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Land cover and land use change in the Italian central Apennines: A comparison of assessment methods

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A B S T R A C T

Analyses of land-use cover changes (LUCC) are fundamental to the understanding of numerous social, economical and environmental problems and can be carried out rapidly, using either cartographic or census data. However, the trends of the two methods differ in direction and quantity.
For this study, a historical and a recent remote sensing-derived map were homogenized to reduce misleading changes and to assess spatial aggregation errors. This was carried out by means of a data integration procedure based on landscape metrics, allowing cartographic and census trends to be compared. Discrepancies between data were thus highlighted, both in absolute surface value and in evolution.
The methodology presented, and the results obtained, could be employed to evaluate and improve LUCC analyses aimed at assessing landscape identity, both in the case of analyses based only on LU census data, or of those based only on LC cartographic data. This could lead to benefits for both biodiversity conservation and environmental planning on a large scale.

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Introduction

Land-use and -cover change (LUCC) are among the most important alterations of the Earth's land surface (Lambin et al., 2001). Moreover, since the Second World War, LUCC and landscape transformation processes have accelerated (Antrop, 2005; Ewert, Rounsevell, Reginster, Metzger, & Leemans, 2005). Consequently, understanding and predicting the causes, processes and consequences of LUCC has become a major challenge to anyone involved in landscape ecology, regional land-use (LU) planning, biodiversity conservation (Etter, McAlpine, Pullar, & Possingham 2006), or protecting water resources from non-point pollution (Ripa, Leone, Garnier, & Lo Porto, 2006).

Accurate methods of LUCC assessment have been developed, and are currently used, by the scientific community. In contrast, governance agencies and local administrations responsible for the planning of territories often rely on LU and land-cover (LC) information without understanding its inherent characteristics. As a result, they are not aware of its suitability, or of its limitations, for the analysis of territorial dynamics. LU and LC are not identical. A knowledge of LC does not necessarily define LU. The LU function of an LC type needs to be known in order to understand changes in LC (Lambin & Geist, 2001).

Abbreviations: LC, land cover; CLC, CORINE land cover; LU, land use; LUCC, land-use cover change; LUM 2000, Land-Use Map of 2000; GAC, general agricultural census; TCI/CNR, Land-Use Map of 1960; FSY, forest statistics yearbooks; ISTAT, Italian National Statistics Institute; SAU, area used for agriculture; I.N.F.C., National Forest and Carbon Reserve Inventory.

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There are many definitions of LU (Jansen, 2006) and LC. For this paper, LC is defined as "the observed (bio) physical cover on the earth's surface" (Di Gregorio & Jansen, 2000); while LU refers to the manner in which people use these biophysical assets (Cihlar & Jansen, 2001).

Among the many concerns about global environmental change today, there is an increasing awareness of the importance of issues involved in LU and its changes over time, since LU is a key descriptor of human influence. The fundamental problem in mapping LU is that it does not typically leave a distinct signature that can be discerned without a site investigation, possibly including socio-economic and cultural surveys. As site visits are not feasible, except for limited research and field-checking purposes, the production of LU maps for large areas (i.e., $>10^3$ km^2) can only be achieved using other means. The primary (and often only) generally available sub-national LU data are collected through census statistics, and do not show the spatial distribution of LC within the administrative unit (Cihlar & Jansen, 2001).

Nevertheless, because LC maps are more diffuse and easier to prepare, LC information is a key dataset for many LUCC research projects and LU planning (Cihlar & Jansen, 2001) and studies (e.g., Cousins, 2001; Falcucci, Maiorano, & Boitani, 2007; Hietel, Waldhardt, & Otte, 2004; Lasanta-Martìnez, Vicente-Serrano, & Cuadrat-Prats, 2005; Petit & Lambin, 2002; Schneider & Pontius, 2001; Vasconcelos, Mussá Biai, Araújo, & Diniz, 2002). These studies combine different data, such as historical LC maps or remote-sensing derived maps (generally from aerial photographs or satellite images), to analyze LC change in a spatially explicit way, with the support of a Geographic Information System (GIS).

Where LC maps and/or GIS support are not readily available, territories are frequently interpreted using census data, due to its greater ease of access and immediacy. However, the results of such studies are not entirely satisfactory, as cartographic information derived from remote sensing is discordant, i.e., the census and cartographic surfaces do not match. As a result, the dynamics of evolution are also not clear.

To illustrate this, let us consider a specific case of remote-sensing data versus census data. A comparison of LC, as observed in CORINE CLC2000 and CLC1990 (APAT, 2005), shows that at a national level in Italy, there was a general increase in wooded areas (Code CLC 3.1) of 1.07%, and a decrease in areas of natural pastures and meadows (Code CLC 3.2.1.) of 2.07%. In contrast, the Italian National Statistics Institute (ISTAT) data indicate that, on a national level, there was a notable decrease in wooded areas (−16.9%) and meadowland (−17.2%), in the period 1990–2000. The discrepancy with cartographic data is evident.

This discrepancy is due to the aim and methodology of production of the two sets of data. The woodland transition dynamics reported above can be explained by the abandonment of the weakest agroforestry farms (Di Gennaro, Innamorato, & Capone, 2005). As the latter were no longer included in the ISTAT census, they determined a decrease in the area declared as wooded. On the other hand, the forest recovery can be explained by the abandonment of the less productive fields and pastures in places with decreasing populations, such as mountainous regions (Falcucci et al., 2007; Rudel et al., 2005). This took place over a period of about 30–50 years (Pignatti, 1998; Rocchini, Perry, Salerno, Maccherini, & Chiarucci, 2006). Although LC can generally be said to be a consequence of LU, when LU modifications generate relatively modest changes in LC (i.e., if the change is not large enough to cause a shift from one cover type to another), then comparing and linking the two sets of data becomes complicated (Cihlar & Jansen, 2001). This is due to the difficulty in defining the real use, type and intensity of management of the LC by remote sensing methods. For example, in a largely irrigated territory, diffused or isolated crops may not be irrigated. Grassland and open areas may or may not be used as pasture, or may have been used as crops for a large part of the year and used as pasture for the remaining time. Therefore, besides the quality of the sensor, also the period of the year in which the images were collected can influence the resulting land classification. Site visits may be necessary to discriminate some LUs (e.g., to identify irrigation channels and the presence of irrigation equipment, or to verify the presence of animal grazing).

Some authors have discussed the relationships between LC and LU and proposed a methodology to derive LU maps from LC maps (Cihlar & Jansen, 2001). However, as a result of pressure to achieve immediate results simply, analyses of change continue to be performed based on census data or non-homogeneous LC maps. Consequently, erroneous conclusions are drawn and inappropriate decisions are made, which are ineffective and open to criticism. To improve LUCC analyses based only on LU census data, or those based only on LC cartographic data, it is necessary to highlight these misleading results.

Comparing two different sets of data requires that they should be as homogeneous as possible. Since census data cannot be improved, given that it was collected in the past by means of a questionnaire and is not characterized by spatial distribution, the only option is to improve the homogenization of LC maps.

In order to detect long-term changes, all the available information is needed. However, since the type of data varies greatly, this poses a series of problems. For example, aerial photographs and satellite images may not have the same spatial and spectral resolutions, and thus may not yield the same level of detail in LC classification. Furthermore, the LC information displayed on certain old topographic maps is even more difficult to integrate with LC maps derived from remote sensing. Indeed, the geometric and thematic characteristics of historical maps are not always perfectly known (Petit & Lambin, 2001). Moreover, historical maps may have been derived from a cartographic generalization whose primary aim was to convey a clearly readable image that is esthetically pleasing. Thus, the formation and displacement of "placeholder" objects (e.g., a building representing a group of buildings) are tolerated (Weibel & Jones, 1998). In short, the detection of LC change between such different data is contaminated by imprecision and inconsistency.

In order to reduce these problems, a map (or database) generalization is commonly realized. This consists in a process of informed extraction, emphasizing the essential while suppressing the unimportant, in which logical and unambiguous relations between map objects are maintained. At the same time, the accuracy and legibility of the map image are preserved as far as possible (Weibel & Jones, 1998).

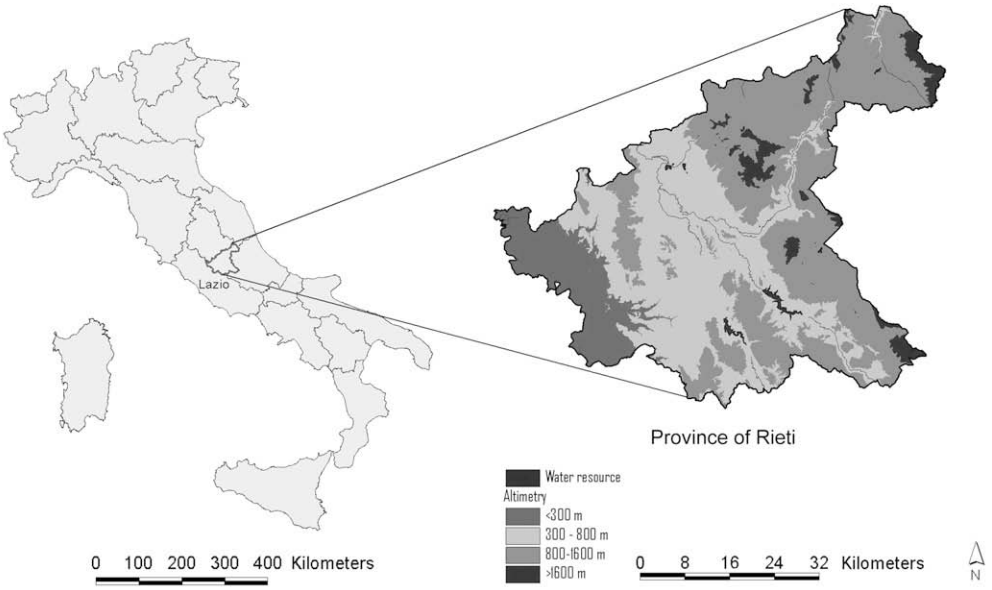

Fig. 1. Map of the study area showing average height a.s.l.

In this study, an analysis and assessment of the available maps was carried out on a regional level. Subsequently, a homogenization of historical and remote-sensing derived LC maps was performed and various LC and census data trends were compared. The results allowed the different dynamics of a wide area in central Italy to be identified, bringing to light divergences between the trends suggested by census and cartographic data, in a context where there has been a high level of land abandonment. Of more general interest, the results and the methodology could clearly serve as useful guidelines for the analysis of LUCC over wide areas, from the middle of the twentieth century to the present day, thus providing essential input for many planning processes.

Materials

Study area

The area selected for this study was the Rieti Province (Lazio Region, central Italy, Fig. 1), which covers an area of about 275,000 ha in a prevalently mountainous zone of the Apennines. The orography is very diversified and complex and includes hill systems, river ramparts, intra- and inter-mountain basins, and thick layers of debris. The altitude of the study area ranges between 11 and 2454 m a.s.l., with an average of 336 m a.s.l. The only areas in which irrigated agricultural practices occur are the flat zones beside the River Tiber and the Rieti plain. Pasture, particularly of sheep, has a considerable importance in the Rieti landscape. The orographic characteristics, the social and economical factors of development (a 17.7% decline in population over the last 50 years) and the ageing of the farmers (56.4% over 60 years old—source ISTAT 2000) have determined a strong decline in the agricultural sector. In 2002, it contributed only 4.9% of the Provincial Gross Domestic Product (GDP) compared to 41.7% in 1951 (Istituto Guglielmo Tagliacarne, 2003). According to the census, the population of the Province of Rieti fell by 29% between 1951 and 2001; this trend was particularly marked in the smallest towns and villages, rather than the provincial capital or larger towns (Table 1).

The following data were analyzed:

a) Census data: the General Agricultural Census (GAC) and the Forest Statistics Yearbooks (FSY), i.e., the two typologies of Italian census available from 1961 onwards (ISTAT, several years a, several years b).

Table 1
Variation in population between 1951 and 2001.

	Years			61/01		51/01	
	1951	1961	2001	Variation	Var.%	Variation	Var.%
Province of Rieti	179,157	162,405	147,410	−14,995	−9.2	−31,747	−17.7
Rieti (Capital of Province)	33,241	35,441	43,785	8344	23.5	10,544	31.7
Fara Sabina	6203	6838	10,801	3963	58.0	4598	74.1
Cittaducale	5301	4887	6542	1655	33.9	1241	23.4
Other communities	145,916	126,964	103,625	−23,339	−18.4	−42,291	−29.0

b) The National Forest and Carbon Reserve Inventory (I.N.F.C.), i.e., a survey carried out to discover the entity and quality of forest resources (currently not completely published).
c) The Lazio region LU Map (LUM 2000), produced by the Lazio Region in 2000.
d) The 1960 LU Map of Italy (TCI/CNR) produced by the Center for Studies in Economic Geography of the National Research Council and the Italian Touring Club.

Census data

The LU census data referred to in this paper were collected by the GAC for the years 1961, 1970, 1982, 1990 and 2000, and the FSY, for the years 1961, 1970, 1982, and 1990. The first GAC of 1961, reports only Total Agricultural Surface, number of farms, meadowland, wheat and grapevines; therefore, for other uses it was only possible to start the transition analysis from 1970 onwards.

The GAC data refer to agroforestry farms active in the territory. The FSY, on the other hand, were produced to quantify forest areas, and therefore take into account land belonging to public agencies and to mountain communities, as well as those of private agroforestry farms. The data regarding forest areas included in the FSYs are therefore more reliable than those reported in the GAC, while the data regarding areas reported as used for agricultural crops are more reliable in the latter.

A further source of information contributing to the evaluation of land use was the National Forest and Carbon Reserve Inventory (I.N.F.C.), a survey carried out in Italy to discover the entity and quality of forest resources by means of the census and classification of trees and forests. The I.N.F.C. uses a CORINE LC classification system, and definitions standardized by the FAO and Forest Resources Assessment of the year 2000 (FRA2000). Land-cover data was obtained using photo-interpretation of digital orthophotographs, following an evaluation method elaborated in close collaboration with the Italian State Forest Police and the Forest and Range Management Research Institute (I.S.A.F.A.) and the ISTAT. To date, a complete I.N.F.C. survey has not yet been published, but the initial results on a national and regional scale are available on Internet (INFC, 2007).

Map data

In common technical language, Italian maps are often named maps of LU, but considering the concepts defined above they should, in fact, be intended as maps of LC. However, in this paper, in order not to create confusion, the original denomination of the maps has been maintained. Table 2 shows the main characteristics of the available regional level LC maps. The so-called LU Map of Italy (TCI/CNR map) was used to show the 1960 LC types, while the so-called Lazio region LU Map (LUM 2000) was used to show the 2000 LC types.

The CLC 2000 map, although used in other studies to detect changes compared to the 1960 TCI/CNR map (Falcucci et al., 2007), does not include irrigated crops and vineyards. These crops are currently present in the province and are plotted on the TCI/CNR map. The CLC2000 map fails to detect these LCs, as a result of the methodology used in its production and its level of detail. For this reason it was excluded from the present study.

The 1960 TCI/CNR map was the first document on LC produced on a national scale using information deriving from cartographic survey methods and site visits. The initial information was generally mapped on a scale of 1:2000 or 1:1000–1:500 for highly fractionated land. It was then reported, through operations of cartographic generalization (Petit & Lambin, 2001; Weibel & Jones, 1998) performed by the Cadastral Administration, the Italian Touring Club (TCI) and the National Research Council (CNR), on an existent cartographic basis (Road map), on a scale of 1:200,000. The minimum map unit was fixed as 4 mm×4 mm, corresponding to 64 ha. The first TCI/CNR sheet map was produced in the early months of 1952, and work was completed in the 1960 s, with the publication of all 26 sheets. Each sheet, before its publication, was properly tested by means of site visits (Pelorosso, 2008; Vitelli, 2007). Thus, the TCI/CNR map allows an analysis of LUCC over a sufficiently

Table 2
Land-cover maps available and main characteristics.

Map	Metadata and year of reference	Scale and detail	Source
Land-Use Map of Italy (TCI/CNR)	Cartographic data 1960	Scale 1:200,000 Key 21 items (+6 sub-items for nut or pod orchard and industrial cultivation)	Center for Studies in Economic Geography of the National Research Council/Italian Touring Club
CORINE Land-Cover 1996, third level	Landsat 5 images 1988–1993	Minimum unit interpreted 25 ha—scale 1:100,000 Key 44 items	Lazio Regional Environmental Information System (S.I.R.A.)
CORINE Land-Cover CLC1990, third level (reviewed interpreting the Landsat 5 images again)	Landsat 5 images 1988–1993	Minimum unit interpreted 25 ha—scale 1:100,000 Key 44 items	APAT CORINE Land cover project I and CLC2000
CORINE Land-Cover CLC2000, third level	Landsat 7 images year 2002/aerial photographs year 2000	Minimum unit interpreted 25 ha—scale 1:100,000 Key 44 items	APAT CORINE Land cover project I and CLC2000
ISTAT 1990 Lazio Region	Landsat 5 images 1988–1993	Minimum unit interpreted 1 ha—scale 1:25,000 Key 6 items	Lazio Regional Environmental Information System (S.I.R.A.)
Land-Use Map (LUM) Lazio Region	Digital color vegetation photographs years 1998–1999/Landsat 7 images years 1999–2000	Minimum unit interpreted 1 ha—scale 1:25,000 Key 72 items	Lazio Region—Territorial Office, Urban Planning and Housing Department

long period. Moreover, the map refers to the period immediately proceeding the intense phase of urbanization and industrialization characteristic of the last 40 years. Sheets 13 and 14 of the TCI/CNR Map, relating to the Province of Rieti, were acquired using a scanner (600 dpi resolution), and geo-referenced with Arcmap 9.0 software on the basis of the Regional Topographic Map (CTR), scale 1:100,000. LC was digitalized to obtain a vectorial LC map of the Province.

The LUM 2000 was produced interpreting digital color orthophotographs on a scale of 1:10,000 referring to the years 1998 and 1999, and Landsat 7 ETM images. The minimum linear dimensions for insertion of data into the map were 25 m×250 m, while the minimum area was 1 ha (Lazio Regional Administration, 2003). The format of this map is vectorial (shape files). The coordinate system of all the maps was UTM 33N Datum ED50.

Methods

Overview

To increase the comparability between heterogeneous maps, it is necessary to equalize their level of thematic content and spatial detail. In the present study, the data integration procedure was divided into three steps: (1) thematic generalization, (2) spatial resolution generalization, and (3) selection of the generalized map most similar in terms of spatial details to the coarser resolution LC map (target map), following the method proposed by Petit and Lambin (2002).

The next stage was to detect changes in LC. Spurious results and errors, generated by thematic and spatial aggregation (Moody & Woodcock, 1994), were evaluated to assess the reliability of change detection. The results were compared, in terms of surface area covered, with the relative census data at class level.

Some areas (such as tares, roads, isolated houses or other) are included in map data as "other LC", although they are not included in the census data. These surfaces were considered insignificant because they were too small and/or relatively stable over time. The mistakes and the gaps in the census data were considered as homogeneously distributed not only among the types of cultivation, but also over the entire territory investigated. The different steps of the study are detailed below.

Data integration

Different classification options were available to obtain a thematic generalization. On the basis of an analysis of previous work (Falcucci et al., 2007) together with the LC class definitions reported by the TCI/CNR and LUM maps in the study area, a thematic generalization was realized in seven sections. This allowed a comparison of the LC trends emerging from the maps with those emerging from similar LU types surveyed in the census. Six alternative thematic aggregations for the LUM legend and two for the MLC1960 were performed, giving a total of eight maps (Fig. 2).

Section 2 groups LCs with similar LU and meaning (e.g., pastures, grassland, meadowland). In order to facilitate the reading of this article, lands covered with grass or herbage and suitable for grazing by livestock, were denoted "meadowlands". Since neither scrubland nor shrubs were present in the TCI/CNR classification, class 3.2.2 of the LUM 2000 was incorporated into two alternative thematic aggregations (i.e., section 2, "meadowlands", assuming a possible grazing of this LC, and section 1, "woodlands", assuming that scrubland and shrubs may have been classified in the TCI/CNR map as woodlands. The LC definable as "heterogeneous agricultural areas" in LC mapping does not exist in the census. The LC classes comparable to this type of cover (code CORINE 2.4.1, 2.4.2 and 2.4.3) were aggregated alternately to the following sections: meadowlands, non-irrigated annual crops and orchards.

As stated above, in order to obtain a homogeneous spatial resolution of the maps, the methodology proposed by Petit and Lambin (2001, 2002) was applied, although modified to introduce a variability linked to thematic aggregations. First, the eight thematically generalized maps were transformed from the original vector data format to the raster data format, assigning the same cell size to each raster (10 m×10 m). Then, starting from 10 m, by steps of 100 m, successive spatial aggregations from 100 up to 800 m were realized for each thematic aggregation of the LUM 2000, using a majority rule aggregation procedure. Then 48 new generalized maps were produced (six different thematic aggregations times eight different spatial aggregations). Next, using FRAGSTAT 3.3, the spatial structure of the original and derived maps of 2000 and of the two TCI/CNR maps (target maps) was estimated using five non-redundant landscape metrics: the Landscape shape index (LSI), Shannon's diversity index (SHDI), the mean patch fractal dimension (MPFD), the total core area index (TCAI) and the total edge contrast index (TECI). Finally, a Euclidean normalized distance in the space of landscape metrics was measured for all possible combinations (48+6 maps of 2000 times 2 maps of 1960) and a mean value was computed for each resolution. These data were then used to identify the resolution at which the levels of generalization of the TCI/CNR and LUM maps were as similar as possible (using a minimum distance criterion), while also allowing change detection to be performed at the finest possible spatial resolution. Fig. 3 shows the data integration design thus developed.

Land cover change detection

After data integration and the subsequent choice of the optimal resolution, LC change detection between each pair of maps was performed using a post-classification comparison. This yielded a total of 12 combinations for the time frame 1960–2000 (two in 1960 times six in 2000) (Fig. 3). The post-classification comparison was the only available option, because no collateral

Sections
1 woodlands
2 meadowlands
3 non-irrigated annual crops
4 orchards
5 irrigated annual crops
6 urban areas
7 Water bodies

1960 TCI/CNR land-use classes	key A	key B	CORINE Code	2000 Lazio Region LUM land-use classes	key 1	key 2	key 3	key 4	key 5	key 6
Coppice - High trunk wood	1	1	311	Broadleaf woodlands	1	1	1	1	1	1
			312	Conifer woodlands						
			313	Mixed conifer and broadleaf woodlands						
			3241	Natural recolonisation areas						
			3242	Artificial recolonisation areas						
Pasture and uncultivated productive even if partially or temporarily used for arable crops; Non-irrigated grasslands and grasslands associated with trees	2	2	321	Natural pasture and high altitude meadows	2	2	2	2	2	2
			322	Scrub land and shrubs	2	1	2	2	1	1
			331	Beaches, dunes and sand	2	2	2	2	2	2
			332	Bare rock,cliffs, outcrops						
			333	Areas of sparse vegetation						
			3343	Areas degraded by fire or other events						
			231	Areas of dense grass cover						
Non-irrigated annual crops associated with trees	3	4	241	Temporary cultivation associated with permanent cultivation	2	2	3	4	3	4
			242	Complex particle and cultivation patterns						
			243	Areas mostly used for agriculture with important natural spaces						
Non-irrigated annual crops	3	3	2111	Arable crops in non-irrigated land	3	3	3	3	3	3
			2113	Market gardening in non irrigated areas: in fields, green-houses, under protective plastic sheeting						
Sweet chestnut groves - Olive groves - Vineyards - Vineyards mixed with olive groves	4	4	221	Vineyards	4	4	4	4	4	4
			222	Fruit trees and berry plantations						
			223	Olive groves						
			22411	Poplar stands, willow stands and other broadleaf trees						
			2242	Sweet chestnut groves						
Irrigated annual crops	5	5	2121	Arable crops in irrigated land	5	5	5	5	5	5
			2122	Nurseries in irrigated land						
			2123	Market gardening in irrigated areas: in fields, green-houses, under protective plastic sheeting						
Built up areas and other uses	6	6	11	Residential areas	6	6	6	6	6	6
			12	Productive built up areas, private and public services, transport networks and infrastructures						
			131	Mining areas						
			1321	Opencast and underground mining, industrial and public waste dumps and deposits						
			1322	Open air scrap heaps						
			1331	Building sites and excavations						
			1332	Artificial and reworked surfaces						
			141	Urban parks and gardens						
			1421	Campsites, holiday villages with bungalow type accommodation						
			1422	Sports facilities						
			1423	Theme parks						
			1424	Archeological sites						
			143	Cemiteries						
Water bodies	7	7	411	Inland wetlands	7	7	7	7	7	7
			5111	Rivers, torrents and ditches						
			5121	Basins without obvious productive activities						
			5124	Aquaculture						

Fig. 2. Reclassification scheme of the original legend in seven sections for historical LU comparison.

spectral information was available for 1960 (Falcucci et al., 2007). The function CROSSTAB in IDRISI 32 was performed for each combination, and the results were then used to obtain the mean surface change and the standard deviation for 1960–2000.

Error associated with data integration

Errors generated by spatial and thematic aggregation can be classified as: (1) spatial aggregation errors, associated with different levels (coarser or finer) of aggregation and with a change in data models (change from coverage to raster); (2) thematic aggregation errors; and (3) classification errors (Moody & Woodcock, 1994).

Errors associated with different levels of spatial aggregation were not present because only one was chosen, i.e., the level at the optimal resolution. Therefore, each generalized raster map was compared with the original vectorial map from which it was derived. The same was done with the TCI/CNR map. Differences in area for each LC class, expressed by percentage of area lost or gained, were measured in order to identify any spatial aggregation errors associated with the change in data models.

Variability linked to thematic aggregation error was included in the analysis. The mean surface of area changed and the standard deviation obtained with the 12 possible combinations were calculated for each LU/LC class. No measure of classification errors was possible for the TCI/CNR map (Falcucci et al., 2007) or the CUS map (Lazio Regional Administration, 2003).

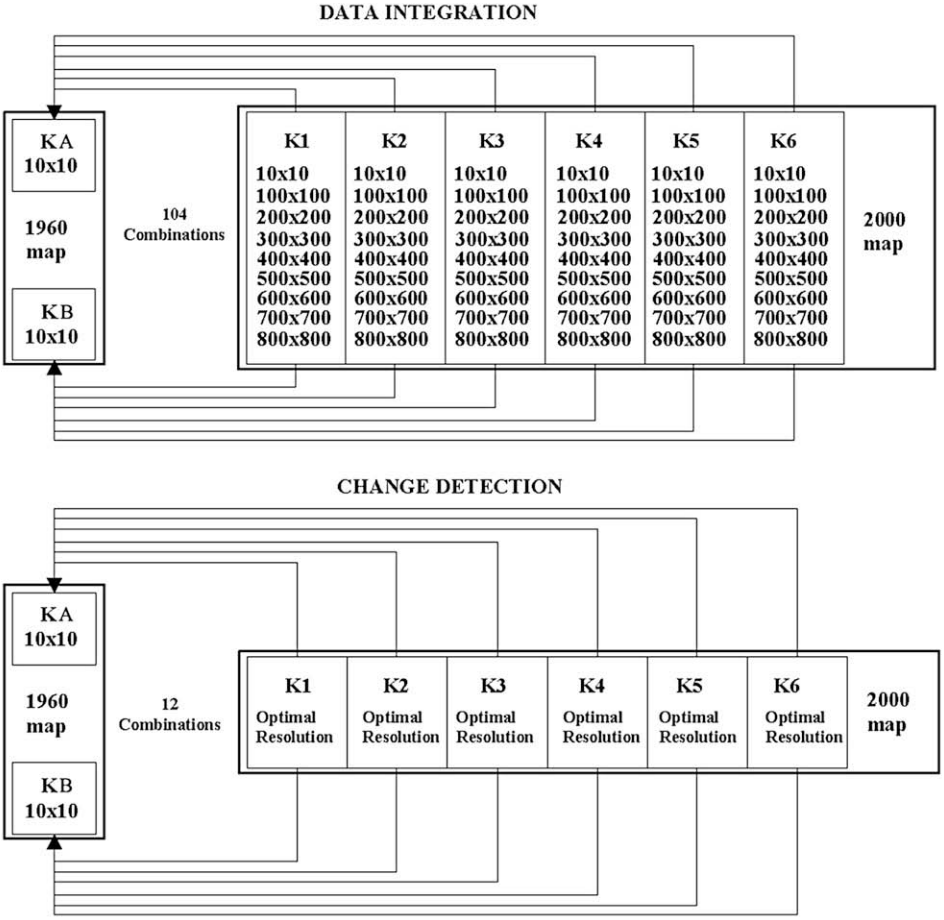

Fig. 3. Design of data integration and change detection methodologies. The letter K represents the keys of thematic aggregation of Fig. 2.

Results

Analysis of census data

An analysis of the data from the GAC (Table 3) shows that a reduction of about 66972 ha (−26.65%) occurred in the total agricultural surface in the Rieti Province between 1961 and 2000. The number of farms decreased by 29.90% from 30,200 to

Table 3
Variation in some LU and farm characteristics in the GAC data.

	Variation (ha)			Variation (%)		
	Mountain	Hill	Total	Mountain	Hill	Total
Woodland and shrubs[a]	−8145.10	−1589.49	−9734.59	−11.92	−13.63	−12.27
Meadowlands[b]	−11,073.16	−757.54	−11,830.70	−16.21	−10.47	−15.66
Meadowlands[a]	3535.31	−1370.79	2164.52	6.6	−17.5	3.5
Irrigated and non-irrigated crops[a]	−15,595.65	−339.22	−15,934.87	−52.40	−3.09	−39.11
Irrigated crops[c]	–	–	−432.17	–	–	−15.7
Orchards	−5368.17	−5672.18	−11,040.35	−55.47	−30.77	−39.28
SAU[a] (surface used for agriculture)	−17,428.51	−7382.19	−24,810.70	−18.71	−19.81	−19.03
SAU not used[c]	−4054.19	−1420.35	−5474.54	−49.98	−51.85	−50.45
Other surface[a]	−13,126.59	−1637.28	−14,763.87	−83.77	−56.88	−79.60
SAT[a] (total agricultural surface)	−55,758.25	−11,213.91	−66,972.16	−28.22	−20.87	−26.65
Number of farms[b]	−10,321	1255	−9066	−50.40	12.90	−30.00
SAT/farm[b]	4.31	−1.65	0.40	44.67	−29.99	4.80
SAU/farm[a]	0.05	0.00	0.05	1.44	0.07	1.05

[a] Variation 2000/1970.
[b] Variation 2000/1962.
[c] Variation 2000/1982.

Table 4
Trend of livestock between 1961 and 2000 (number of animals and variation percentage), GAC data.

	1961			2000			Variation (%)		
	Mountain	Hill	Total	Mountain	Hill	Total	Mountain	Hill	Total
Cattle and buffalos	27,441	16,351	43,792	19,119	13,172	32,291	−30.3	−19.4	−26.3
Sheep and goats	85,633	14,574	100,207	57,766	32,046	89,812	−32.5	119.9	−10.4
Total	11,3074	30,925	143,999	76,885	45,218	122,103	−32.0	46.2	−15.2

21,168, while the average farm size (calculated from the ratio between total agricultural surface and number of farms) rose slightly from 8.32 to 8.71 ha/farm. Therefore, all the cultivated and wooded surfaces decreased.

Regarding woodlands, the FSY show a slight increase in wooded areas between 1961 and 1990 (+5.7%, from 95,163 to 100,601 ha) and a considerable increase in permanent forage cultivation (+48.6%, from 43,579 to 64,760 ha). On the whole, these results reflect the different subjects involved in the two census surveys. The FSY forest data are also greater because they include areas used for sweet chestnut groves that are excluded from the GAC forest data.

It is of interest to analyze the differences in evolution between hill communes (characterized by diffusely elevated surfaces below 700 m a.s.l., ISTAT) and mountain communes (over 700 m a.s.l.) (Table 3). The main differences in LU change relate to orchards and crops, which were reduced in hill communes (by 30.7% and 3.09%, respectively). In mountain communes, however, they decreased much more (by 55.4% and 52.4%, respectively). Meadowlands, instead, decreased to a roughly similar degree in both zones (10% vs. 16%).

An analysis of animal breeding gives further insight into the difference between hill and mountain areas (Table 4). In the Province of Rieti, as in most parts of the Apennines, pastures are used mainly for sheep and goats' cheese production. An important decrease in the number of sheep and goats took place in mountain communes (−32.5%), whereas hill communes showed an increase in animal breading (+119.5%) and a reduction in pastures.

Integration and change detection of cartographic data

A resolution of 200 m was shown to provide the best level of generalization of the maps for change detection (Fig. 4). Table 5 shows the mean of the transitions (and related standard deviations), which took place in the seven sections in the period 1960–2000, obtained with the 12 thematic aggregation combinations. The standard deviations measured for the changes in each LC class were relatively small, indicating that the results obtained can be considered as having a high level of reliability. The only exceptions were the classes "non-irrigated crops" and "orchards", for which the standard deviation values were sometimes over half the mean values. Change from urban areas to other LCs can be considered erroneous. It should be noted that the urban areas reported on the 1960 map only include the biggest cities, usually corresponding with the current historic centers that are still present today. These cities and towns are represented with symbols as placeholder objects (Weibel &

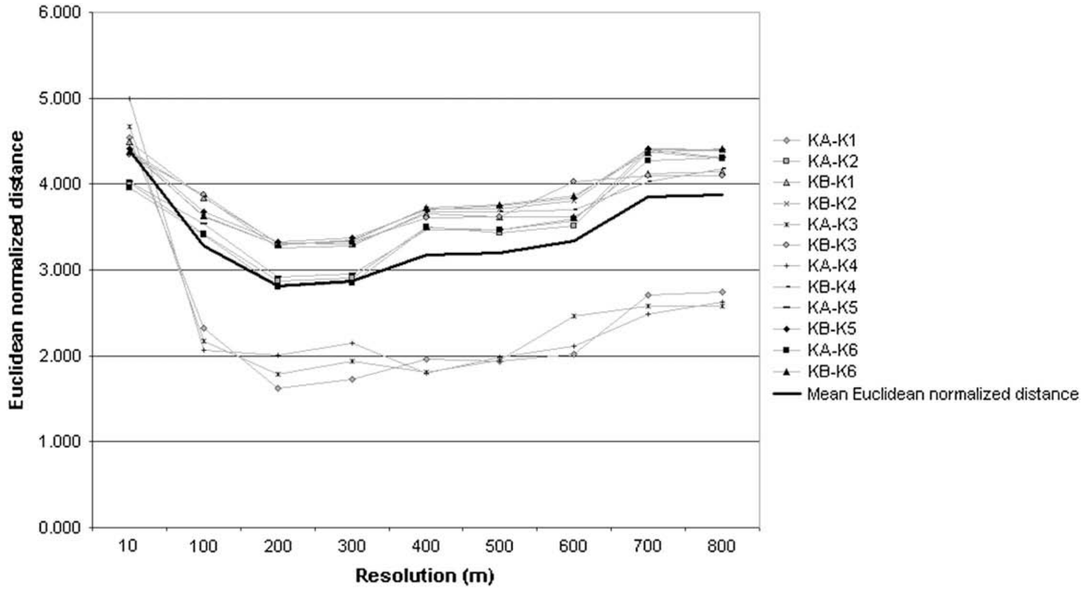

Fig. 4. Distance in the five-dimensional space of the landscape metric between the different resolution of the generalized maps of 2000 and the target maps of 1960. Twelve possible combinations among the keys (abr. K) of thematic aggregation were considered.

Table 5
LC change for the time step 1960–2000 in the Province of Rieti.

	TCI/CNR 1960													
	Woodlands		Meadowlands		Non-irrigated crops		Orchards		Irrigated crops		Urban		Water	
LUM 2000														
Woodlands	**62,993**	*1126*	**43,554**	*3403*	**27,435**	*5391*	**12,720**	*4738*	**276**	*19*	**149**	*5*	**313**	*11*
Meadowlands	**6536**	*1114*	**21,748**	*3373*	**12,939**	*3191*	**3178**	*1786*	**59**	*23*	**116**	*19*	**41**	*11*
Non-irrigated crops	**2026**	*133*	**2691**	*123*	**26,668**	*5601*	**8132**	*5510*	**403**	*12*	**106**	*18*	**78**	*4*
Orchards	**1765**	*115*	**818**	*110*	**6613**	*3111*	**16,006**	*2974*	**42**	*9*	**72**	*15*	**15**	*1*
Irrigated crops	**629**	*6*	**325**	*1*	**8627**	*2310*	**2374**	*2310*	**189**	*0*	**39**	*3*	**310**	*1*
Urban	**50**	*2*	**32**	*2*	**1219**	*640*	**810**	*640*	**58**	*0*	**274**	*4*	**3**	*2*
Water	**14**	*0*	**52**	*1*	**231**	*28*	**35**	*28*	**0**	*0*	**14**	*0*	**1048**	*1*

The bold number is a mean surface (measured in ha), while the italic one is the standard deviation obtained with 12 combinations of thematic aggregation among 1960 TCI/CNR and 2000 LUM maps at the optimal resolution pointed out after data integration.

Jones 1998); therefore, any comparison with the urban areas indicated on the LUM 2000 map is likely to be erroneous. Nevertheless, the analyses confirm the great post-World War II urban development (+216%). Water bodies, in contrast, would appear to show a 23% decrease over the time span 1960–2000. However, since the TCI/CNR map was produced for other purposes, it is the authors' opinion that further specific analyses are required to investigate this specific context.

The errors associated with the conversion from vectorial to raster format were negligible (<0.05%) in the 1960 TCI/CNR map while they were greater in the 2000 LUM map. In particular, urban areas (−55.77%) and water bodies (−24.47%) showed the greatest differences between data format, followed by more modest differences regarding irrigated crops (+8.33%), non-irrigated crops (+6.49%), meadowlands (+3.68%), woodlands (−1.02%) and orchards (−0.29%).

Comparison between cartographic and census data

Woodlands

The extension of woodland is largely underestimated by the GAC (Fig. 5). In fact, the difference between the GAC and cartographic data cannot entirely be explained, even if scrubland and shrubs are excluded from section 1, "woodlands" (Key 1, 2, 3 of the LUM map), but included in the GAC data.

Furthermore, woodland areas reported in the FSY should also be considered underestimated. Indeed, the provisional Regional I.N.F.C. data suggest that the true woodland cover may be much greater (Fig. 6), even if a simple comparison is not possible because there are different methodologies of detecting and defining woodland involved. In fact, it can be seen from Fig. 6 that the I.N.F.C. data correspond to the LUM 2000 data, which can be considered as the most correct available data regarding the area covered by woodland and shrubs.

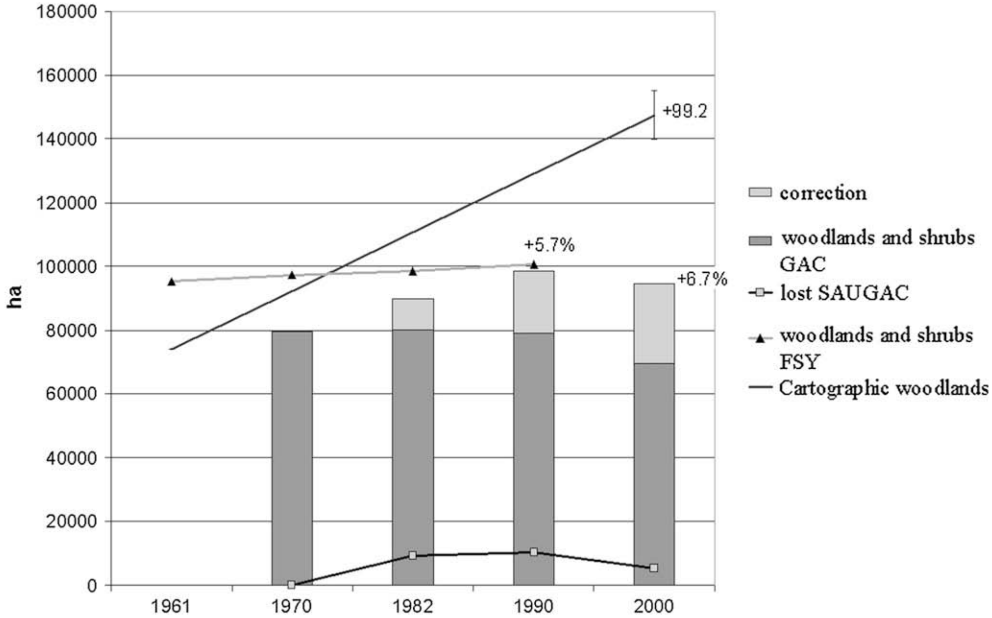

Fig. 5. Trends of woodlands and shrubs, lost SAU (surface used for agriculture), GAC and correction of GAC data.

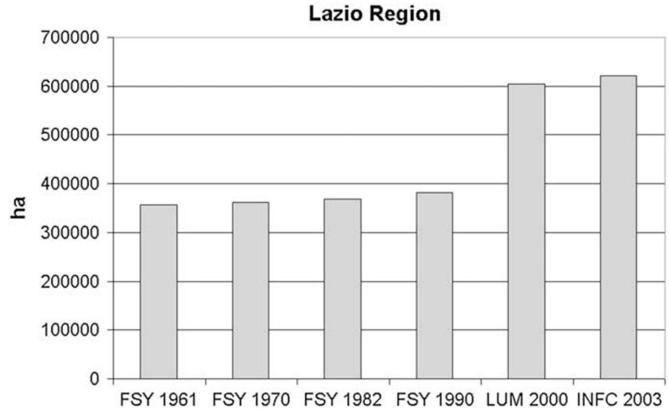

Fig. 6. Regional woodland and shrub trends according to the FSY, LUM 2000 and INFC 2003 (provisional).

According to the cartographic data, woodland and shrubs is the LC that increased most in the Rieti Province, in contrast with the GAC data (Table 3 and Fig. 5). Basically, the 2000 GAC underestimated woodlands and shrubs by 50–55%, compared to the cartographic data. This value is much higher than the National average of 20% reported by Piussi and Pettenella (2000). To reduce this difference between data, the GAC abandoned territories were assigned to the GAC single class denominated "woodlands and shrubs". Updating the GAC data each 10 years with the relative abandoned surfaces (see lost SAU GAC, Fig. 5), it is thus possible to include new formations of shrubs, since shrubs are the first colonizers of abandoned lands.

In consequence, it can be stated that, woodlands and shrubs in the Rieti Province certainly increased, mainly through the forestation of meadowlands and abandoned lands. Both the FSY and the corrected GAC data show a slight increase: respectively, 5.7% (between 1961 and 1990) and 6.7% (between 1970 and 2000). Instead, the cartographic analysis indicates a far greater increase than either, comprised between 88.8% and 109.7% (mean 99.2%).

Meadowlands

The cartographic meadowlands in the Rieti Province decreased between 24.4% and 46.7% (mean 35.5%) while the GAC meadowlands decreased by 15.7% (Fig. 7). In particular, the FSY data show a low level of reliability for the description of this section because of the high increase in meadowlands reported between 1982 and 1990. This represents a unique case compared to the other Provinces in the Lazio Region. The GAC meadowlands in 2000 cover a larger area compared to those detected by the LUM 2000. The difference is less remarkable, when scrublands and heterogeneous agricultural areas are included in the section "meadowlands" (see Key 1 of the LUM map, Fig. 2). For meadowlands, the census data is overestimated compared to the cartographic data by 22–73% (mean 43%).

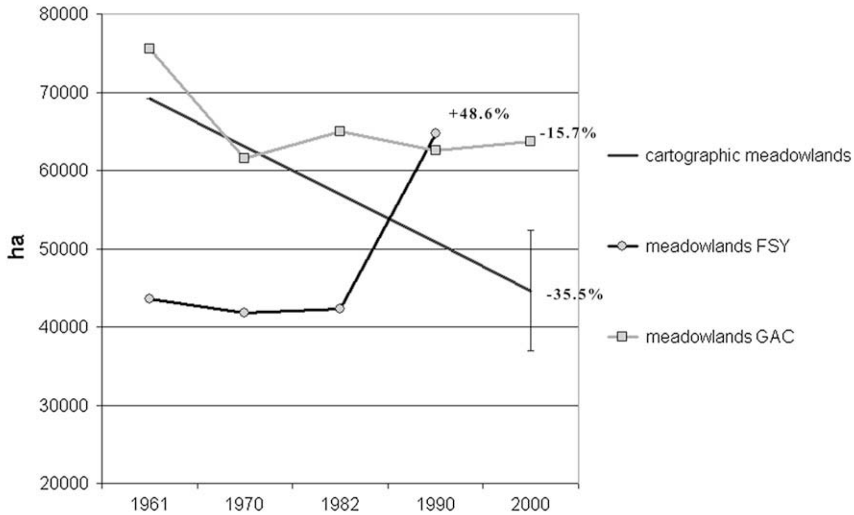

Fig. 7. Trend of meadowlands in the Province of Rieti—GAC, FSY and cartographic data.

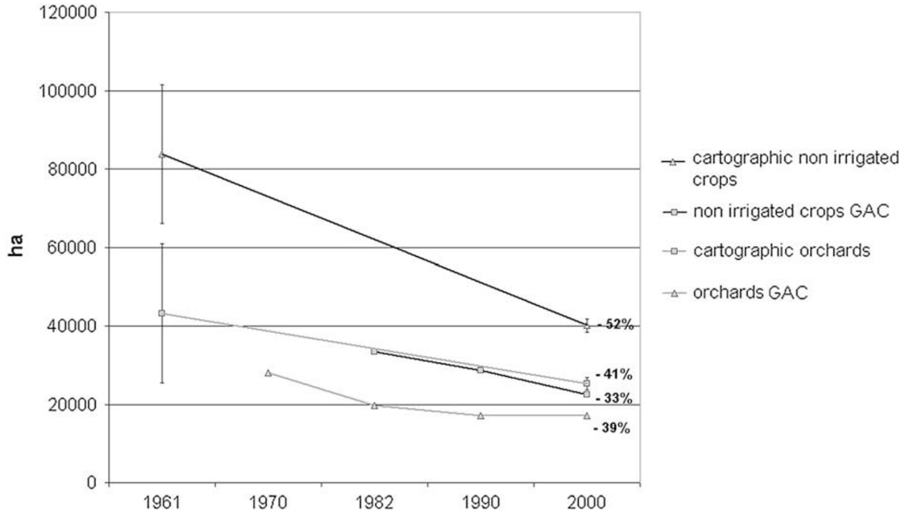

Fig. 8. Trends between 1961 and 2000 of non-irrigated crops and orchards—GAC and cartographic data.

Tillage

Overall, cartographic data for tillage lands is overestimated compared to the GAC data. Nonetheless, census and cartographic data both report a similar reduction trend in non-irrigated crops and orchards (Fig. 8). In fact, for non-irrigated crops the GAC reports, a decline of 33% compared to the −52% (mean value) of cartographic data, while for orchards the GAC reports a decline of 39%, compared to 41% (mean value) reported in the cartographic data.

A different evolution trend exists, instead, in irrigated crops. Census data report a 15% decrease between 1982 and 2000, while the cartographic data show a large increase (+1115%) between 1960 and 2000. Furthermore, the GAC irrigated crops in 2000 cover a very smaller area compared to those detected by the LUM 2000. Indeed, the total irrigated census surface represents only 18.5% of the irrigated cartographic surface (Fig. 9).

Discussion

The differences in LU change (Table 3) and animal breeding (Table 4) confirm the specialization and the intensive exploitation of resources in the hill territories rather than those in the mountains of the Rieti Province. These results reflect the trend that has been taking place in various European regions since the middle of the twentieth century (Ewert et al., 2005; Falcucci et al., 2007). The processes of forestation and the abandonment of animal breeding require further study (e.g., spatial models of change) in order to assess risks and develop sustainable management for these territories.

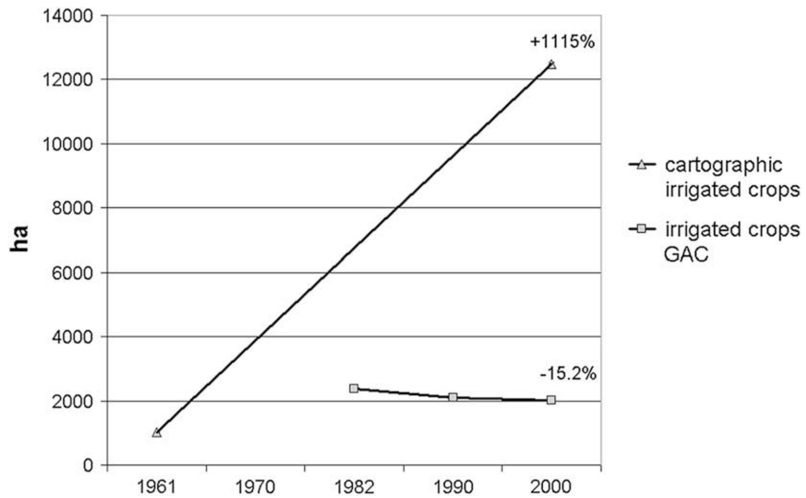

Fig. 9. Trend of irrigated crops in the Province of Rieti between 1961 and 2000—GAC and cartographic data.

The data integration, developed for this study using the method proposed by Petit and Lambin (2002), allowed the uncertainty associated with each LC change to be measured explicitly. These uncertainties almost always resulted tolerable, confirming that the analysis has a high level of reliability. Moreover, it is possible to make certain considerations about the different thematic classifications adopted. Fig. 4 shows that the Euclidean normalized distance between maps seems smaller for some thematic aggregations with respect to others (e.g., when Key A is used). It is not possible, however, to link this parameter directly with the thematic aggregation. The data integration was developed for one purpose only, i.e., to search for the optimal spatial aggregation of maps in order to improve change detection. The spatial distribution of a landscape pattern can be strongly modified by LUCCs; thus, further investigations, supported by the 1960 ground truth, are necessary to evaluate how efficient the method is at discriminating the best thematic aggregation of maps.

The great variation in the increase reported for changes in tillage land was caused by the classification "heterogeneous agricultural areas". These areas were assigned alternately to crops, orchards and meadowlands (Table 5, Figs. 7–9). This is a difficult problem to resolve, because every LC map reports this cover differently depending on data acquisition type, sensor resolution, photo-interpretation scale and/or cartographic generalization methodology. Only very high-resolution LC maps can resolve this problem, but they are very expensive and impossible to obtain for the past. Another cause of high variability is the classification of scrublands. This LC, if not correctly identified, can change the interpretation of the dynamics of woodlands and meadowlands considerably (Table 5, Figs. 5 and 7).

The greatest differences verified between cartographic and census data regard meadowlands, woodlands and shrubs, i.e., those coverings characterized by low human impact. For these types of LC, levels of abandonment and inadequate pasture maintenance are high and, therefore, broad territories, no longer farmed, are at risk of spontaneous re-colonization. Since the census data analyzed only measures the LU of administrative territories, they do not take into account these phenomena, consequently the census data on woodlands and meadowlands are questionable from this point of view. In fact, woodlands and shrubs are underestimated and meadowlands are overestimated by the census, probably because there was no provision for a check of the real state of the land. On the other hand, meadowlands are difficult to recognize using LC maps, because the management of these lands is hard to detect by remote sensing.

The cartographic data also overestimates those LU typologies characterized by a high level of exploitation of resources (orchards, irrigated and non-irrigated crops), compared to the census data. This was due to the difficulty of defining the real use, type and intensity of management of these types of cover by remote sensing methods. Diffused or isolated crops may be non-irrigated even if they lie in largely irrigated territories. Grasslands and open areas may or may not be used as pasture, may have been used as pasture for part of the year and tilled or left fallow for the remaining time. Therefore, besides the quality of the sensor also the period of year in which the images were acquired can influence the resulting classification of the land. Therefore, both a knowledge of local practices and site visits might be necessary to discriminate these LUs (e.g., to identify irrigation channels and the presence of irrigation equipment, or to verify the presence of animal grazing).

In conclusion, in situations where human activity either does not modify the natural appearance of the LC or modifies it in a way that is indistinguishable from changes made by other LUs, census data can be used to analyze changes over time, provided that problems related to quality, and to the lack of spatial distribution of information within the administrative unit, are always kept in mind. Instead, LC maps should be the main tool used to analyze LUCC, especially if produced with high spectral and metric resolution images and the support of site visits. They can be easily implemented to map large territories and they are essential in assessing the evolution of natural environments not used for agroforestry production. The data integration procedure proposed and the different assessment methods explained above could be used to help assess and improve LUCC analyses, whether based only on either LU census data or LC cartographic data, by identifying the degree of discordance between them.

The 1960 TCI/CNR map, even with its limits of quality and spatial resolution, is the only source of information available nationally with a high thematic detail. In fact, aerial photographs are the only alternative source of information about the same period, but their reduced scale and scarce quality hamper a similar classification of cover types (Rocchini et al., 2006; Pelorosso, 2008). The production of a new woodland map derived from historical black and white aerial photos (e.g., Fly GAI) is, however, both possible and necessary because the woodlands of the TCI/CNR map are undoubtedly underestimated (Pelorosso, Della Chiesa, & Boccia 2007; Pelorosso, 2008).

Conclusions

Historical LC maps are an important source of information regarding landscape dynamics and can be used for the study of LC change.

LC maps derived from remote sensing or photo-interpretation offer many advantages in terms of costs production. Moreover, they provide a spatial distribution of information that varies with sensor resolution. However, the weak point of using LC maps is the difficulty in identifying LC details, above all in intensively farmed agricultural land, such as irrigated areas, crops and orchards, etc. An alternative is census data, which generally contain such information. However, census data lack information on the surface surveyed and on the spatial distribution of the information collected.

The aim of this paper is to stress the usefulness of both these types of information in evaluating landscape dynamics and related environmental concerns. It proposes a methodology to homogenize a historical and a recent remote-sensing derived map, in order to compare LU census and LC cartographic trends. A medium–long term LUCC analysis is evaluated, highlighting discrepancies between data, both in absolute surface value and in evolution.

From the point of view of LU interpretation, the main results are that census data are not suitable for the analysis of woodland trends, while cartographic data underestimates meadowland and overestimates LU typologies characterized by intensive agriculture.

From a more general point of view, it is possible to conclude that, where the acquisition methodology does not consider geo-referenced surveys, such as in the case of Italy, census are data characterized by a low level of reliability. On the contrary, the accuracy of cartographic data is more easily verifiable, by ground truths or by ancillary, indirect information. This makes cartographic data a more valid source of information from a quantitative point of view, although census data remain very important for their LU details.

Hence, it is important to integrate both census and cartographic information and the proposed procedure gives generally applicable solutions in this sense. This is illustrated through a specific case, by means of a comparison between historical and recent LC maps. The information thus provided could be of fundamental interest for a number of purposes, including the assessment of territorial identity, the preservation of biodiversity by landscape ecological connectivity, the protection of water resources from non-point pollution sources, and environmental planning in general.

In particular, historical maps of the fifties, such as those used in this study (TCI/CNR map), are very important, because they give information on a fundamental period before the major landscape changes started after the Second World War in Italy and in Europe.

The final results of this work confirm the general trend for Mediterranean mountain landscapes, i.e., a strong reduction in meadowland landscape, mainly due to woodland recovery after land abandonment. This change, together with a general decline in extensive agriculture and an increase in urban settlements, has caused the loss of large areas of traditional landscape over a reduced time span. This study provides a clearer picture of these transformations, thus making a useful contribution to interregional development plans committed to environmental tutelage, which are aimed at reducing the risk of natural resource losses and preserving both the traditional landscape and the cultural heritage of the mountain population.

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