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Research paper

The 1936 Italian Kingdom Forest Map reviewed: a dataset for landscape and ecological research

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Abstract - The recovery, digitalization in vector format and a first analysis of the 1936 Italian Kingdom Forest Map (IKFM) (276 sheets 1:100,000) is described. The original document is available in paper format using a datum and a map projection no longer in use, therefore it is not suitable for analysis using current digital tools. Besides it is a unique document that describes the forest extent and species composition for the whole of Italy. This map provides historical, ecological and landscape information and fills a great temporal gap in those portions of Italy where landscape maps are available for some earlier periods. Its importance is extended to parts of Croatia, Slovenia and France. Therefore, the effort to make it available for analysis using current digital tools was done. The technical problems faced in the recovery and transformation of the cartography into a usable format are described and discussed. A first data overview and analysis based on a test study, and comparisons with current national forest inventory data aimed to highlight potential and limits of IKFM are presented. The results demonstrate the validity and usability of the digital version that is available on-line through a WebGIS at the address carta1936.dicam.unitn.it

Keywords - Forest Landscape; Historical Cartography; Milizia Forestale; Vector Conversion; WebGIS

Introduction

The analysis of landscape and ecological changes that occurred through the years using GIS (Geographic Information System) to compare historical geographical data is being increasingly used to reconstruct and understand the past ecological evolution at different scales, taking into account long periods (Bieling et al. 2013, Mikusinska et al. 2013). Similar examples that analyse only some decades can be widely found, in particular in Italy (Geri et al. 2010, Bracchetti et al. 2012, Palombo et al. 2013, Garbarino et al. 2013), other regions of Europe (Sitzia et al. 2010), South and North America (Renó et al. 2011, Zald 2008) and Asia (Zhou et al. 2011, Tang et al. 2012). This type of data and analysis has also been used to model possible future scenarios (Schirpke et al. 2012, Cimini et al. 2013), to design future interventions (Marignani et al. 2008), and to evaluate the hydrological impact of land use changes in water basins (Glavan et al. 2013, Zlinszky & Timár 2013). It has also been suggested that using a combined approach of GIS modelling and historical data analysis could enable the comparison of biomass production in different periods (Sacchelli et al. 2013).

The evidence demonstrates that past land use has a significant influence on the present biodiversity distribution and status (Falcucci et al. 2006, Pezzi et al. 2011, Aggemyr & Cousins 2012, Amici et al. 2012) and on traditional ecological knowledge (Ianni et al. 2015, Tattoni et al 2017), so historical information is crucial for the interpretation of many of the results of present ecological analysis, including those obtained with field sampling (Geri et al 2016).

The sources of information that can be used in this type of study are mostly satellite imagery, aerial photographs and historical maps, which are often the oldest documents. Some Landsat images can date back to the 1970s, while aerial photographs at the national scale are available for the majority of the countries from the 1940s or 1950s. Occasionally, single aerial photographs taken in earlier periods can be found in the archives for small areas, like the photographs taken during the World War II reconnaissance campaigns over Italy in 1944 by the British Royal Air Force (Merler et al. 2005). In this framework, historical maps are particularly useful, but they are difficult to find and often cover limited areas or have not been specifically created to show ecological features or vegetation features (Marchetti et al. 2009).

Thus, reliable historical maps that report detailed vegetation features over a large area in the past are a treasure, full of information that is particularly useful and important to understand the profound changes that occurred over the years in

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the landscape and ecology of an area or the whole of a country.

The first representations of forest coverage in some portions of Italian territory date back to the medieval period (Marchetti et al. 2009), but the first documents based on cartographic projections that can be compared with the current cartography date back to the beginning of the 19th century and were carried out in the framework of a local cadastre creation or updating, sometimes with specific attention given to the forest cadastre (Tattoni et al. 2010). Those maps represent limited areas with a single public or private owners, and the information contained is so heterogeneous that it is almost impossible to compare two different maps or check them against current data (Marchetti et al. 2009, Corona et al. 2001).

The Tourist Map produced in 1914 by the Touring Club Italiano (1:250,000) represents a generic "forest" category distribution in the whole Italian territory derived by enquiries to all CAI (Club Alpino Italiano - Italian Alpine Club) members, Alpine expert trekkers and specialists (Vota 1954, Meyer 2012). No distinctions were highlighted among species, forest structure or management schemes (for example, bushes and trees or coppice and high forest).

This work presents a detailed description of the vector transformation of the first homogenous map that represents Italian forests categorized under a recognizable scheme, the "Carta Forestale della Milizia Forestale del Regno d'Italia del 1936", i.e., the 1936 Italian Kingdom Forest Map (IKFM, hereafter), published by the Milizia Forestale del Regno d'Italia in 1936 (Brengola 1939, Marchetti et al. 2009). The digital map is a very unique and important document that describes the forest extent and main species composition in the whole Italian territory in 1936. The IKFM is the first document that records the distribution of forests at the national level and fills a temporal gap often present in studies in the Alps and in Italy, the critical period between the two world wars (Tappeiner et al. 2007, Ciolli et al. 2012). Moreover, its importance is not limited to Italy because it covers some areas that have now become parts of other countries (Croatia, Slovenia and France). Aim of the work is to describe the different technical problems tied to the quality of the original materials that were faced in the creation of the digital vector map. The technical and practical choices taken to solve these problems are also discussed, and the results are presented.

Despite our long and repeated searches in all the available Italian libraries, universities and research institute archives, as well as interviewing living people who later met some of the people involved in the original work in 1936, it was not possible to find reliable sources explaining in detail the taxonomy and the criteria used in the field work classification and in the final map. Therefore, the only information available are the IKFM legend labels and conventions, and this brings us to the second aim of this work, that is, to carry out a preliminary analysis of the data to determine whether the classification is reliable and evaluate what type of analysis can profitably be carried out.

Tests comparing area calculations on the digital version and old paper documents were carried out. The use of IKFM in the existing studies is highlighted. A comparison of the data in the digital IKFM map with two national forest inventories data, the IFNI 1985 Inventario Forestale Nazionale (IFNI, 1985) and the INFC 2005 Inventario Nazionale delle Foreste (INFC, 2007), is provided. Additionally, a first data overview based on landscape metrics and indices (Uuemaa et al. 2009) in 1936 at the national and regional levels is presented.

Materials and methods

The 1936 map material

The cartographic base for the IKFM map consists of 276 sheets (Fig. 1), with a 1:100'000 scale of representation. The original field sampling was initially reported on 1:25'000 official maps of the time, created by the Istituto Geografico Militare Italiano (IGMI), and then transferred to maps in the final 1:100'000 scale, also provided by IGMI.

The material used for conversion from raster to vector consisted of a set of 276 scans of the sheets of the maps, provided by the former Corpo Forestale

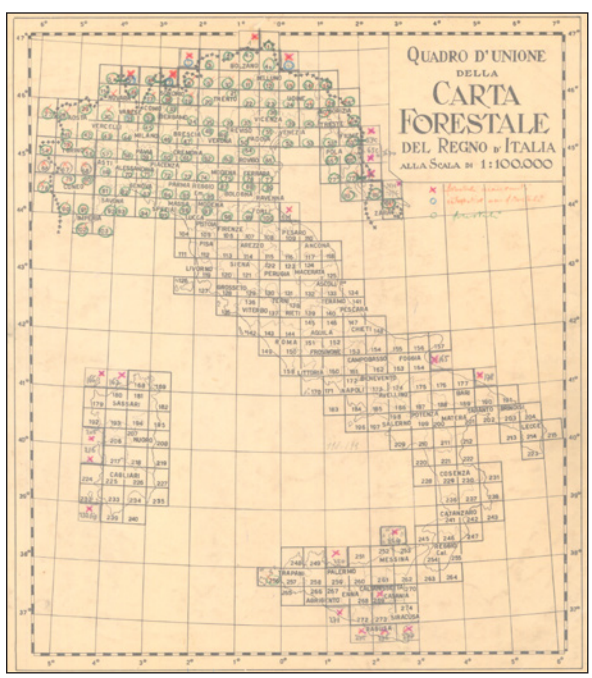

Figure 1 - IKFM original index map, representing all the single sheets of the 1936 map.

dello Stato in the frame of this work. The dimensions of each image was approximately 112 Mb, 6'650 * 5'900 pixels, with a resolution of 400 ppi (pixel per inch), RGB bands, projected in the Italian national Rome40 datum, Gauss-Boaga projection, east or west zone, depending on the location of the map sheet. The division into two different zones was maintained during the entire digitalization process, creating two different GRASS GIS Locations, Fuso Est (East Zone) and Fuso Ovest (West Zone).

Approximately 63'000 areas detected in the raster format were transformed into vector polygon format.

The IKFM forest classification system

The three levels system used in 1936 for the classification of the forest in the IKFM was based on species composition and silvicultural system, highly related to a definite distinction between wood for construction or furniture versus firewood (Marchetti et al. 2009). The 1st World War had ended a couple of decades before, and forests were an irreplaceable source of goods providing income and satisfying many of the primary needs of the Italian population (like firewood, bushmeat, mushrooms, herbs used for food and medicines), not much different from what is happening now in some developing countries, in which the growing population is increasingly impacting on forests and natural resources (Martin et al. 2012). The forest classification system chosen in the map description reflects the practical approach of the period but also contains a large amount of ecological information, like, as an example, the distribution of the main species and the general boundaries of the forests.

The forest cover at national level is divided into 3 macrocategories (conifers, broadleaves and "degraded forests") and 8 different categories, with some sub-categories related to forest system features for broadleaves (Fig. 2 translated in Tab. 1). The conifers sub-categories were classified depending on the main species that can be found in each polygon.

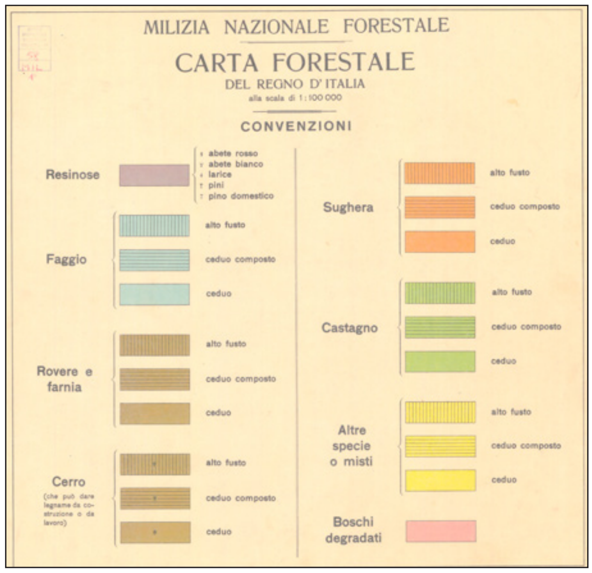

Figure 2 - IKFM original legend showing the different levels of the forest classification system represented with different colours, symbols and hatchings in 1936. The main categories are Resinose (Conifers), Faggio (Beech), Rovere e Farnia (Sessile oak and English oak), Cerro (Turkey oak), Sughera (Cork oak), Castagno (Chestnut), Altre specie o misti (other species or mixed wood), and Boschi degradati (Degraded forest). Detailed English translations of the names can be found in Tab S1.

Table 1 - Original label translated from italian (in brackets the original italian terms)

Macrocategory	Category	Subcategory
Conifer (RESINOSE)	Conifer (RESINOSE)	Norway spruce (ABETE ROSSO) Silver fir (ABETE BIANCO) Larch (LARICE) Stone pine (PINO DOMESTICO) other pines (PINI)
Broadleaves (LATIFOGLIE)	Beech (FAGGIO)	high forest (alto fusto) coppice with standard (ceduo composto) coppice (ceduo)
	Sessile oak and English oak (ROVERE E FARNIA)	high forest coppice with standard coppice
	Turkey oak (CERRO)	high forest coppice with standard coppice
	Cork oak (SUGHERA)	high forest coppice with standard coppice
	Chestnut (CASTAGNO)	high forest coppice with standard coppice
	Other species or mixed wood (ALTRE SPECIE O MISTI)	high forest coppice with standard coppice
Degraded forest (BOSCHI DEGRADATI)		

Map digitalisation

The digitization work was carried out using the open source software GRASS 6.4.3 (Neteler et al. 2012, Preatoni et al. 2012, Zambelli et al. 2013) and QGIS Quantum GIS version 1.4.0-Enceladus.

Because the amount of cartographic material was huge, an approach to limit the use of manual digitalization has been tested, with the use of the supervised image classification procedure available in GRASS to extract the forest data. To facilitate automatic detection, various pre-processing techniques were applied, combining colour separation with filtering and map algebra.

This approach did not give good results, with many problems due to the original data quality and many ambiguous situations in which the intervention of the operator is fundamental. Some map sheets presented defects due to scanning problems, and some imperfections regarding colour representation were due to the original print process.

The use of the automatic extraction technique has been applied to different sample map sheets, and the time necessary to complete the semi-automatic procedure, consisting of the automatic extraction and successive manual correction, has been compared to the time necessary to accomplish the same task using a completely manual procedure, and the latter has been shown to take up to 50% less time.

The semi-automatic procedure was slower because the time needed to correct errors due to the misinterpretation of colours, bad signs on the map or incorrect hatching was much higher than the time the operator needs to make a decision on what to do during the manual digitalization process.

The following rules were observed during the digitization:

a) always assign to each area the corresponding subcategory according to original legend (Fig. 2, Tab S1);
b) always digitize the black borders and not the coloured area extent, unless the black external border is absent. In this case, the coloured area extent is digitized;
c) always follow the black border, even if part of the border covers a lake or the sea surface;
d) in the case of an area without well-defined hatching, common sense has been used;
e) in the case of an area without colour, because it was not possible to assign the area to a specific subcategory, the value 25 in the field VALUE has been inserted, corresponding to the label NON CLASSIFICABILE (not classifiable);
f) regarding the representation of purple (conifers), two cases were possible: the first was that the area was without any species symbol, and in this case we inserted the value 0 in the field VALUE; the second possibility for purple (conifer) areas was that one or more forest subcategories symbols, each indicating the presence of a conifer species, were represented. In this second case, we inserted the value 0 in the field VALUE, but we also counted the number of symbols of different subcategories and inserted it into the field RESINOSE (conifers) according to the following codification:

AR = abete rosso (*Picea abies* Karst, European Spruce)
AB = abete bianco (*Abies Alba* Mill., European silver fir)
L = larice (*Larix decidua* Mill., European Larch)
P = pini (*Pinus sp.* Pines)
PD = pino domestico (*Pinus pinea* L., Stone Pine).

Because the only information available about the abundance of the conifer species is the number of species symbols reported in each conifer area of the map, we decided to preserve the historical information by decoding it into a text label to facilitate data extraction via Structured Query Language (SQL). For example, an area in which we can count symbols for 10 spruces, 4 firs, 3 larches and 1 pine will contain in the RESINOSE (conifer) field the label 10AR4AB3L1P.

Apart from digitalisation errors, the size of the smallest polygon is about 0.14 hectares. Areas of this size are clearly visible in the original map and are compatible with similar maps generated at the same scale in the same period in Europe (Kaim et al 2014).

The Italian boundary was derived from the map (shape file, Gauss-Boaga/Rome40) available on the Italian National Institute of Statistics (ISTAT) website (http://www.istat.it/en).

Projection and reference system transformation errors

The overall geometric uncertainties for the coordinates in the final vector map can be assessed as the sum of three terms: the geometric uncertainties of the original map, errors introduced by the datum transformation and inaccuracy during the vectorialization. The first term is easily estimated from the scale of the original map: a scale of 1:100’000 corresponds to an expected accuracy of 20 m.

Datum transformation errors are not available for the transformation used in this application, but their magnitude for the transformation between these two datums can be reliably assumed to be of the order of 10-20 cm (Radicioni & Stoppini 2009).

Finally, the digitalization error, excluding gross errors in the choice of the correct feature, is less than half the size of a pixel. The pixel sizes vary slightly approximately 6.5 m between raster sheets, so this error can be estimated to be less than 3.5 m. Consequently, the total error on the coordinates is less than 30 m, with the original map accuracy being the main factor.

The transformation from the original datum, using a Bessel ellipsoid oriented around Genoa and the Sanson-Flamsteed equal-area map projection, to the national one, using the Rome40 datum with the Gauss-Boaga conformal projection, has been carried out with a two-step procedure by the former Corpo Forestale dello Stato. This procedure involves the interpolation of the transformation parameters evaluated for the corners of each original map sheet. This transformation inevitably leads to a variation of the surfaces of the areas on the maps: a complete analysis of this issue is under way, but a first assessment has already been carried out. A set of 46 map sheets, selected partly at random and partly by choosing those sheets where the surface variation is expected to be more relevant (i.e., the sheets farthest from the central meridian and on the north and south extremities of the region covered by the map), has been tested by comparing the surface of the original sheets to the reprojected ones.

According to this test, the variation of the surface due to the reprojection procedure has a mean value of 0.2%, with a maximum of 0.6% (std dev 0.2), and it can be considered negligible with respect to the other uncertainties involved.

Errors in the original map

The original map contained some recurring errors, which are unavoidably also present in the raster format and thereby in the vector transformation.

The most frequent errors consist of the area colour filling expanding beyond the black border of the areas, the total or partial absence of the black border with the presence of the colour filling (fig. 3 and fig. 4), the presence of the black border with the total or partial absence of the colour filling and the spreading of the black borders beyond terrain limits into water bodies (fig. 5). Where possible, the black borders have been used to define areas to introduce the minimum modifications to the original paper map.

Another repeated error was the presence of incongruous hatchings that began horizontally and then became vertical or slanting or abruptly disappeared. Some of these errors are probably due to inattention, and they were not corrected on the original map in 1936 because once the drawing of the hatching was begun, it was not possible to erase it and change it without redoing the whole sheet. The classification of these areas was done trying to respect the content of the original map as much as possible, but in some cases, the choice of the forest subcategories involves a certain degree of subjectivity.

Figure 3 - Example of an area without colour filling (near the pink area) and example of an area without a black border (the yellow area at the bottom of the figure) in IKFM original material.

Figure 4 - An example of an area with the black border but without colour filling is visible on the right side of the figure: the forest in this area is not classifiable.

Figure 5 - Example of a forested area that partially overlapping the sea in IKFM original material.

Errors during digitalization

During the digitalization process, there is the possibility that some polygons may be assigned by the operator to the wrong category. A sample of one hundred areas, chosen randomly, has been checked for misclassification and no errors were found, but it is impossible to guarantee that all 63'000 forested polygons have been correctly classified.

An error that must be taken into account is the error due to the thickness of the lines. This error is present in all paper maps and is due to the width of the lines representing the graphical entities. The smaller the scale, the larger this thickness error is. A one millimetre wide line, if represented in a 1:10'000 map, corresponds to a 10 m thick line on the ground, and it corresponds to a 100 m thick line on the ground if represented in a 1:100'000 map.

To determine how this error can affect the final results, some sampling has been carried out to measure the widths of the boundaries of different areas in the original raster format. Most of the lines are 3 or 4 pixels wide, that is, 20-25 metres on the ground, but some of them are wider, up to approximately 50 metres on the ground.

To minimize this source of error, the lines have been digitized as close as possible to the centre of their section. The effect of choosing the centre rather than the inner or outer border of a boundary line is shown in fig. 6, where the influence of this choice on the resulting area can be easily appreciated.

Figure 6 - Variation of an area depending on the location of the digitized boundary with respect to the original line drawing in IKFM, external (blue), intermediate (red) and internal (green) margins of the border are indicated.

The red line (intermediate part of the border) corresponds to an area of 7.13 hectares (assumed as 100%), while the green line (internal margin of the border) corresponds to an area of 6.43 hectares (90.2% of the intermediate) and the blue line (external margin of the border) corresponds to an area of 8.08 hectares (113.3% of the intermediate). It is evident how different the extent of a polygon can be when digitized on the internal or external margin of the border.

The final data were checked for topological errors using the topology checker tools available in QGIS.

Map availability

IKFM has been made available, in both raster and vector format, in a WebGIS, as this type of tool allows the efficient distribution of geographic data and even data processing (Federici et al. 2013).

The map is available through the site carta1936.dicam.unitn.it. The data have been released in the Creative Commons licence and will be free to be downloaded and used in the frame of European communication on open data (http://ec.europa.eu/digital-agenda/en/open-data-0), with the obligation of citing the present paper as a reference.

The system was made available on a virtual machine containing both software and data.

The virtual machine was built using VMware as virtualization software and Xubuntu 15.10 64 bit as a guest OS. The WebGIS is based on Geoserver, Tomcat, PHP, OpenLayers, Ext.js, PostgreSQL, PostGIS and GRASS.

The WebGIS shows the IKFM in vector format, using additional maps for the background to help the user identify the current location. The IKFM can be downloaded in the shape file format.

The digital map data set is based on the 276 maps of Carta Forestale del 1936, and additional maps were downloaded from official or free databases that can be found on the web. The Italian state, region and province boundaries were downloaded from the ISTAT site, and maps with the Slovenian and Croatian borders were downloaded from the GADM database of Global Administrative Areas (http://www.gadm.org/). Maps with the main roads, rivers and railways were taken from the www.OpenStreetMap.org site and were processed to reduce the number of geographical entities. Maps with the lakes (category 5.1.2 Inland waters, Water bodies) were derived from Corine Land Cover version 13 (02/2010) using the Italian boundaries.

The data are displayed using the spherical projection EPSG:3857.

The vector IKFM forest data are represented using different colours for each of the 25 subcategories in the map, trying to be coherent with the original category colours (Tab S1).

In the download section of the WebGIS, it is possible to select the maps to download. The system automatically selects the raster maps covering the area in the current visualization window and clips the vector map to the same window.

It is possible to download the whole vector map in a single file for Fuso Ovest (west zone EPSG:3003) and a single file for Fuso Est (east zone EPSG:3004), including Istria.

Tests on the data set

We carried out some basic analysis to verify the data reliability, to check some information about the forest subcategories and to test the possibility of using vector IKFM data.

To emphasize the contribution that this map can offer to ecological studies, it has been used in a study on ecosystems and forest coverage. Therefore we selected a case study in which the modifications to vegetation in the Trentino region, in the North-East of Italy, have been investigated over a period of time spanning almost two centuries (Tattoni et al. 2010, Ciolli et al. 2012). The digital IKFM map was compared to historical cartography, aerial photographs and Natura2000 ecosystem mapping.

Then, area values extracted from the IKFM digital version were compared to original IKFM tables created by hand by Milizia Forestale personnel in 1936, and the results are presented. The IKFM forest cover surfaces were compared to those of IFNI 1985 and INFC 2005 to evaluate whether the results are in line with what is expected and to highlight possible problems and issues.

Finally, some considerations of the forest categories and subcategories are presented, and some IKFM landscape pattern metrics were compared (using Patch Analyst 3.1) among Italian regions in 1936 to evaluate whether the results are reasonable in terms of subcategories quality, quantity and distribution. In our case (vector theme), edge calculations include all the edge on the landscape including boundary edge. In order to set the parameters of the Patch Analyst 3.1 procedure we considered ecologically relevant the differences between different forest subcategories and also relevant the differences between forest/no forest.

Results

The case study we selected (Tattoni et al. 2010, Tattoni et al. 2011, Ciolli et al. 2012) is particularly interesting because reliable historical maps describing the land use in 1800 are available for Trentino (Buffoni et al. 2003). Other maps are available from forest management plans from the 1950s or by photo-interpretation of different series of aerial photographs starting from 1954 and taken in 1973, 1985, 1994, 2000 and 2006.

The information on the total forest cover from the digital IKFM has been successfully compared to the forest situation in 1859 and in 1954, and the results were used to draw conclusions about ecosystem fragmentation, forest expansion and future scenarios (Tattoni et al. 2010, Tattoni et al. 2011, Ciolli et al. 2012, Tattoni et al 2017). To further test whether the IKFM data correctly represent the spatial pattern of the existing forest in 1936, they were also compared to photographic documentation available in touristic images or postcards from the same period (Tattoni et al. 2010).

Forest and land surface

A first apparently obvious use of IKFM data is to collect simple statistics regarding the forest cover total area and macrocategory distribution. The total forest area in the map is approximately 6'000,'000 ha (Tab S2), with 76% broadleaves, 18.4% conifers and 5.6% degraded forest. Overall, mixed forest (broadleaves or conifers) represents 42% of the total forest area. Nevertheless, a comparison of the total values calculated using the IKFM digital data and the summary paper tables that were originally provided by IKFM in 1936, containing the areas of the forest calculated for each administrative region (Province) and the macro regions or zones (north, centre, south and islands), reserves some surprises.

The area values in these tables are not coherent, as the same totals evaluated from different partial subtotals are different, and nor do they agree with the areas computed from the digital map (Tab. 2).

Table 2 - Comparison between areas from IKFM tables measured and calculated by hand in 1936 and areas calculated with GIS from the digital map (Italian boundaries at 1936). The four values should ideally coincide and should be similar to the digitized IKFM, but the sum of the forest calculated for each administrative region (province) and subtotals for macro regions (zones) are not coherent, probably due to the use of manual calculations in 1936. These tables were officially used to produce statistics in the past, and this highlights the importance of the digital version of this document.

Source	Type of sum	Surface ha	difference % compared to shp
IKFM report paper	tables of the provinces	5'519'900	14.0
IKFM report paper	Summary of forest-zones	6'047'460	5.7
IKFM report paper	Summary of forest-province	6'057'462	5.6
Digitized IKFM shp	fuso est with istria + fuso ovest	6'415'473	-

The comparison (Tab S3) of the IKFM - that represents a picture of the Italian forest distribution, cover and surface (Marchetti et al. 2009) in 1936 - with successive situations in 1985 (IFNI 1985) and 2005 (IFNC 2005) shows different situations and trends.

The same regions (Liguria and Trentino-Alto Adige), have the highest values of forest cover percentage in all three surveys. Conversely, the forest cover percentage for Sardinia increases considerably, exceeding the value for Tuscany in the 2005 survey.

Overall, the forest cover increased by 43.9% in 1985 and by 73.6% in 2005 with respect to 1936. The

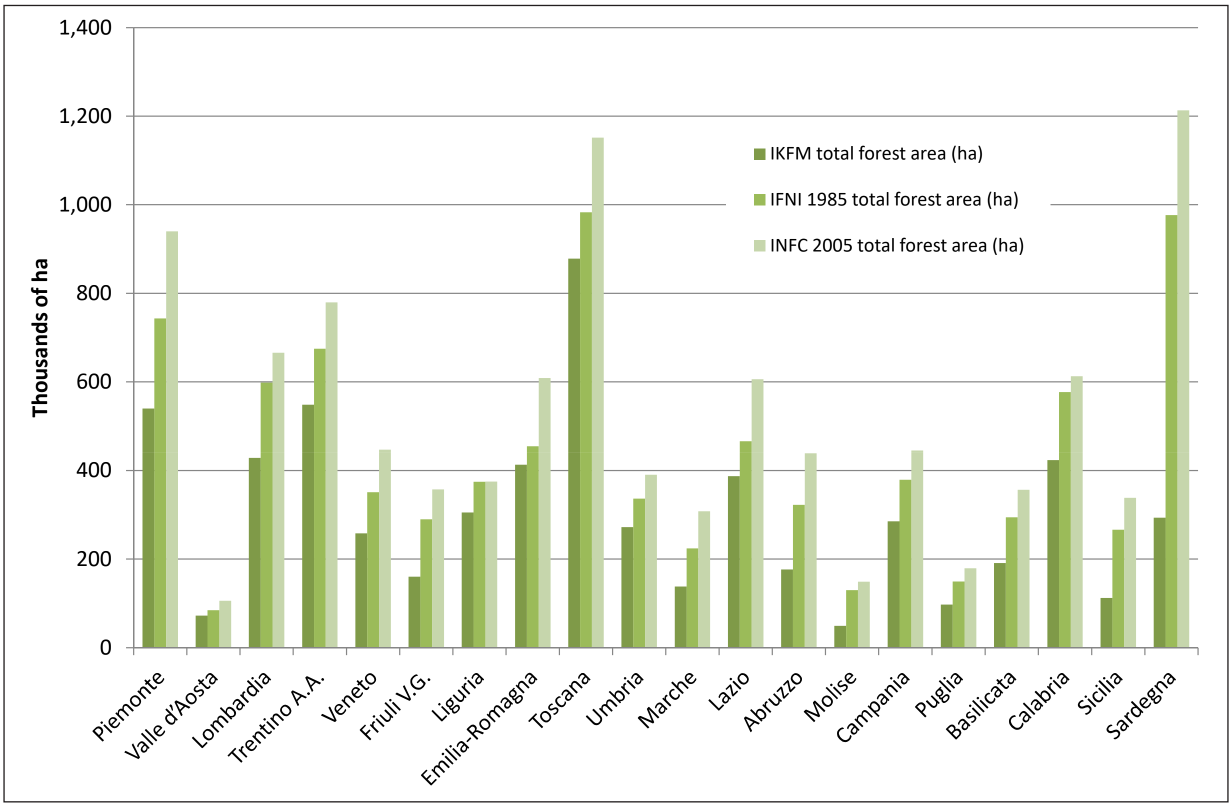

Figure 7 - Forest coverage (hectares) in Italian regions as originally recorded from the analogue IKFM 1936 and two later forest inventories, the IFNI 1985 Inventario Forestale Nazionale [Forest National Inventory] and the INFC 2005 Inventario Nazionale delle Foreste [National Inventory of Forests]. An increasing trend can be observed across regions.

forest cover percentage grew from 20% to 28.8% to 34.7% over the same time span.

While the forest cover increased in every region, the increment ranges from only 22.9% in Liguria to more than 300% in Sardinia (Fig. 7) .

In IKFM, the most common forest species (fig. 8) are 5: Broadleaves: other species or mixed wood, *Quercus robur/Quercus petrea*, *Castanea sativa*, *Fagus sylvatica*, and Mixed conifers (*Abies alba*, *Picea abies*, *Larix decidua*).

Landscape pattern metrics in 1936

The application of some landscape pattern metrics allows for a comparison of each forest subcategories in 1936 (Tab S4) and the total forest cover in the different regions of Italy in 1936 (Tab S5). For exemplifying, we can consider a landscape analysis of the IKFM by region highlights the results of the forest patch mean size, median size and total number for the Emilia-Romagna and Marche regions. Those two regions showed low values of the forest mean patch size and high total patch numbers; on the opposite the patches in Trentino-Alto Adige were larger and significantly less numerous.

Regarding the patterns of the different forest species, Turkey oak woods usually features large patches with mean patch sizes larger than those of patches of beech forest.

Large patches are also common for Cork oak, chestnut and mixed conifers. Mixed conifers account for a huge surface.

A very evident finding is that stone pine forests feature a high mean shape index.

Discussion

Forest and land surface

As reported before, the area values in Tab. 2 are not coherent.

These differences are possibly due to a series of factors:

a) approximation errors;
b) errors in the evaluation of the surfaces in 1936 (the way they were computed is unknown, but the staff definitely measured the polygons and performed the sum of all the areas by hand);
c) involuntary omissions of some of the polygons;
d) transcription errors on the final document.

It appears that the sum carried out in 1936 measuring by hand the individual polygons and summing them up was not reliable. The different sums (Province, Summary of forests-zones and Summary of forests-province) should reach the same measures of the total surface area, therefore some errors are present in the original paper documents (not in the paper map). It is clear that summing up more than 63'000 polygons by hand could introduce calculation errors. It is therefore highly probable that if some of the forest statistics at the national level calculated in the 1930s and later periods relied on these paper data, these statistics obtained imprecise results. The transformation of the IKFM into vector format makes available a more robust and consistent geo-referenced database that can be analysed using GIS.

The comparison (Tab S3) of the IKFM with successive situations in 1985 (IFNI 1985) and 2005 (IFNC 2005) is obviously affected by approximations and errors, which can be described but not evaluated; the main problems are due to the facts that

a) data have been collected using completely different instruments;
b) instructions given in 1936 to personnel for the survey are unknown;
c) although minimal, transformations from analogue (paper) to digital maps inevitably introduce approximations.

Even with the considerations above, common to other studies that deal with historical forest maps (Kaim et al. 2014), a comparison (Vizzarri et al. 2015) can lead to interesting considerations.

The comparison results (Tab S3) are compatible to the landscape dynamics described in the areas (Falcucci et al. 2006), the general forest cover trend is confirmed in every region (Fig. 7) and the results are in line with what is expected and described and basically confirm the general validity of the IKFM data.

Regarding the reliability of the IKFM forest classification system, some interesting considerations about the forest species (mixing categories and subcategories) in IKFM arise from a simple observation of the distribution of the different forest species (Fig. 8).

The "Broadleaves, other species and mixed wood" category is the most common, but it seems reasonable to suppose that this class includes every forest that the surveyors were not able to classify, so it must be treated with caution. The *Quercus robur/petraea* is also very common but, according to the knowledge of the 1936 forest species distribution, the suspicion is raised that mistakes in the attribution of patches to *Quercus cerris*, *Quercus pubescens* and *Quercus robur/petrea* have occurred. This fact must be taken into account if data are used to compare the present situation, and the different IKFM Quercus species should be grouped into a single one.

Landscape pattern metrics in 1936

The application of some landscape pattern metrics allows for a comparison of each forest subcategories in 1936 (Tab S4) and the total forest cover in the different regions of Italy in 1936 (Tab S5). This comparison may be useful both to understand whether the forest landscape described by the categories and subcategories is plausible based on the peculiarities of the different regions and to determine whether the forest subcategories indicated in the legend can be trusted. In Emilia-Romagna and Marche regions the low values of the forest mean patch size and high total patch numbers can be explained by the fact that these regions are mostly covered by plains and low hills, with widespread agricultural activity and a more fragmented forest environment. In mountainous areas with low population density and agricultural activity, the patches in 1936 were larger and significantly less numerous, describing a forest management approach with large areas (Trentino-Alto Adige).

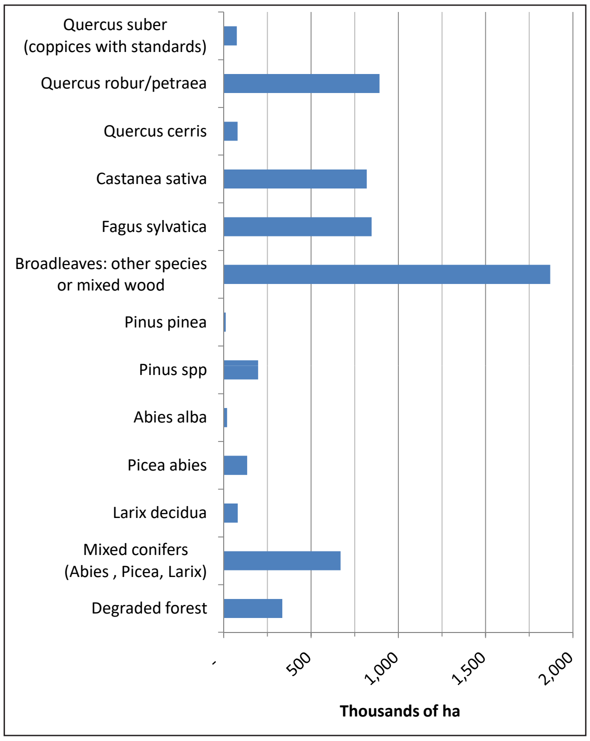

Figure 8 - Forest coverage in hectares according to the original 1936 categories of IKFM.

Regarding the patterns of the different forest species, Turkey oak woods usually features large patches, typical of diffuse forests cultivated wherever possible, with mean patch sizes larger than those of patches of beech forest.

It is hard to tell how much the large surface of Mixed conifers is affected by the very general classification.

The high mean shape index for stone pine forests is mostly due to the fact that their patches have stretched shapes along the coasts.

Considering the above examples, we can say that despite the 1:100'000 scale of the IKFM, the landscape patterns are compatible with the situation in 1936 and contain very descriptive information, at least for some classes, although the generic classification system suggests the need for caution if researchers want to compare these classification system across different periods.

The considered case study clearly demonstrate that with the digital format it is possible to create maps for each forest subcategories that are useful, in assessing forest subcategories distributions or to build custom maps describing the status in 1936 that can be checked against the current situation or historical data. Finally, the use of the digital IKFM in determining the total forest cover is reliable.

Conclusions

The availability of the IKFM makes it possible to fill a gap in the Italian forest mapping timeline, providing accurate, complete and interesting information for researchers who are interested in the study of landscape and ecological changes.

The transformation into vector polygons allows the manipulation of data through the connected database, exploiting its efficiency and flexibility in data querying and processing.

SQL allows a profitable storage of otherwise unavailable information, like the numbers of conifer symbols, although the reliability of these data must be carefully investigated.

The information in the IKFM map has already proven to be useful in reconstructing the total forest cover in past situations at local scale (Geri et al. 2010, Tattoni et al. 2010, Tattoni et al. 2011, Ciolli et al. 2012, Amici et al. 2013, Biasi et al. 2015, Salvati et al. 2015, Tattoni et al 2017) and at country scale (Cammaretta et al. 2017, in the press).

Because the Italian border changed before and after 1936, the data in this map have a super-national value. Some forest areas mapped in the IKFM are presently part of Slovenia, Croatia or France and can now be used to study forest changes in those countries. Moreover, the borders of Italy touch France, Switzerland, Austria, Slovenia and Croatia, and researchers in all these countries may be interested in the historical ecological features on the boundaries, as the borders can have a significant effect on their neighbourhood.

Given the currently available GIS tools and the features of the original material, the manual interpretation and digitization was more productive than a mixed approach based on automatic recognition and a posteriori manual correction. The description of how we dealt with the many technical and practical problems encountered in the creation of this map can be useful for the digitization of similar historical maps in other contexts.

The studies in the historical archive and the tests we carried out highlight validity of the IKFM for GIS processing, although the limits and uncertainties of the original forest classification and thereby of the digitized data must be taken into account by users.

We encourage the research community to perform further studies and comparisons using 1930s historical material at the national but also at the regional and local levels that will help further elucidate the significance of the single forest subcategories adopted for the classification in IKFM.

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Tab S 1: VALUES is the ID number of the subcategory, COLOUR is the colour that represents the IKFM category, LABEL is the original IKFM subcategories label, GRASSRGB is the RGB (Red, Green, Blue) value that encodes the colour in GRASS that matches the original colour of the paper map.

VALUE	COLOR	LABEL	GRASSRGB
0	purple – viola	Conifer - RESINOSE	155:80:125
1	purple – viola	Conifer Norway spruce - RESINOSE ABETE ROSSO	155:80:125
2	purple – viola	Conifer Silver fir - RESINOSE ABETE BIANCO	155:80:125
3	purple – viola	Conifer Larch - RESINOSE LARICE	155:80:125
4	purple - viola	Conifer other pines - RESINOSE PINI	155:80:125
5	purple - viola	Conifer Stone pine - RESINOSE PINO DOMESTICO	155:80:125
6	blue - azzurro	Beech high forest - FAGGIO alto fusto	123:169:156
7	blue - azzurro	Beech coppice with standard - FAGGIO ceduo composto	123:169:156
8	blue - azzurro	Beech coppice - FAGGIO ceduo	123:169:156
9	brown - marrone	Sessile oak and English oak high forest - ROVERE E FARNIA alto fusto	150:35:35
10	brown - marrone	Sessile oak and English oak coppice with standard - ROVERE E FARNIA ceduo composto	150:35:35
11	brown - marrone	Sessile oak and English oak coppice - ROVERE E FARNIA ceduo	150:35:35
12	brown - marrone	Turkey oak high forest - CERRO alto fusto	150:35:35
13	brown - marrone	Turkey oak coppice with standard - CERRO ceduo composto	150:35:35
14	brown - marrone	Turkey oak coppice - CERRO ceduo	150:35:35
15	orange - arancione	Cork oak high forest - SUGHERA alto fusto	255:120:15
16	orange - arancione	Cork oak coppice with standard - SUGHERA ceduo composto	255:120:15
17	orange - arancione	Cork oak coppice - SUGHERA ceduo	255:120:15
18	green - verde	Chestnut high forest - CASTAGNO alto fusto	125:160:80
19	green - verde	Chestnut coppice with standard - CASTAGNO ceduo composto	125:160:80
20	green - verde	Chestnut coppice - CASTAGNO ceduo	125:160:80
21	yellow - giallo	Broadleaves: other species or mixed wood high forest - ALTRE SPECIE O MISTI alto fusto	255:190:65
22	yellow - giallo	Broadleaves: other species or mixed wood coppice with standard - ALTRE SPECIE O MISTI ceduo composto	255:190:65
23	yellow - giallo	Broadleaves: other species or mixed wood coppice - ALTRE SPECIE O MISTI ceduo	255:190:65
24	pink - rosa	Degraded forest - BOSCHI DEGRADATI	243:87:125
25	none - nessuno	Not classifiable - NON CLASSIFICABILE	
99	none - nessuno	Island - ISOLA	

Tab S2: Areas for forest subcategories, categories and macrocategories from IKFM vector map (Italian boundaries at 2016), as reported in the original legend.

Forest subcategories	**IKFM subcategories**		**Categories**		**Broadleaves-Conifers (macrocategosies)**	
Name of IKFM subcategories	**ha**	**%**	**ha**	**%**	**ha**	**%**
01 - Quercus suber - high forests	64,080	1.06				
02 - Quercus suber - coppices	10,393	0.17				
03 - Quercus suber - coppices with standards	394	0.01	74,867	1.2		
04 - Quercus robur/quercus petraea - high forests	134,788	2.24				
05 - Quercus robur/quercus petraea - coppices	681,010	11.30				
06 - Quercus robur/quercus petraea - coppices with standards	76,324	1.27	892,122	14.8		
07 - Quercus cerris - high forests	57,990	0.96				
08 - Quercus cerris - coppices with standards	21,667	0.36	79,657	1.3		
09 - Castanea sativa - high forests	481,323	7.98				
10 - Castanea sativa - coppices	323,760	5.37				
11 - Castanea sativa - coppices with standards	13,762	0.23	818,845	13.6		
12 - Fagus sylvatica - high forests	260,912	4.33				
13 - Fagus sylvatica - coppices	550,782	9.14				
14 - Fagus sylvatica - coppices with standards	35,238	0.58	846,932	14.0		
15 - Broadleaves: other species or mixed wood - high forests	146,146	2.42				
16 - Broadleaves: other species or mixed wood - coppices	1,586,647	26.32				
17 - Broadleaves: other species or mixed wood - coppices with standards	137,009	2.27	1,869,802	31.0	4,582,225	76.0
18 - Pinus pinea 10,993	0.18					
19 - Pinus spp 197,222	3.27					
20 - Abies alba 19,345	0.32					
21 - Picea abies 133,820	2.22					
22 - Larix decidua 79,848	1.32					
23 - Mixed conifers (Abies alba, Picea abies, Larix decidua)	669,262	11.10			1,110,490	18.4
24 - Degraded forest	335,588	5.57				
Total	**6,028,303**	**100.00**				

Tab S3: Comparison between areas in IKFM (Italian boundaries at 2016) and in later forest inventories, the IFNI 1985 Inventario Forestale Nazionale [Forest National Inventory] and the INFC 2005 Inventario Nazionale delle Foreste [National Inventory of Forests]. The last three columns report the forest coverage percentage. Calculations were carried out using present Italian boundaries.

	IKFM forest area (ha)	IFNI 1985 forest area (ha)	IFNC 2005 forest area (ha)	Total area from INFC 2005 (ha)	Increment from IKFM to IFNI 1985 %	Increment from IKFM to IFNC 2005 %	IKFM with respect to total area %	IFNI 1985 with respect to total area %	INFC 2005 with respect to total area %
Piemonte	539.759	743.400	940.116	2.539.983	37,7	74,2	21,3	29,3	37,0
Valle d'Aosta	72.111	84.600	105.928	326.322	17,3	46,9	22,1	25,9	32,5
Lombardia	428.426	598.500	665.703	2.386.285	39,7	55,4	18,0	25,1	27,9
Trentino Alto Adige	548.395	675.000	779.705	1.360.687	23,1	42,2	40,3	49,6	57,3
Veneto	258.063	351.000	446.856	1.839.122	36,0	73,2	14,0	19,1	24,3
Friuli V.G.	159.975	289.800	357.224	785.648	81,2	123,3	20,4	36,9	45,5
Liguria	305.291	374.400	375.134	542.024	22,6	22,9	56,3	69,1	69,2
Emilia Romagna	412.981	454.500	608.818	2.212.309	10,1	47,4	18,7	20,5	27,5
Toscana	878.172	982.800	1.151.539	2.299.018	11,9	31,1	38,2	42,7	50,1
Umbria	272.092	336.600	390.255	845.604	23,7	43,4	32,2	39,8	46,2
Marche	137.839	224.100	308.076	969.406	62,6	123,5	14,2	23,1	31,8
Lazio	387.240	466.200	605.859	1.720.768	20,4	56,5	22,5	27,1	35,2
Abruzzo	176.386	322.200	438.590	1.079.512	82,7	148,7	16,3	29,8	40,6
Molise	49.265	129.600	148.641	443.765	163,1	201,7	11,1	29,2	33,5
Campania	285.251	378.900	445.274	1.359.025	32,8	56,1	21,0	27,9	32,8
Puglia	97.335	149.400	179.040	1.936.580	53,5	83,9	5,0	7,7	9,2
Basilicata	190.981	294.300	356.426	999.461	54,1	86,6	19,1	29,4	35,7
Calabria	423.310	576.900	612.931	1.508.055	36,3	44,8	28,1	38,3	40,6
Sicilia	112.223	266.400	338.171	2.570.282	137,4	201,3	4,4	10,4	13,2
Sardegna	293.205	976.500	1.213.250	2.408.989	233,0	313,8	12,2	40,5	50,4
Italy	**6.028.301**	**8.675.100**	**10.467.533**	**30.132.845**	**43,9**	**73,6**	**20,0**	**28,8**	**34,7**

Tab S4: Main landscape pattern metrics by forest subcategories in 1936 according to IKFM (Italian boundaries at 2016).

Subcategory	Class Area (ha)	No. of Patches	Mean Patch Size (ha)	Median Patch Size (ha)	Patch Size Coefficient of Variance	Patch Size Standard Deviation	Total Edge (m)	Edge Density (m ha^{-1})	Mean Patch Edge (m)	Mean Shape Index
01 - Quercus suber - high forests	64,080	237	270.4	63.4	297.8	805.3	1636629	0.271	6906	1.427
02 - Quercus suber - coppices	10,393	95	109.4	27	224.7	245.8	381584	0.063	4017	1.368
03 - Quercus suber - coppices with standards	394	11	35.8	7.5	142.8	51.2	25857	0.004	2351	1.276
04 - Quercus robur/quercus petraea - high forests	134,788	1311	102.8	24.3	484.1	497.8	5548444	0.92	4232	1.449
05 - Quercus robur/quercus petraea - coppices	681,010	14046	48.5	10.9	380.8	184.6	42629141	7.071	3035	1.425
06 - Quercus robur/quercus petraea - coppices with standards	76,324	898	85	24.6	357.3	303.7	4123837	0.684	4592	1.526
07 - Quercus cerris - high forests	57,990	156	371.7	162.5	167.1	621.2	1623030	0.269	10404	1.635
08 - Quercus cerris - coppices with standards	21,667	75	288.9	122.7	156.4	451.7	795405	0.132	10605	1.804
09 - Castanea sativa - high forests	481,323	4310	111.7	21.4	643.8	719	20655668	3.426	4792	1.492
10 - Castanea sativa - coppices	323,760	4824	67.1	10.9	410.9	275.8	16842695	2.794	3491	1.439
11 - Castanea sativa - coppices with standards	13,762	142	96.9	32.9	303.7	294.4	641227	0.106	4516	1.506
12 - Fagus sylvatica - high forests	260,912	740	352.6	47.1	402.8	1420.3	6568624	1.09	8877	1.558
13 - Fagus sylvatica - coppices	550,782	3629	151.8	19.6	394.6	599	21323939	3.537	5876	1.531
14 - Fagus sylvatica - coppices with standards	35,238	162	217.5	109.1	170.7	371.3	1316624	0.218	8127	1.679
15 - Broadleaves: other species or mixed wood - high forests	146,146	1536	95.1	25.7	275.9	262.5	6489060	1.076	4225	1.498
16 - Broadleaves: other species or mixed wood - coppices	1,586,647	18655	85.1	12.7	618.1	525.7	75039181	12.448	4022	1.513
17 - Broadleaves: other species or mixed wood - coppices with standards	137,009	1003	136.6	29.2	320.5	437.8	5359135	0.889	5343	1.562
18 - Pinus pinea	10,993	110	99.9	44.9	155.3	155.2	626028	0.104	5691	1.725
19 - Pinus spps	197,222	1764	111.8	31.5	577.8	646	8267262	1.371	4687	1.485
20 - Abies alba	19,345	201	96.2	31.6	222	213.7	912082	0.151	4538	1.448
21 - Picea abies	133,820	859	155.8	42.8	300.1	467.5	6167029	1.023	7179	1.682
22 - Larix decidua	79,848	933	85.6	30.4	222.3	190.3	4349101	0.721	4661	1.538
23 - Mixed conifers (Abies alba, Picea abies, Larix decidua)	669,262	2632	254.3	7.1	504.4	1282.7	23447560	3.89	8909	1.573
24 – Degraded forest	335,588	4452	75.4	23.5	271.3	204.5	17965281	2.98	4035	1.493
Italy	6,028,304									

Tab S5: Main landscape pattern metrics by region in 1936 according to IKFM (Italian boundaries at 2016).

Regione	Total area (ha)	IKFM with respect to total area %	Total Landscape Area (ha)	No. of Patches	Mean Patch Size (ha)	Median Patch Size (ha)	Patch Size Coefficient of Variance	Patch Size Standard Deviation	Total Edge (m)	Edge Density (m ha^{-1})	Mean Patch Edge (m)	Mean Shape Index
Piemonte	2,539,983	21.3	539,759	7178	75.2	18.5	417	313.6	30,005,754	55.6	4,180	1.56
Valle d'Aosta	326,322	22.1	72,111	382	188.8	38.2	264.8	499.9	3,266,408	45.3	8,551	1.82
Lombardia	2,386,285	18.0	428,426	4827	88.8	20.2	364.6	323.6	22,293,841	52.0	4,619	1.54
Trentino Alto Adige	1,360,687	40.3	548,395	1849	296.6	20.6	467.6	1386.8	20,145,831	36.7	10,896	1.78
Veneto	1,839,122	14.0	258,063	3514	73.4	8.4	705.7	518.3	13,008,625	50.4	3,702	1.46
Friuli V.G.	785,648	20.4	159,975	2953	54.2	12.1	401.8	217.7	9,093,626	56.8	3,079	1.36
Liguria	542,024	56.3	305,291	2806	108.8	24.4	309.6	336.8	13,926,153	45.6	4,963	1.55
Emilia Romagna	2,212,309	18.7	412,981	11991	34.4	6.6	480.1	165.3	30,677,459	74.3	2,558	1.43
Toscana	2,299,018	38.2	878,172	7417	118.4	18.7	630.6	746.7	35,874,774	40.9	4,837	1.50
Umbria	845,604	32.2	272,092	3677	74.0	15.4	498.2	368.7	14,493,127	53.3	3,942	1.50
Marche	969,406	14.2	137,839	4485	30.7	8.5	356.8	109.7	11,493,911	83.4	2,563	1.47
Lazio	1,720,768	22.5	387,240	3737	103.6	20.5	364.7	377.9	18,113,481	46.8	4,847	1.59
Abruzzo	1,079,512	16.3	176,386	1864	94.6	17.1	392.9	371.8	7,520,025	42.6	4,034	1.45
Molise	443,765	11.1	49,265	372	132.4	44	303.8	402.3	1,882,157	38.2	5,060	1.51
Campania	1,359,025	21.0	285,251	1220	233.8	53	386.4	903.4	8,321,351	29.2	6,821	1.52
Puglia	1,936,580	5.0	97,335	1648	59.1	12.6	434.5	256.6	5,018,226	51.6	3,045	1.40
Basilicata	999,461	19.1	190,981	1505	126.9	28.1	324.6	411.9	8,197,905	42.9	5,447	1.58
Calabria	1,508,055	28.1	423,310	1665	254.2	55.4	408.1	1037.5	11,723,711	27.7	7,041	1.52
Sicilia	2,570,282	4.4	112,223	651	172.4	42.8	292.6	504.4	3,300,331	29.4	5,070	1.34
Sardegna	2,408,989	12.2	293,205	906	323.6	112.9	351.2	1136.7	7,115,612	24.3	7,854	1.45
Italy	11,226,157	20.0	6,028,304	62781	96.0	15.7	552.7	530.7	272,734,424	45.2	4,344	1.49