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Detection of harvested forest areas in Italy using Landsat imagery

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A B S T R A C T

This study presents a thorough approach, based on the application of multi-spectral remote sensing Landsat imagery, to determine human-induced forest cover change in Italy during the decade 2002–2011. A total of 785.6 ×1 0^4 ha of forestland was mapped using the main forest classes described within the CORINE land cover 2006 database (3.11 – broad-leaved forest; 3.12 – coniferous forest; 3.13 – mixed forest). The approach employs multi-temporal Landsat imagery to determine large-scale spatio-temporal variations in forest cover with a high degree of precision. The semi-automated procedure is based on Normalized Difference Vegetation Index (NDVI) pixel-oriented image differencing technique. The results were validated and rectified as a result of on-screen visual interpretation, whereby all the false-positive forest changes that were incorrectly mapped during the automatic procedure were identified and removed. The derived high-resolution data of forest cover change show that 317,535 ha (4.04% of the total forest area in Italy) were harvested during the period under review. The 125,272 individual clear-cut areas identified are mainly located within protected areas of the European Natura 2000 network. The outcome of this study is a publicly accessible database that can encourage further studies in the framework of international biodiversity and soil protection conventions (http://eusoils.jrc.ec.europa.eu/library/themes/erosion/italy/). The methodology can contribute to the monitoring of human-induced forest changes in support of the Kyoto Protocol.

1. Introduction

The side effects of deforestation and tree harvesting are major environmental issues on a global scale (FAO, 2012). The world's forestland is cleared, degraded and fragmented by timber harvesting, man-made fires and land-use conversion (Cochrane, 2003; Richards & Tucker, 1988; Williams, 2000). Every year, about 13 million hectares (ha) of forest are converted to other land uses (FAO, 2010). Agriculture is still a primary cause of deforestation, accounting for 80% of deforestation, followed by logging (14%) and fuel wood (5%) (UNFCCC, 2007).

In Europe, the largest clearance of forest area occurred between the Classical period and the Industrial Revolution (Kaplan, 2009). Currently, logging is still widely practised in most of the EU Member States (European Commission, 2003). It is estimated that about 420 million m^3 of roundwood forests were harvested in the European Union (EU-27) in 2010 to meet the domestic timber demand (Eurostat, 2011).

Despite the amount of Eurostat data available about the production and trading of wood in the European Union, no information is available on the locations of tree extractions. This knowledge deficit could trigger serious issues, particularly given the fact that a vast part of the European forest area is privately owned (e.g. 72% of the 368,820 km^2 of forestland of Central-Western Europe is privately owned) and widely exploited for wood supply. Moreover, the intense harvesting of forests goes against the forest management programmes of the European Commission (e.g. forest resource stocks, productivity and harvesting activities – MCPFE, 2009).

Remote sensing observation data can help address this knowledge deficit. Remote sensing (RS) has been used as a powerful tool for detecting changes in land-use and vegetation over the past decades (Coppin & Bauer, 1996; Kennedy & Spies, 2004; Mas, 1999).

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RS is a recognised technique for monitoring forest change at multiple scales (Collins & Woodcock, 1996; Hansel et al., 2008; Potapov, Turubanova, & Hansen, 2011; Singh, 1989), as RS data include comprehensive information about the spatial and temporal distribution of forest changes (Coppin & Bauer, 1996). The most frequently used data for assessing forest cover change are those captured by Landsat satellite sensors (MSS, TM, ETM+), which are available since 1972 (Asner, Keller, Pereira, & Zweede, 2002; Coppin & Bauer, 1994; Cohen et al., 2002; Coops et al., 2010; Hansen et al., 2001; Healey, Cohen, Zhiqiang, & Krankina, 2005; Li et al., 2009; Wilson & Sader, 2002; Woodcock, Macomber, Pax-Lenney, & Cohen, 2001; among others). The widespread use of the Landsat sensor data is attributable to the good compromise that they offer in terms of spatial resolution and temporal coverage (Williams, 2006). In addition, a broad database of orthorectified Landsat scenes is available free of charge from the United States Geological Survey (USGS) (Woodcock et al., 2008). Landsat imagery is considered to be the most cost-efficient tool for forest monitoring, with respect to high-resolution images. The cost of obtaining high-resolution images for a large study area can be prohibitive, ranging from €1 to €2/km (SPOT5) to €15 to €20/km (Ikonos, QuickBird). However, given the small average size of the Italian clear-cut areas (about 2.5 ha – Borrelli, Rondón, & Schütt, 2013a), the coarse-resolution imagery of other sensors (e.g. MODIS – 250 × 250 m, NOAA-AVHRR – 1.1 × 1.1 km) is of limited use for the current study.

Post-classification analysis is one of the most commonly applied methodologies for detecting environmental changes (Lu, Mausel, Brondízio, & Moran, 2004; Rodriguez-Galiano & Chica-Olmo, 2012). However, the potential errors deriving from the classification of land units (Linke et al., 2009) may represent an unnecessary restriction during the detection of forest cover change. Therefore, the cover of large forestlands could be better monitored by methods that rely on pixel-oriented change detection techniques (Singh, 1989) and use vegetation indices (Lyon, Yuan, Lunetta, & Elvidge, 1998; Wilson & Sader, 2002). Borrelli et al. (2013a) have tested a pixel-oriented change detection technique over a 34,000 km^2 area of central Italy, with encouraging results (Kappa Index of Agreement: 0.906).

The objective of this study is to compile an inventory of forest cover changes at national-scale based on an image differencing technique (Singh, 1989). The study area is the territory of Italy, which has a total forestland area covering 104.7 × 10^5 ha (34.7% of the national surface) (INFC, 2007). The resulting database covers the decade 2002–2011. It can further promote studies in the context of international conventions on areas such as biodiversity protection (European Commission, 2011), soil conservation (European Commission, 2006) and compliance with the requirements of the Kyoto Protocol.

2. Study area

The study area (Fig. 1) covers about 785.6 × 10^4 ha, corresponding to the main forest units of the CORINE land cover 2006 database (EEA, 2011), i.e. broad-leaved forests (547.9 × 10^4 ha, 70%), coniferous forests (128.6 × 10^4 ha, 17%) and mixed forests (109.1 × 10^4 ha, 13%).

The dominant tree species are *Quercus* (*petraea*, *robur*, *petraea*, *cerris*, *carpinifolia*, *sativa*, *ilex*) *Fagus sylvatica*, *Picea abies* and *Abies alba* (Vacchiano, Magnani, & Collalti, 2012). On average, 34.7% of the Italian territory is covered by forests. The coefficient of woodiness (INFC, 2005) is lower in the southern regions (the EU NUTS-2 administrative units of Apulia, Basilicata, Calabria) and on the islands (Sicily and Sardinia) (Table 1), where other forms of wooded land (e.g. shrubs and macchia) represent a substantial portion of the forest area. The most densely wooded regions are Liguria and Trentino, with a coverage rate of 69.7% and 65.5% respectively. An important aspect of the Italian forest area is its ownership. A total of 63.5% of the forest area (forest and other wooded land) is privately owned, 32.4% is publicly owned, while almost 4% of the area has not been classified (Pompei & Gasparini, 2007). About 366.3 × 10^3 ha (41.8% of the Italian forestland) is currently managed as coppice forest (INFC, 2007).

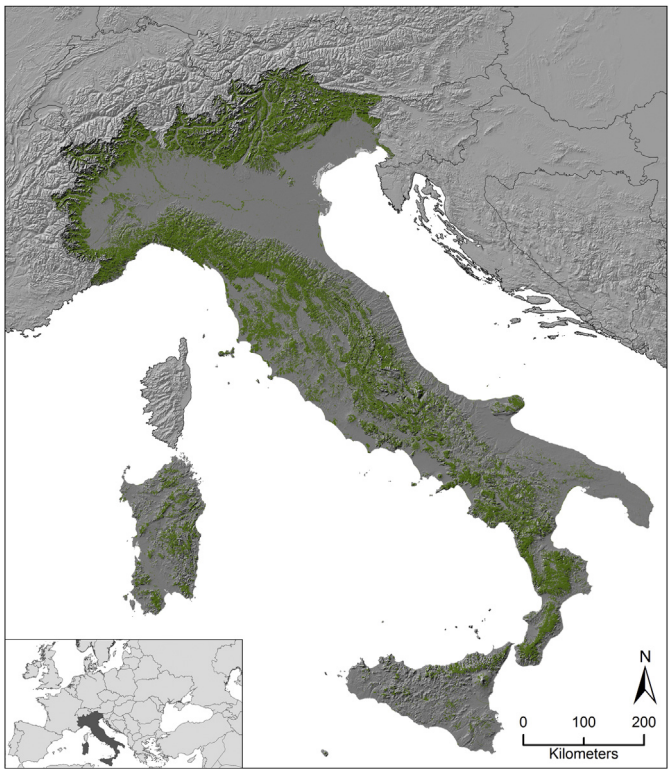

Fig. 1. Study site (in green the target forest areas according to CORINE land cover 2006 – EEA, 2011). [For interpretation of colour referred in this figure legend, the reader is referred to web version of the article.]

Table 1
Italian forestland statistics by NUTS-2 administrative units (INFC, 2007).

NUTS-2	Forest	Other wooded lands [ha]	Total forest coverage
Piedmont	870,594	69,522	940,116
Valle d'Aosta	98,439	7489	105,928
Lombardy	606,045	59,657	665,703
South Tyrol	336,689	35,485	372,174
Trentino	375,402	32,129	407,531
Veneto	397,889	48,967	446,856
Friuli V.G.	323,832	33,392	357,224
Liguria	339,107	36,027	375,134
Emilia Romagna	563,263	45,555	608,818
Tuscany	1,015,728	135,811	1,151,539
Umbria	371,574	18,681	390,255
Marche	291,394	16,682	308,076
Lazio	543,884	61,974	605,859
Abruzzi	391,492	47,099	438,590
Molise	132,562	16,079	148,641
Campania	384,395	60,879	445,274
Apulia	145,889	33,151	179,040
Basilicata	263,098	93,329	356,426
Calabria	468,151	144,781	612,931
Sicily	256,303	81,868	338,171
Sardinia	583,472	629,778	1,213,250
National coverage	8,759,200	1,708,333	10,467,533