking cooperative. Grape production was therefore not necessarily central to their livelihood as it is for the winemaking ‘domaines’. Furthermore, when land is passed on from one generation to the next, grape production can be abandoned but the land retained. Property values are known to increase in the region, so land represents a secure financial investment. This explains some of the conversion from vineyard to grassland and then forest, and it accounts for the paradoxical situation of agriculture conquering marginal lands on steep slopes while abandoning fertile land in the plain to grassland and forest.

The shift in agriculture from the alluvial plain to fields located on bedrock soils is probably specific to vineyard production since vines adapt better to cultivation on steeper slopes than most crops. In addition, steeper slopes with thin soils brought into cultivation are generally terraced, and soil depths are significantly improved by terracing. Upland slopes are dominated by schist and gneiss which tend to generate slightly acidic sandy soils. In an unpublished analysis of 24 soil samples from vineyards from both the plain and foothills, there was very little variation within the catchment in texture and pH. Clay contents were low for all samples (mean and median of 7.6% and 6.6%, respectively), coarse sand contents were high (mean and median of 45.3% and 48.4%, respectively), and pH values were all slightly acidic (mean and median of 6.6 and 6.7, respectively). Hence, soil attribute differences generated by different geological substrates were minor, and the French notion of ‘terroir’ in wine production can be considered preserved despite the move of some fields from the plain to the foothills. It is, however, probable that the alluvial plain soils benefit from better soil moisture conditions in the summer, but there are no data available to support this.

Grassland dynamics are particularly complex in the catchment. As discussed above, some of the growth in grassland is due to land abandonment in the fertile alluvial plain. However, several other factors come into play. One is the conversion of vineyard to grassland (mostly pasture) along stream channels and this is probably related to flooding risks (Figure 10) where lowland areas along stream channels experience regular flooding. This probably also accounts for the relatively low gains in built area close to stream channels. With time, abandoned vineyard evolves into grassland (or shrubland) first (Serra et al., 2008), then forest afterwards, accounting for grassland–forest transitions and the increase in forest area in the alluvial plain in 1982–2008 (Figure 2a). Although the reverse is intuitively unlikely, clearing of forest to create fire breaks was a priority after the 2003 fires that ravaged >4000 ha, and some fire breaks were present before then. Finally, some of the vineyard–grassland transition is related to the creation of horseback riding activities in recent years. Tourism is a major local industry and the proximity of large expanses of forest with paths and dirt roads makes horseback riding an attractive tourism activity. Cori (1999) explains that rapid growth of the tourism industry increased dramatically in the last few decades and influenced the land cover change on the northern shores of the



Figure 10. Flooding in vineyard close to stream channel.

Mediterranean. He reported that agricultural land decreased and nonagricultural land increased in the Spanish, French, and Italian Mediterranean regions due to the spread of touristic activities. And Nainggolan et al. (2012) found significant land cover change over 72% of their study area in a Mediterranean catchment due to biophysical and socio-economic factors, most of which were associated directly or indirectly with rapid urbanization and tourism. The combination of all these dynamics explains the high swapping of land between forest, vineyard, and grassland.

Built area increased substantially between 1950 and 2008. During the initial period, about 223 ha were added to the catchment in 32 years (7.0 ha y^{-1}); this value increased to 448 ha in 1982–2008 (17.2 ha y^{-1}). Other authors (Antrop, 2005; Salvati et al., 2013) have also found that urban sprawl accelerated in Euro-Mediterranean countries in the 1980s. Permanent population for the three main cities grew faster in 1982–2007 (about 296 pers. y^{-1}) than in 1962–1982 (about 229 pers. y^{-1}), but built area growth in the region probably depends as much on the nonpermanent population. Many new secondary homes were built during the past two decades (EAA Annual Report, 2010) near Mediterranean beaches to attract European and French populations (Blue Plan Papers, 2001). In addition, French and immigrated foreign retirees tend to settle in Mediterranean cities or use their coastal house as a secondary home. According to Cori (1999), half of total secondary homes in France are situated in the Mediterranean coastal area. Spatially, previously built area had a stronger impact on newly built area location in 1982–2008 than in 1950–2008, and urban expansion occurred almost exclusively within 100 m of roads and was concentrated mainly at low altitudes and on low to intermediate slopes. This agrees well with the findings of Schneider and Woodcock (2008) on the growth trends in 25 cities across the world in 1990–2000.

5. Conclusion

As in much of Mediterranean Europe, significant land cover changes occurred in 1950–2008. Forest remained the dominant land cover at all the times, and relative changes in forest cover were small for several reasons: its large surface (more than 85% of the catchment) and location at higher altitudes and on steeper slopes. Despite this, forest swapping with vineyard and grassland were high. Vineyard lost considerable area. It was

converted mainly into grassland, urban, and suburban land covers. Grassland was highly dynamic and experienced large losses and gains due to vineyard abandonment and the creation of fire breaks and pasture land. Grassland expanded mainly on abandoned vineyards. Most land cover changes occurred at lower altitudes and on flat to gently sloping areas in the eastern part of the catchment. All distance variables (from streams, roads, built area, and the sea) had significant impacts on land cover change dynamics.

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