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Progressive fragmentation of a traditional Mediterranean landscape by hazelnut plantations: The impact of CAP over time in the Langhe region (NW Italy)

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1 **Progressive fragmentation of a traditional Mediterranean landscape by hazelnut plantations:**
2 **the impact of CAP along time in the Langhe region (NW Italy)**

3

4 **Abstract**

5 Land use change is strongly modifying the traditional landscape of hilly productive Mediterranean
6 sites. An example of this situation is the *Langhe* region (Piemonte, NW Italy), where woody
7 plantations such as vineyards and orchards have been cultivated on hillslopes for centuries. In this
8 paper we assess the landscape changes occurred in the *Diano* study area (2651 ha) in the 1954-2000
9 period and we ascertain land use transition paths and rates in this rural ecosystem. Land use
10 mapping obtained from object-oriented analysis of aerial photographs was used to quantify land use
11 changes between 1954 and 2000. To examine the spatio-temporal patterns of land use change over
12 time, a set of spatial statistics that capture different dimensions of landscape change was identified.
13 An increase of landscape heterogeneity from 1954 to the present was observed due to the expansion
14 of orchards and the fragmentation of field crops. A significant portion (55%) of current orchards
15 surface is represented by former field crops, 24% by vineyards and 15% by forests. The strong
16 expansion of hazelnut orchards concurred to the fragmentation of the traditional rural landscape
17 dominated by vineyards, field crops and forests. Hazelnut orchards expansion was mainly located in
18 places where the cultivation of grapes was less remunerative. A further expansion of hazelnut in the
19 area should be planned, discussed and carefully monitored through change detection studies in order
20 to avoid potential unsustainable use of the land.

21 **Key words**

22 Historical aerial photograms; land use change; *Corylus avellana* L.; landscape metrics; spatial
23 pattern

24

25 **1. Introduction**

26 Rural landscapes in Mediterranean Europe have been managed and modified by people for
27 centuries. These human dominated landscapes experienced both intensification and extensification
28 of agricultural practices that are strong drivers of land use and land cover changes (Turner and
29 Gardner, 1990). In most productive sites agricultural activities (e.g. intensive cultivation and forest
30 logging) and urban sprawl increased (Stoate et al., 2001). In more marginal areas traditional rural
31 practices declined or ceased causing the abandonment of agricultural lands (Bonet, 2004; Sluiter
32 and de Jong, 2007) and favouring a subsequent reforestation process (Sitzia et al., 2010). Rural
33 European areas have recently undergone several important socio-economic changes that influenced
34 their landscape dynamics. From the beginning of the twentieth century urban areas development
35 increased to the detriment of rural ones (Antrop, 2004) causing a progressive abandonment of such
36 regions. In addition to the rural-urban migration phenomenon, between the second half of the
37 nineteenth century and the first decades of the following one, about 40 millions of European
38 workers moved to more industrialized countries (Hatton and Williamson, 1994). In the second half
39 of the twentieth century, as a consequence of post-war dynamics, a local growth of industrial
40 districts was observed (Fauri, 1996; Becattini and Coltorti, 2006). An opposite process was recently
41 observed in Europe, where a decrease in industrial employees was caused by global economical
42 changes such as the outstanding development of late-industrializing countries (Amsden, 1991) and
43 the restoration of some abandoned marginal rural areas (Pinto-Correia, 2000). The restoration of
44 rural areas was also favoured and often sustained by institutional financial support (Meeus et al.,
45 1990; Vos and Meekes, 1999).

46 Land use change drivers such as urbanization, globalization and population growth are translated by
47 policy-makers into land use regulations at regional, national or supra-national scale (Van Rompaey
48 et al., 2001), but environmental conditions such as vegetation, soil, topography and climate act as
49 local constraints for the landscape pattern. The establishment in Europe of a common agricultural
50 policy (EU-CAP) is thus considered a fundamental factor influencing rural landscape change
51 (Rabbinge and Van Latesteijn, 1992; Tanrivermis, 2003). Up to 1992 EU-CAP was a production-

52 oriented subsidy policy aimed to guarantee self-sufficiency in basic foodstuffs (Martinez-
53 Casanovas et al., 2010). Through the 1992 EU-CAP reform EU supported the farmers relative to
54 set-aside land on their farm (Van Rompaey et al., 2001). The EU-CAP reform in 2003 introduced
55 an agricultural policy that supported the long-term livelihood of rural areas focusing the attention on
56 conservation agriculture and sustainable farming (European Commission, 2004; Martinez-
57 Casanovas et al., 2010). The effects of the EU-CAP subsidies in Europe have been diverse
58 depending on local rural policies and due to the varied environmental conditions of the rural
59 landscape.

60 There are several methods and tools for land use change assessment or change detection. Among
61 them the analysis of historical geographical sources is a preferred tool to reconstruct traditional land
62 mosaic (McClure and Griffiths, 2002, Cullotta and Barbera, 2011). The most common historical
63 geographical data sources are aerial images (Schiefer and Gilbert, 2007) and cadastral maps
64 (Vuorela et al., 2002), but also old satellite images acquired for military purposes are used
65 (Scardozi, 2008). These geographical data sources can be employed separately or combined,
66 according to their availability for a certain study area. In change detection studies the adoption of
67 aerial images is preferred as they allow a direct interpretation of landscape elements, rather than
68 historical maps where land is represented by symbols (Morgan et al., 2010).

69 In this paper we study land use change in a hilly region of southern Piemonte (north-western Italy).
70 The choice of our study area is motivated by the following considerations: (i) the landscape is a
71 traditional complex mosaic of forests, vineyards, orchards and other cultivated fields; (ii) the land
72 use changes in the area are particularly strong; (iii) we had the opportunity to use the camera
73 calibration certificates to perform a rigorous photogrammetric processing of the historical images;
74 (iv) the entire *Langhe* region is famous for the quality of its wine and food and is candidate to be
75 included in the UNESCO World Heritage List.

76 The goals of our study are: (i) to quantify and analyze the landscape changes occurred in the area
77 between 1954 and 2000; (ii) to determine the location of land cover change and the type of change;

78 (iii) to determine transition paths and transition rates of the land use categories in this ecosystem.
79 Finally, the potential effects of European and local agricultural policies on the rural landscape of
80 *Langhe* region are discussed in relation to the sustainability of the modern farming systems.

81

82 **2. Materials and methods**

83

84 **2.1. Study area**

85 Land cover changes and landscape structure has been studied in a 2651 ha area (Fig. 1) located in
86 the southern part of Piemonte region, north-western Italy (44°40' N, 07°59' E). The elevation ranges
87 from 190 to 634 m a.s.l. and the climate belongs to type Cfa in areas lower than 500 m a.s.l., having
88 humid summer and dry winter seasons and to type Cfb with milder conditions at upper elevations,
89 in terms of Köppen-Geiger's classification (Peel et al., 2007). Annual precipitation ranges from 800
90 to 1100 mm with a main minimum in July and a secondary one in winter and with a peak in
91 autumn. Total annual rainfall averages 730.4 mm and mean annual temperature averages 11.9 °C
92 (Rodello climatic station, 415 m a.s.l.). Lithological substrate is made up of siltstone and marlstone
93 on hillsides and alluvial deposits in valley bottoms and soils are mainly represented by Entisols and
94 Inceptisols (ARPA, 2012).

95 The study area (*Diano*) is part of *Langhe* hilly region which is characterized by strong agricultural
96 character and is widely renowned for its high quality wine production like Barolo and Barbaresco
97 (Delmastro, 2005). The entire *Langhe* region is currently candidate to be included within the
98 UNESCO World Heritage List (UNESCO, 2012). The study site falls within the municipalities of
99 Diano d'Alba (52%), Alba, Grinzane Cavour, Serralunga d'Alba, Rodello, Benevello and
100 Montelupo Albese. We used the demographic data of Diano d'Alba and the agricultural statistics of
101 the entire Cuneo Province in order to describe the demographic trends experienced by the analyzed
102 land surface. The population density declined in the first part of the studied period (1951-1971)

103 from 2612 to 2216 respectively, but consistently increased in the last decades from 2216 in 1971 to
104 2980 in 2001.

105

106 **2.2. Image analysis**

107 Historical aerial photographs were retrieved in the archive of Italian National Research Council
108 (CNR-IRPI, Torino), where historical and recent aerial images concerning hydrogeological
109 phenomena are stored (IRPI, 2012). During the archive consultation a small block of four
110 photograms has been recovered. These aerial photographs belong to the Gruppo Aeronautico
111 Italiano (GAI) flight that represents the first available flight covering almost all Italian territory after
112 the Second World War. Older aerial images for Italian territory are available from the beginning of
113 the twentieth century. Both USAAF (Today USAF) and RAF employed images for
114 photointerpretation purposes in order to plan bombing or army raids (Kaye, 1957). These images
115 were also processed and merged with the aim of making three-dimensional terrain models of the
116 theatre of operations (Reed, 1946). On the other side Luftwaffe and Regia Aeronautica performed
117 several flights for intelligence purposes and to monitor Allied campaign in southern Italy (Ceraudo,
118 2005). GAI flight was carried out in 1954-55 with a flight height ranging from 10000 m a.s.l. in
119 mountain regions to 5000 m a.s.l. in the plains, and having a medium scale of 1:33000 (Campana
120 and Francovich, 2003; Acosta et al., 2005; Beni Culturali, 2011).

121 We had the extraordinary opportunity to find the camera calibration certificates of the investigated
122 flight at the Italian Military Geographic Institute (IGMI) historical archive allowing us to perform a
123 rigorous image orientation. Each photogram was scanned in TIF format to 600 dpi resolution, and
124 its orientation was obtained through the Automatic Aerial Triangulation approach (Mikhail et al.,
125 2001) and the employment of the above-mentioned certificates assuring an overall accuracy of 2.22
126 meters. The oriented images were then orthorectified and mosaicked at 1-m resolution. Because the
127 calibration certificates for GAI flight are usually rare, we assessed their role in the process by
128 computing a second orientation employing only the focal length value. Through a comparison of the

129 obtained residuals we observed a quality loss of an order of magnitude when the process is carried
130 out without calibration data (Table 1). The whole image processing was accomplished using Z-Map
131 software. A recent, RGB, orthoimage (Terraitaly - IT2000™, Blom C.G.R. S.p.A) having a nominal
132 scale of 1:10000 and a ground resolution of 1-m, was employed in the change detection analysis.

133

134 **2.3. Image classification**

135 Automated segmentation with eCognition (scale parameter = 100, shape factor = 0.5) with manual
136 correction was used to delineate polygons on the test area. The segmented images were on-screen
137 classified into six categories of land cover (Table 2). The two resulting maps (1954 and 2000) were
138 then enhanced in a GIS environment in order to reduce the effect of different input image quality
139 and achieve a minimum mapping unit (MMU) of 100 m². At the end of the above-mentioned phase
140 an additional topological check was performed by merging adjacent polygons of the same land
141 cover category (Fig. 2).

142

143 **2.4. Landscape analysis**

144 Landscape changes in the studied period (1954-2000) were assessed through change detection
145 approach and a comparison of landscape metrics over time. The change detection analysis on the
146 two land cover maps was performed by using the “Change detection” free extension in ArcView
147 environment (Chandrasekhar, 1999). This GIS extension allowed computing a transition matrix
148 reporting the transition between each pair of land cover categories as extent or proportion of area
149 per unit time.

150 To analyze changes in landscape pattern, we used Fragstats software (McGarigal and Marks, 1995)
151 to calculate several key landscape metrics for the studied period, applying an 8-cell neighbourhood
152 definition. We selected representative metrics for landscape configuration and composition,
153 including patch size and density, edge, contagion, connectivity, and diversity (Cushman et al.,
154 2008). Since many metrics are closely related at the landscape level and describe similar aspects of

155 landscape structure (Riitters et al., 1995; Cain et al., 1997; Neel et al., 2004), ten landscape-level
156 metrics were selected excluding those that were highly correlated ($r > 0.8$) (Tischendorf, 2001).
157 Landscape structure was also analyzed at the class level by computing 13 metrics for the
158 6 land cover classes, for the two time periods.

159

160 **3. Results**

161

162 **3.1. Landscape structure**

163 An accuracy assessment was performed on each land use map resulting in the K statistic (Landis
164 and Koch, 1977) ranging from 0.86 (90.2% overall accuracy) for the 1954 image to 0.87 (90%
165 overall accuracy) for the 2000 image. Our analyses on landscape structure showed that important
166 changes have been occurred at *Diano* study site during the 1954-2000 period. A general increase in
167 landscape heterogeneity from 1954 to the present was observed. The metrics computed for the
168 landscape as a whole (Table 3) showed an increase in patch density (PD) and a decrease of patch
169 area (AREA_MN, LPI). A reduction of shape complexity (Shape Index, Contiguity Index) was
170 confirmed by a reduction of Edge Density (ED). Patches aggregation (CONTAG) decreased and a
171 decline in the isolation of patches of the same category (ENN_MN) was also observed. Patch
172 richness (six categories) remained unchanged during the observed period, but diversity (Simpson's
173 Diversity Index) slightly increased.

174

175 **3.2. Landscape change**

176 The change detection approach highlighted remarkable changes in study area land use. 'Fields' and
177 'Orchards' land cover categories experienced the strongest variations (Fig. 3). The total surface of
178 'Orchards' increased of 24.6%, instead the 'Fields' category strongly (-26.9%) decreased. A slighter
179 increasing tendency (3.6%) was observed for the 'Urban' class too. A relatively little change was
180 observed for both the 'Forests' and 'Vineyard' categories that experienced an increase and a

181 reduction respectively. Based on transitions occurring in the period from 1954 to 2000 (Table 4),
182 five main transformations can be highlighted:

183 Fields → Orchards (375 ha), Fields → Vineyards (269 ha), Vineyards → Orchards (165 ha), Fields
184 → Forests (161 ha), Forests → Orchards (105 ha).

185 The establishment of new settlements took place at the expenses of fields, forests and vineyards
186 mainly. The noteworthy variation experienced by the ‘Orchards’ category pushed us to deepen our
187 analysis on class level transitions. Only 3% of the total surface of ‘Orchards’ category remained
188 unchanged, while 55% of them were former fields, 24% vineyards, 15% forests and 3% other
189 categories.

190

191 **4. Discussion**

192

193 **4.1 Landscape changes**

194 Land use change study requires careful approaches able to deal with the heterogeneity of the
195 involved tools (e.g. resolution) and the variability of the landscape processes (e.g. spatial and
196 temporal scale). Such an investigation should be carried out by employing trustworthy data sources
197 in order to correctly reconstruct historical landscape patterns (Burgi and Russell, 2001). For this
198 reason, we adopted a rigorous photogrammetric approach that involved camera calibration
199 certificate assuring accurate orthorectification results (Rocchini et al., 2012). In particular was
200 possible to obtain an orientation quality for the GAI flight images higher than those from previous
201 studies (Peroni et al., 2000; Gennaretti et al., 2011). The adopted image processing approach
202 together with the obtained high classification accuracy assured a reliable land use change analysis.
203 Among the six land use categories, ‘Orchards’ increased from 1954 to 2000, replacing mainly other
204 agricultural areas (‘Fields’ and ‘Vineyards’) and ‘Forests’. During the same period, ‘Fields’
205 drastically decreased and were replaced mainly by ‘Orchards’, ‘Vineyards’ and ‘Forests’. The
206 strong expansion of ‘Orchards’, together with the increase of ‘Urban’ areas (Chiabrando et al.,

207 2009, 2011) transformed a traditional landscape that was dominated by vineyards, crops and forests
208 in a more fragmented land mosaic represented by a higher evenness between the land use
209 categories. Moreover, a decrease of patch shape complexity was observed at landscape level
210 (Contiguity and Landscape Shape indices) and this was probably due to the regular boundaries of
211 the new hazelnut plantations. Particularly interesting is the overall dynamic of forests and vineyards
212 that remained almost constant in terms of total surface but experienced a substantial change. In the
213 case of forests, the natural reforestation process confined to the more marginal areas contrasted the
214 expansion of orchards. The reforestation pattern observed at *Diano* study sites is in agreement with
215 other Italian and European (Falcucci et al., 2007; Sitzia et al., 2010; Cocca et al. 2012) mountainous
216 and hilly areas, but the productive nature of the site greatly limited the trees encroachment. The
217 nonmarginal character of the investigated area is also witnessed by a remarkable increase of
218 inhabitants observed in the last decades. This trend is in contrast with many other sites in Italy and
219 other EU countries (Pinto-Correia, 1993; Peroni et al., 2000; Conti and Fagarazzi, 2004; Zomeni et
220 al., 2008). As opposite to forests, the vineyards expanded in the most accessible and productive
221 sites, thus limiting the orchards expansion too. However a reduction of vineyards surfaces in
222 marginal and less accessible sites in favour of orchards was observed and confirmed by other
223 studies in the Mediterranean region (e.g. Marull et al., 2010; Corti et al., 2011). On the contrary,
224 there are other Mediterranean-climate ecoregions where a strong expansion of vineyards was
225 favoured by wine market booming (Merenlender, 2000; Fairbanks et al. 2004) or agricultural
226 policies (Cots-Folch et al., 2006).

227

228 **4.2 Transition from vineyards to hazelnut orchards**

229 The land use category defined as ‘Orchards’ in the present paper was almost entirely represented by
230 hazelnut (*Corylus avellana* L.) orchards. A wider classification that included all the orchards was
231 used in this paper in order to reduce misclassification errors (Franco, 1997). The domestication of
232 hazelnut in Mediterranean areas probably started during the Greeks and Romans periods (Trotter,

233 1921; Boccacci and Botta, 2009), but became important for the *Langhe* region at the end of 1800
234 (Comunità Montana Alta Langa, 2009). At that time the appearance of downy mildew (*Plasmopara*
235 *viticola* [Berk. & Curt] Berl. & de Toni), of grape phylloxera (*Daktulosphaira vitifoliae* Fitch) and
236 other grapevine parasites increased the uncertainty of winemakers that started to cultivate the
237 hazelnut (Valentini and Me, 2002). A similar dynamic has been observed also in the metropolitan
238 region of Barcelona, Spain (Marull et al., 2010). During the Second World War the hazelnut oil was
239 used as a surrogate for olive oil, but only in the late 80s its cultivation became really important and
240 expanded in Piedmont region. The hazelnut cultivated surface increased by 20% in the last decade
241 of the study period, and the highest increment peak was observed during the 1990 – 1995 period
242 (Valentini and Me, 2002). Moreover, during the 1981 – 2000 period the surface expansion triggered
243 an increase of hazelnut production from 9.171 tons to 11.959 tons and of its price from 1.66 €/Kg to
244 1.96 €/Kg. A shift of vineyard cultivation toward hazelnut is detectable from the historical statistics
245 on cultivated surfaces of the Cuneo province (ISTAT 1971-2001). In a twenty year time span (1980
246 - 2000) hazelnut orchards have nearly doubled their surfaces, while vineyards have shown a
247 remarkable decrease (Fig. 4). These historical statistics confirmed the results observed at *Diano* site
248 through change detection analysis.

249

250 **4.3 Agricultural policies concerning hazelnut cultivation**

251 The strong increase of hazelnut surfaces occurred in Piedmont at the beginning of the 90s, reflected
252 an increasing interest of landowners towards hazelnut and its economical potential (Valentini and
253 Me, 2002). Even if we did not directly measure the effects of local and European agricultural
254 policies on the hazelnut cultivation, it is interesting to mention those events that influenced its
255 diffusion in Piedmont region. The European Union supported young farmers through a regulation
256 devoted to improve the efficiency of agricultural structures (EC 2328/91) and encouraged the
257 adoption of agronomic practices with a positive impact on the environment, through the agri-
258 environment regulation (EU 2078/92). Probably the most important policy measure regarding

259 hazelnut in Piedmont is a decree of the Italian Ministry of Agricultural and Forestry Policies (DM n.
260 2/12/93) that recognized its Protected Geographical Indication (PGI) under the appellation
261 “Nocciola Piemonte”. In 1996 the European Union registered the “Piedmont hazelnut” as a
262 Protected Geographical Indication (PGI) through a regulation on the registration of geographical
263 indications and designations of origin (EC 1107/96). The two latter regulations supported and
264 acknowledged the quality of the hazelnut fruit, but other measures favoured the hazelnut expansion
265 too. A direct Community aid to farmers producing hazelnuts was granted since the 2003 (EC
266 1782/03) and more recently (2007) the hazelnut variety cultivated in the *Langhe* region was
267 registered within the Community Plant Variety Office (CPVO) with a new name (“Tonda gentile
268 Trilobata”) for a more efficient preservation. All these European regulations were locally
269 acknowledged by the PSR 2007-2013 (Action 214) rural development plan (Regione Piemonte,
270 2009). The success of hazelnut orchard in the *Langhe* region was favoured by the increasing
271 demand for quality products related to the sweet factory market (Garrone and Vacchetti, 1994;
272 Cova and Pace, 2006) that together with the EU food-labelling (PGI) policy facilitated the
273 “Nocciola Piemonte” to survive against stronger producer countries such as Turkey (Reis and
274 Yomralioglu, 2006). In fact, according to FAO database (FAOSTAT, 2010), hazelnut plantations in
275 Turkey increased their surface by 40% during the 1961 – 2000 time span. A smaller increase (23%)
276 of hazelnut surface in Italy and a stable situation in Spain have been observed in the same period.

277

278 **4.4 Management issue**

279 Hazelnut cultivation in the *Langhe* region expanded at the expenses of other orchards, fallow lands,
280 grasslands and generally in places where the cultivation of grapes was less remunerative (Valentini
281 and Me, 2002). Particularly important is the decline of crops in hilly regions such as *Langhe* that
282 resulted less productive than those located in flat areas (Comunità Montana Alta Langa 2009). The
283 rapid expansion of hazelnut plantations is radically transforming the rural landscape of *Langhe*
284 region and its further expansion could result in a use of not suitable areas for its cultivation. This

285 phenomenon has been recently observed in Turkey, where the hazelnut production exceeds the
286 demand mainly due to a lack in land use policy (Reis and Yomralioglu, 2006; Aydinoglu, 2010).
287 Medium-term consequence for this may include the abandonment of no more profitable hazelnut
288 orchards and consequent land degradation. These potential problems could be averted if the
289 effective quality of *Langhe* hazelnut production will continue to be achieved and adequately
290 protected. This paper highlights the potential of change detection investigations as a support for
291 national and international bodies in evaluating rural policies for valuable agriculture (London
292 Economics, 2008) and their effects on landscape, production and society (Westhoek et al., 2006;
293 Martinez-Casasnovas et al., 2010; Van Berkel and Verburg, 2011). Future researches should extend
294 the study area to give an accurate estimation of rural landscape dynamics filling the research gap
295 regarding remote detection of hazelnut cultivations expansion in the Mediterranean area (Franco,
296 1997; Reis and Yomralioglu, 2006). Moreover, socio-economic factors should be integrated in the
297 analysis of the drivers of land use change in order to achieve a more coherent and complete study of
298 the process under study (e.g. De Aranzabal et al., 2008; Tzanopoulos et al., in press).

299

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Tables

Table 1 Comparison of root mean square errors obtained through the orthorectification of the 1954 aerial photographs with calibration certificate or with focal length only.

	<i>ResX</i>	<i>ResY</i>	<i>ResZ</i>	<i> ResX </i>	<i> ResY </i>	<i> ResZ </i>
	(<i>m</i>)	(<i>m</i>)	(<i>m</i>)	(<i>m</i>)	(<i>m</i>)	(<i>m</i>)
Calibration certificate						
<i>Mean</i>	-0.11	-0.95	-1.29	2.45	1.80	1.51
<i>RMS</i>	3.12	2.07	1.48	1.65	1.25	1.22
Focal length						
<i>Mean</i>	1.36	4.27	14.86	8.42	16.73	18.78
<i>RMS</i>	13.51	19.95	15.86	10.10	9.63	9.88

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330

331 Table 2 Description of the land use/land cover (LUCL) categories adopted in the aerial images

332 classification at *Diano* site.

333

LULC class	Abbreviation	Description
Forests	FO	Forest patches or single trees, excluding arboriculture plantations
Fields	FI	Cultivated or uncultivated grasslands and polygons not univocally identified
Vineyards	VI	Surfaces cultivated with vine
Urban	UR	Human infrastructures and buildings
Orchards	OR	Arboriculture and hazelnut orchards
Waters	WA	Water bodies (lakes and rivers)

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350 Table 3 Metrics on landscape level (McGarigal and Marks 1995) computed for the *Diano* study site

351 at two periods (1954-2000 land use maps).

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Metrics (abbreviation)	Component measured	Units	Land Use maps (2651.59 ha)	
			1954	2000
Patch Density (PD)	Density	n/100 ha	213.26	344.86
Patch Area Mean (AREA_MN)	Area	ha	0.47	0.29
Largest Patch Index (LPI)	Area	%	4.25	3.68
Edge Density (ED)	Edge	m/ha	486.95	411.43
Landscape Shape Index (LSI)	Edge	-	63.78	54.05
Shape Index Mean (SHAPE_MN)	Shape	-	1.99	1.52
Contiguity Index Mean (CONTIG_MN)	Shape	-	0.66	0.41
Euclidean N.N. Distance (ENN_MN)	Isolation	m	7.06	4.39
Contagion Index (CONTAG)	Contagion	%	60.08	53.55
Simpson's Diversity Index (SIDI)	Diversity	-	0.69	0.77

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361 Table 4 Transition matrix showing land cover changes (ha) from 1954 to 2000. Values are
 362 expressed in hectares and in percent (in parentheses) relative to the total area of the class in 1954.
 363

Land uses in 1954	Land uses in 2000						Total area (ha)
	Forests	Fields	Vineyards	Urban	Orchards	Water	
Forests	388.21 (60%)	58.77 (9%)	56.07 (9%)	41.93 (6%)	105.17 (16%)	0.89 (<1%)	651.04 (25%)
Fields	160.81 (15%)	221.19 (20%)	268.69 (24%)	72.50 (7%)	375.24 (34%)	0.77 (<1%)	1099.20 (41%)
Vineyards	78.69 (11%)	83.34 (11%)	370.93 (50%)	36.59 (5%)	165.09 (22%)	0.18 (<1%)	734.82 (28%)
Urban	12.16 (11%)	19.03 (17%)	13.85 (12%)	54.62 (48%)	14.19 (12%)	0.16 (<1%)	114.00 (4%)
Orchards	6.16 (18%)	1.25 (4%)	3.66 (10%)	1.56 (4%)	22.31 (64%)	0.00 (<1%)	34.92 (1%)
Water	7.20 (41%)	2.97 (17%)	0.05 (<1%)	1.74 (10%)	4.16 (24%)	1.49 (8%)	17.60 (1%)
Total area (ha)	653.23 (25%)	386.54 (15%)	713.23 (27%)	208.93 (8%)	686.16 (26%)	3.49 (<1%)	2651.59 (100%)

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370 Table 5 Total land surface area occupied by hazelnut orchards in Italy. Data are given as a whole
 371 and divided by region (ISTAT, 2012). Statistical records are also reported for Turkey (Turkish
 372 Statistical Institute, 2009).

Italian Regions	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Data source
Piemonte	8042	8042	8042	8043	9211	9519	9718	10531	11671	12366	12388	12142	12133	ISTAT

Campania	24805	24841	25417	25064	23496	22872	22831	22834	22828	22819	22849	12616	22787	ISTAT
Lazio	18930	18878	18949	18999	19033	18996	18974	18985	18929	18914	18968	18969	19008	ISTAT
Sicilia	15878	15730	15368	15368	15431	15146	15090	15080	16482	14930	16075	14350	14740	ISTAT
Others	2140	2134	2058	2071	2094	2080	2244	2245	2394	2011	1749	1521	1814	ISTAT
Italy	69795	69625	69834	69545	69265	68613	68857	69675	72304	71040	72029	59598	70482	ISTAT
Turkey	530700	549500	550000	560000	600000	621200	621200	621200	621200	621200	-	-	-	TSI

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381 **Figure captions**

382 Figure 1 Location of the 2651 ha study area (white dot) within Piedmont region (upper image) and
383 its topography (lower image) with main rivers and settlements.

384 Figure 2 Land use classifications of 1954 (upper map) and 2000 (lower map) orthoimages.

385 Figure 3 Land uses expressed as proportion of the total study site surface in 1954 (black bars) and
386 2000 (grey bars) at *Diano* site.

387 Figure 4 Agricultural statistics of Cuneo (Piedmont, Italy) province in the 1971-2001 period.

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