Applied Geography 98 (2018) 78–86

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

Diachronic analysis using aerial photographs across fifty years reveals significant land use and vegetation changes on a Mediterranean island

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ARTICLE INFO

Keywords:
Mediterranean Basin
Land use change
Agricultural land abandonment
Vegetation dynamics
Elba island

ABSTRACT

Understanding land use changes provides data suitable for decision making processes in biodiversity conservation and landscape planning. We examined temporal change in landscape and vegetation formations on Elba Island (Tyrrhenian Sea, Italy) using digital aerial photographs (1954, 1978, 2000) and deriving land-use maps from photo interpretation. The detected variations of landscape composition, patch size and isolation revealed that the decline of agriculture is the main anthropogenic driver causing significant changes in the landscape, leading to a complete shift from an island under cultivation to a largely naturally vegetated island. The patchiness and the fragmentation have decreased so that natural vegetation with localized intensive cultivation and settlements, especially along the coast, remained the dominant elements of the mosaic. These changes in landscape composition and pattern are expected to have dramatic functional consequences and a landscape management plan avoiding land-use polarization through tourism is needed.

1. Introduction

Land use changes significantly affect ecosystem structure and functions (Foley et al., 2005; Lambin et al., 2001) and thus, analyzing landscape dynamics through time can be crucial for developing predictive models for ecosystem management and conservation (Luque, 2000).

The Mediterranean Basin is recognized among the most altered hotspots of biological diversity globally (Myers, Mittermeier, da Fonseca, & Kent, 2000). Over many centuries, landscapes in the Mediterranean Basin and their sustainable functioning remained stable. This long-term stability is the result of a combination of traditional land-use practices and underlying ecosystem processes (Blondel, 2006). However, many studies found significant land use changes taking place since the end of World War II (Vogiatzakis, Pungetti, & Mannion, 2008). These changes are mainly associated with a shift from a traditional economy based on agriculture towards an economy dominated by mass tourism, which leads to rural abandonment and in many cases to a loss of cultural identity. The effects of land use changes on islands are often stronger than those observed in mainland areas (Delanoë, Montmollin, & Olivier, 1996; Nunn, 2004). In addition, while the impacts of mass tourism are most visible near the coast, drastically replacing natural habitats with tourist resorts and associated infrastructures, the abandoned agricultural land in the hinterland experiences forest expansion and a loss of secondary habitats such as scrublands and pastures. These processes are often subject to unstable vegetation dynamics, in the short-term often leading to soil erosion and other forms of land degradation (García-Ruiz & Lana-Renault, 2011).

The detection and analysis of land use changes have been applied successfully to many different mainland areas across the Mediterranean Basin (for examples, see Ales, Martin, Ortega, & Ales, 1992; Debussche, Lepart, & Dervieux, 1999; Gargano, Mingozzi, Massolo, Rinaldo, & Bernardo, 2012; Mazzoleni, di Pasquale, Mulligan, di Martino, & Rego, 2004; Romero-Calcerrada & Perry, 2004). However, until now the same effort has not been applied to islands (Tzanopoulos & Vogiatzakis, 2011; Tzanopoulos, Mitchley, & Pantis, 2007). In this context, the distinction between small and larger (such as Sicily, Sardinia or Crete) islands should be noted. Although all islands irrespective of their sizes are subject to similar socio-economic and physical processes, the effects of those processes can be profounder on small islands (Foggi, Lastrucci, Geri, & Rocchini, 2015a; Nunn, 2004), in a similar way as reported above contrasting mainland with islands. The islands of the Tuscan Archipelago in the Tyrrhenian Sea, midway between mainland Italy and Corsica have been strongly affected by the socio-economic changes

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https://doi.org/10.1016/j.apgeog.2018.07.010
Received 26 January 2018; Received in revised form 28 May 2018; Accepted 1 July 2018

associated with a shift from an agricultural economy towards a mass tourism economy (Arrigoni, Baldini, Foggi, & Signorini, 2003; Carta, Bedini, Guidi, & Foggi, 2013). With a total area of 220 km^2, Elba is considered a medium-sized island, but it is the largest of all islands forming the Tuscan Archipelago. The island reaches a maximum altitude of 1019 m a.s.l. and possesses an extraordinary geomorphologic variability, leading to the establishment of three distinct bioclimatic belts and a large vegetation variability (Foggi, Cartei, Pignotti, Signorini, & Viciani, 2006). Altogether, these conditions allow Elba to be a well suited model to test various hypotheses and to identify historical and current processes that shape the current landscape within a well defined and circumscribed system. In addition, although its vegetation dynamics and land use development have not been studied until now, accurate maps of the current vegetation exist (Foggi et al., 2006; Viciani et al., 2016). Consequently, the aim of this study was to study landscape dynamics that occurred over a 50-year time frame. During this period, the island experienced a socio-economic transition from an economy based largely on traditional agricultural exploitation to one based on tourism, determining a substantial land use shift. Today, numerous abandoned agricultural plots, particularly terraces, are clearly visible on the island. Those abandoned areas are nowadays covered by various plant communities, but their general shapes remain evident in the landscape. For this reason, we can assume a recent massive abandonment of agricultural activity, followed by an increase in forest coverage and residential areas as highlighted in studies by Cyffka (2005) and Cipriani, Rosas, and Wetzel (2011), which were only based on field observations. The detected landscape trends were interpreted by considering different drivers, namely climate, landscape structure (fragmentation, spatial heterogeneity), and management policy (distances from specific economic activities). The importance of the presented study exceeds a mere nature conservation interest because the detected landscape trends are responsible for landscape changes in large parts of the Mediterranean Basin where tourism has become the primary economic resource. Specifically, we evaluated the overall landscape composition and evolution across three reference dates (1954, 1978 and 2000) and tested whether during those time periods different trajectories of vegetation dynamics and magnitudes of land cover changes occurred within the three distinct bioclimatic belts. Finally, we also tested whether urbanised areas expanded mostly along the coastline as a result of increased tourism focused on seaside resorts. Implications of our findings for landscape planning and management will be discussed.

2. Materials and methods

2.1. Study area

The study was carried out for the entire island of Elba. Elba is located in the Tyrrhenian Sea, half-way between the west coast of the Italian peninsula and the island of Corsica. The macroclimate is Mediterranean, possessing three distinct bioclimatic belts, based on average temperatures (see Foggi et al., 2006 for a detailed description). The thermomediterranean bioclimatic belt characterises the hotter and drier areas of the island. It mostly occurs along the southern coast and is characterized by *Juniperus turbinata* macchia and by *Salvia rosmarinus* garrigue (called coastal macchia, see below). The mesomediterranean bioclimatic belt is milder and mostly sub-humid. It occupies the largest area of the island and occurs below 800 m a.s.l. It is characterized by the *Quercus ilex* dynamic series. Finally, the supramediterranean bioclimatic belt is restricted to the cooler and wetter areas of the island above 800 m a.s.l. It is characterized by a successional stage characterized by the spiny cushion *Genista desoleana* coenosis (called supramediterranean garrigue, see below). The main vegetation types in each bioclimatic belt can be divided into a large number of sub-types (especially within the mesomediterranean belt) which all represent distinct dynamic vegetation stages, mostly linked to different land use histories (Foggi et al., 2006).

2.2. Derivation of land-use maps

Aerial photographs (grey-scale ortho-rectified images) taken in 1954, 1978 and 2000 (scale 1:10,000 and geo-referenced as Gauss Boaga Projection, datum Roma 40) were provided by the geographical information office of the regional government of Tuscany. The minimum mapping unit was 0.5 ha (except for the shore, beach, dunes for which it was 0.1 ha). The interpretation was done in chronological order and from the more general to the more specific, as suggested by Lillesand, Kiefer, and Chipman (2004). Thus, in a first step and for each reference year, a polygon was created for the whole island as a basis for further divisions into smaller polygons. In a second step, coastal habitats and rocky outcrops were identified and split up. Following this step, the settlements, the mining areas, the agricultural areas and the grasslands were delimited. Finally, the remaining areas were the woodlands, the macchia and garrigues (see below for a description of the land classes). The classification was done manually using an interpretation key consisting of eight criteria (shape; size; tone; shadow; pattern; texture; site; association) as described in Olson (1960). For each criterion some categorizations were employed in order to standardize the interpretation. The shape is the general configuration of individual objects (Lillesand et al., 2004). The size of objects was considered in the context of the image scale and the selected minimum mapping unit. The tone refers to the relative brightness of objects that in our grey-scale images is continuous varying from white to black. Shadow is often a visual obstacle for image interpretation, however, it can also give height information especially about woodlands. Pattern is the spatial arrangement of objects and is usually repeated. Texture is the frequency of tonal change on an image. Site refers to the topographic or geographic location and is a particularly important aid to identify the vegetation types. Association refers to the occurrence of certain features in relation to others (Lillesand et al., 2004). Indeed, some objects are so commonly associated with certain other objects that one object indicates or confirms the other one (Olson, 1960).

Interpretation, classification and polygon drawings were done using ESRI ArcGIS 10.2.2. In addition to the aerial photographs, two maps were available to guide our interpretation, a map of the 1965/1968 vegetation survey (de Lange & Smit, 1971) and the most recent vegetation map showing the status in the year 2000 (Foggi et al., 2006). For subsequent landscape analyses (transition matrix and Kappa index, see below), vector maps were converted into a raster format at a cell resolution of 50 m × 50 m.

The following 14 land classes were recognized using these methods; rock outcrops, grasslands, garrigue (open scrub), macchia (closed scrub), coastal macchia, supramediterranean garrigue, *Quercus ilex* woodlands, *Quercus suber* woodlands, *Pinus pinaster* plantations, coastal rocks, other coastal habitats (shores and dunes), vineyards (including other agricultural fields), mining areas, and settlements. Based on the above mentioned criteria, most of these classes were easily identifiable while grasslands, garrigue and macchia required careful consideration because of their spatial and temporal intra-variability and inter-connectivity.

The grasslands of the island are mostly semi-natural communities that colonise the post-agricultural phase. They can be dominated either by *Brachypodium retusum*, by *Ampelodesmos mauritanicus* or they exhibit typical features of meso-hygrophilous grasslands in floodplains (Foggi et al., 2006). As in most cases it turned out to be impossible to distinguish these types on the aerial photographs, we combined them into the same land class (= grasslands).

Equally, the *Juniperus turbinata* macchia and the *Salvia rosmarinus* garrigue were combined into the same land class (= coastal macchia) because they are often spatially and through time interconnected, in particular at rocky sites in the thermomediterranean belt.

Several additional types of garrigue and macchia had been