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## The Floodplain Woods of Tuscany

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### ABSTRACT

The contraction of lowland forests throughout Europe began in remote times and then intensified strongly with land reclamation by agriculture and urbanization during the first half of the last century. We present a map of the Floodplain Woods of Tuscany on a scale of 1:300,000 as a synthesis of that built at the scale of 1:10,000 and the methods used to obtain it. Nearly 90% of the patches contain habitats of concern to conservation, according to the Habitat Directive. The Tuscan Floodplain Woods remained prevalent in coastal areas, where some levels of protection are guaranteed by the presence of several protected areas, whereas they have practically vanished in the other parts of the regional territory. The resulting patches are very small and distant from each other, so only in-depth management of all potential floodplain forest areas, taking into consideration patches for their regeneration, can be useful to assure their conservation.

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## 1. Introduction

According to Schnitler, Hale, and Alsum (2007), floodplain forests represent one of the major forest communities in Europe and one of the biodiversity hotspots (Geilen et al., 2004; Ward, Tockner, & Schiemer, 1999). The contraction of lowland forests throughout Europe began in remote times and probably increased when the Romans enlarged the agricultural areas of their Empire. This trend has intensified strongly over time, with the exception of during Middle Ages (Sereni, 1961), due to increasing land reclamation and urbanization, at least until the first half of the last century, and has affected most of the European floodplain areas (Muller, 1995). The landscape of the floodplains is now completely ‘tamed’ and consists mainly of a network represented by communication routes inserted into a mosaic dominated by agricultural and urban areas. In this state of deep transformation, the forest, is now present with small surface area patches and in such a sporadic way as to appear exceptional compared with the environmental context that man has redefined with his work over the centuries.

Apart from this generalization, in Tuscany, some more or less extensive floodplain forests, most often coastal, survive because they are internal to large land properties, often connected to old hunting estates and/or villas and parks. Most other potential areas have been transformed into urban, industrial and agricultural

areas or abandoned, determining a generalized process of rarefaction and fragmentation of forested habitats.

This process of rarefaction of wooded ‘tesserae’ leads to greater landscape banality and to an increase in the level of isolation of the remaining formations, the ‘remnant patches’ according to Forman and Godron (1981). The consequences of this phenomenon determined a sudden worsening of the ecosystem quality of the entire territory because, within anthropized matrices, under a certain threshold of isolation and patch size reduction, the forested patches risk losing much of their functionality and biodiversity. In addition, smaller and more fragmented wooded areas are more likely to undergo degradation processes, in which very often we are witnessing the colonization and subsequent proliferation of invasive alien species (Schnitler et al., 2007), in particular *Robinia pseudoacacia* L., *Ailanthus altissima* Swingle and *Amorpha fruticosa* L. Muller and Sukopp (2016) considered the Central European floodplains the ecosystem most vulnerable to invasion by alien species.

In view of these facts, Europe has implemented its legislation on floodplain habitats by means of several Directives, i.e. Flood Protection, Habitat, Birds and so on (Mauerhofer, 2010). In order to comply with the Code of Cultural Heritage and Landscape (DL 42/2004) and the European Landscape Convention (Council of Europe, 2000), in 2015, the Region of Tuscany approved the new regional Landscape Plan,

aimed at preserving the quality of the places to live beyond the simple aesthetic beauty of a place or a villa, etc.

The plan seeks to integrate the three main components of the landscape: aesthetic-perceptive (aesthetic values), ecological (environmental values of the landscape) and structural (relations between cultural and natural aspects that have been structured over time) (Marson, 2016). In particular, the plan identifies the ‘woods figuratively characterizing the territory’, having a protection value from a visual point of view and the ‘Floodplain Woods’ (FW), endowed with an ecological landscape reading: for these types of forest, there is a regulation of ineligibility for the construction of buildings and/or artefacts (see: Invariante II° – I caratteri ecosistemici dei paesaggi = Ecosystemic Characters of the Landscape; Art. 8 of the Discipline of the Plan).

One of the problems detected immediately after the plan approval phase was that a discipline constrained by strict rules or laws does not correspond to a clear definition of what is meant by ‘Floodplain Woods’, and there is no cartographic apparatus capable of identifying these assets with sufficient precision. These woods were in fact identified on a small-scale (1:1,000,000) cartograph contained in a section of the plan dedicated to the treatment of structural invariants (Regione Toscana <http://www502.regione.toscana.it/geoscopio/pianopaesaggistico.html#>). WMS Geoscope Service of the regional administration (2013) (<http://www502.regione.toscana.it/geoscopio/ortofoto.html>).

According to Ellenberg (1988), Arrigoni (1998) and Bernetti (2005) the floodplain forests are the wood vegetation which is established at such a distance from the rivers as to be submerged only during the course of exceptional flooding. The soils in these sites are deep, generally of medium granulometry, with a superficial water table and capillary fringe water ‘always’ within the reach of the roots of the plants. The vegetation that is established in these ecological conditions can be defined as azonal, i.e. not linked to a specific climate but strongly influenced by particular stational/edaphic conditions (e.g. wetlands in our case).

In almost all of Europe, these woods are dominated by the same deciduous broadleaf species: the black alder (*Alnus glutinosa* L.) Gartner in the marshiest areas and the English oak (*Quercus robur* L.) in the typical floodplains. To these species, in our region elm (*Ulmus campestris* L.) and southern ash (*Fraxinus oxycarpa* L.) Bieb.) must be added. In the perfluvial areas, where the influence of river dynamics is no longer effective, like dead meanders, *coenoses* dominated by poplars (*Populus nigra* L. and *P. alba* L.) with elm and residual individuals of white willow (*Salix alba* L.) can be found. The flat sites can also be placed in areas where the water table does not lead to meso-hygrophilous and thermophilous conditions. In these sites, there are species such as the Turkey oak

(*Quercus cerris* L.), the white hornbeam (*Carpinus betulus* L.), the farnetto (*Q. frainetto* Ten.) and, more rarely, the southern ash tree. In recent decades, *Robinia pseudoacacia* L. has become one of the most relevant trees of the Tuscan landscape, especially in the wetter stations, like those investigated in this work. In view of these facts, we decided to also take into consideration the patches where this species is present but only where the conditions for possible naturalization of these places appears to be going on. Recently, a study concerning the phytosociological characterization of these woods has been carried out by our group.

The aim of this survey is to identify, under the aforementioned conditions, and map the FW (FW) on a scale of 1:10,000, for the whole Tuscan territory.

## 2. General setting

Tuscany has an area of 22,991 km<sup>2</sup> and is located on the Tyrrhenian side of the Italian peninsula, between 44°28' and 42°12'N and between 9°42' and 12°27'E. Its altitude ranges from sea level to more than 2000 m (Mt. Prado); climate varies from arid thermo-Mediterranean to supra-Temperate hyperhumid (Blasi, 2010; De Dominicis, Angiolini, & Gabellini, 2010). Finally, it has a high diversity in the type of geological substrata, with calcareous and siliceous sedimentary rocks, volcanic, magmatic and metamorphic rocks, ultramafic outcrops, etc. (Carmignani & Lazzarotto, 2004). Superimposed on these natural factors is a long history of human influence, which has also profoundly shaped the landscape.

## 3. Materials and methods

The realization of the vegetation map follows the process suggested by Zonneveld (1979) and Küchler and Zonneveld (1988). From the Corine Land Use of Tuscany, we delimited all the patches belonging to the classes of Corine Land Cover 3.1.1, 3.1.3, and 3.2.4 (respectively: Broad-leaved forest, Mixed forest, and Transitional woodland-shrub: <https://biodiversity.europa.eu>). In accordance with the definition of forest expressed in the Tuscan LR 39 2000 (art.3), we selected areas with these characteristics: tree cover values more than 20%, surface more than 2000 m<sup>2</sup>, and minimal width larger than 20 m. Twenty-nine patches with a smaller area were determined to be worthy of inclusion due to their proximity to lakes in large areas with no other floodplain forests. In parallel, a Digital Terrain Model (DTM), elaborated in a grid of 10 × 10 m, was built. The analysis of the site characteristics of about 200 published and unpublished phytosociological relevés, distributed in the Tuscan territory and neighbouring areas, with some preliminary personal investigations, showed that the larger parts of the floodplain

woods of Tuscany were distributed in sites with slopes of no more than 2° and elevations below 100 m.a.s.l.

By means of ArcGIS software (version 10.5), we overlaid the first map, derived from the characteristics of vegetation previously defined, with the map of the sites with slopes of no more than 2 degrees and elevations below 100 m.a.s.l.

All the patches were checked successively by means of aerial photo analysis of images taken in 2016 with a resolution of 20 cm (Geoscopio\_wms Ortofoto 20 cm 2016 AGEA – Consorzio TeA) and integrated with the use of Google Maps and Bing Maps to help in the interpretation of land-use soil. The Forest Inventory of Tuscany (IFT: Inventario Forestale della Toscana, Regione Toscana, 2009) was used to help in identifying the presence of the typical tree species of floodplain woods (*Alnus glutinosa*, *Quercus robur*, *Ulmus campestris*, *Fraxinus oxycarpa*, *Populus nigra*, *P. alba*, *Salix alba*, *Quercus cerris*, *Carpinus betulus*, and *Q. frainetto*). In the end, a map with the potential patches containing floodplain woods was realized.

Patches located by these analyses were investigated in the field and, according to the diagnostic species detected, were referred to as Floodplain Woods (FW) or not Floodplain woods (NO-FW). For NO-FW, we intended to include wooded areas, found in the area delimited as above, with none of the three species previously defined or with deeply degraded woods, especially due to the invasion of *Robinia pseudoacacia* L.; and on sites where no restoration seems possible, true riparian linear woods, poplar plantations, and private or public parks.

Figure 1 shows the essential steps of the methodological process used in the realization of the map.

To analyse the landscape position of FWs, we tested the relationships between two thematic maps available for the Tuscany region: the Vegetation Series (Blasi, 2010) and the Morphogenetic Systems of the Landscape Plan maps (Carnicelli, Baldi, Garzonio, & Cadrezzani, 2016; <http://www502.regione.toscana.it/geoscopio/pianopaesaggistico.html#>).

The latter, here referred to as Geomorphotypes (GMT), are derived from the Land Units of Zonneveld (1979), adapted for use on heavily anthropized land.

To test the frequency of finding GMT and vegetation, we first simplified the typologies found in these documents to obtain six different derived GMT and four types of vegetation; some adjustments to the original GMT definition were made based on the field survey. Subsequently, we tested their distribution with respect to a random distribution generated by 2000 permutations, using a chi-square test. We compared the frequencies of grid cells occupied by FW against those occupied by NO-FW, calculated in a raster with grid cells of 10 × 10 m and distinguishing different classes of GMT and vegetation. Following a significance test, to verify which frequencies of

observed types differed significantly from the expected, random frequencies, standardized residuals were used. According to Agresti (2007), the residuals were calculated by means of the following formula: (Observed Frequencies – Expected Frequencies)/square root (V), in which V represents the residual variance of the cells. If the absolute value of the residual standardized in the cells is greater than 2, then it means that the observed frequency is significantly different from the expected one (lower in the case of a negative value and higher in the case of a positive value).

The presence of habitats in Directive 92/43 CEE was detected directly by visual identification or indirectly through data transfer from the available information provided by the HaSCITu (Habitat in the Sites of Conservation Interest in Tuscany) program of the Tuscan Regional Administration (<http://www.regione.toscana.it/-/la-carta-degli-habitat-nei-siti-natura-2000-toscani>), for the Special Areas for Conservation (SAC). Identification of habitat types was made by the use of available Habitat Interpretation Manuals (Biondi & Blasi, 2009; EU, 2013), re-interpreted for Tuscany and downloadable from the site <http://www.regione.toscana.it/-/la-carta-degli-habitat-nei-siti-natura-2000-toscani>. The habitat type was detected in 1304 patches belonging to the FW. The variation in surface area of the habitats in Directive 92/43 CEE was displayed as a box and whisker plot, using PAST software (Hammer, Harper, & Ryan, 2001).

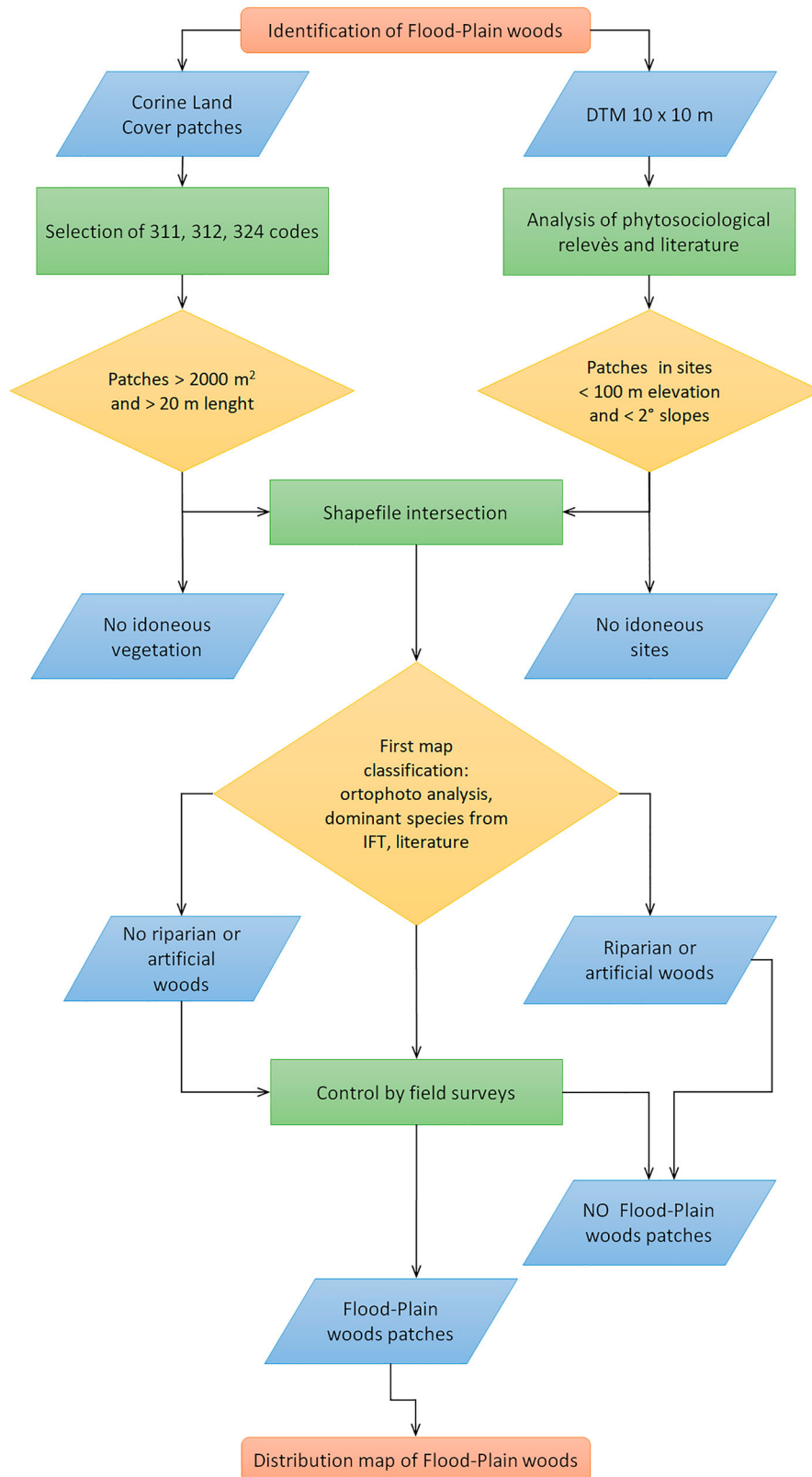
#### 4. Results

Overall, in the photo-interpretation survey, the number of identified polygons was 3098 for an area of 13,191.05 ha. Field control of these patches allowed them to be classified as either FW or NO-FW (Table 1). The distribution of the FW patches is shown in the Map of the Floodplain Woods of Tuscany, on a scale of 1:300,000. In the bottom of the figure, two supplementary maps are shown: 1 – Geomorphotypes (from Carnicelli et al., 2016, simplified) and 2 – Vegetation Series (from Blasi, 2010, simplified); in – the last scheme, a profile of floodplain vegetation is presented.

The total area of the FW of Tuscany is about 6714 ha and represents less than 1% (0.61%) of the whole forested surface area of Tuscany, which is 1,086,000 ha (Regione Toscana, 2012 Regione Toscana.it: 06/11/2012). FW are distributed in 1527 patches. The smallest patch has an area of 0.1 ha (1050 m<sup>2</sup>) and the largest, 136 ha (1,361,574 m<sup>2</sup>).

**Table 1.** Surface (in ha) of Floodplain Woods (FW) and of Non-Floodplain Woods (NO-FW).

Typologies	Patches (num.)	Surface (ha)
Floodplain Woods	1527.00	7531.78
NO Floodplain Woods	1507.00	5659.26
Total	3034.00	13191.05

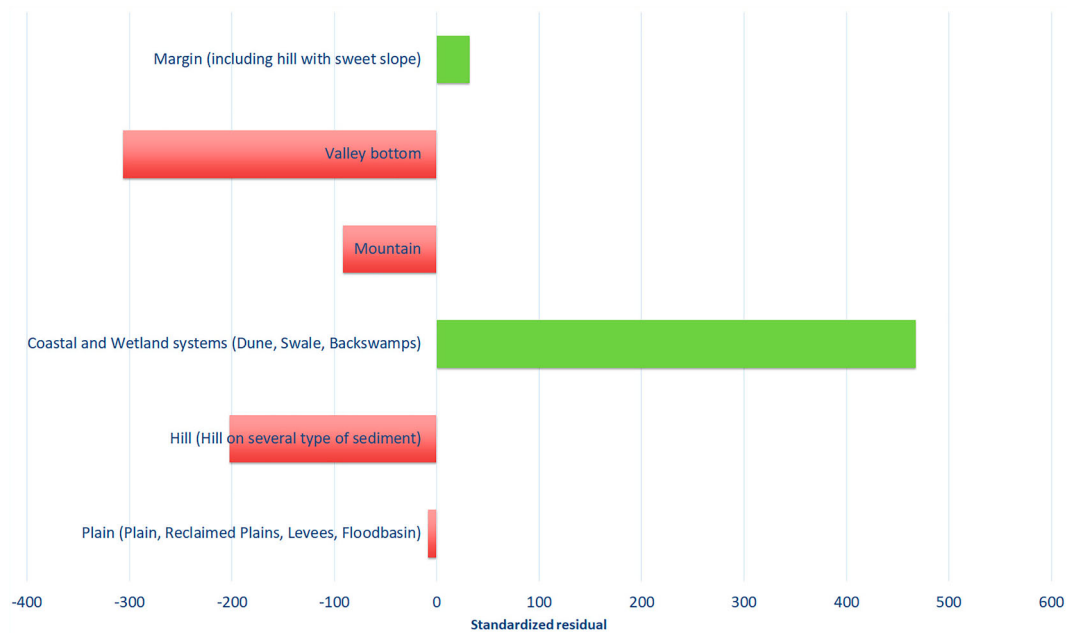


**Figure 1.** Flow-chart of the methodological approach used in the production of the Map of the Floodplain Woods.

In Figures 2 and 3, we report the results of statistical comparison of the presence of FW with the GMT and the Vegetation Series, respectively, following Agresti (2007). With regard to the presence of FW in protected areas, over 70% (72.31%) of these woods are under some form of management-oriented to their conservation. Of these, over 65% fall within the Natura 2000

network (SACs and SPAs). Of course, the proportion of woods outside the Protected Areas system and in particular that of lowland forests (about 25%) remains significant.

The distribution of FW was non-random in different GMT and Vegetation Series (Figures 2 and 3). Concerning GMTs, we verified a net higher frequency of



**Figure 2.** Correlation among the presence of Floodplain Woods (FW) and of Non-Floodplain Woods (NO-FW) (Figure 1) against the geomorphotypes (delimitation as in Figure 1(a)). Pearson’s Chi-squared test with simulated *p*-value (based on 2000 replicates).  $X^2 = 287,860$ ,  $df = NA$ ,  $p\text{-value} = 0.0004998$ . In green positive correlation; in red negative correlation.

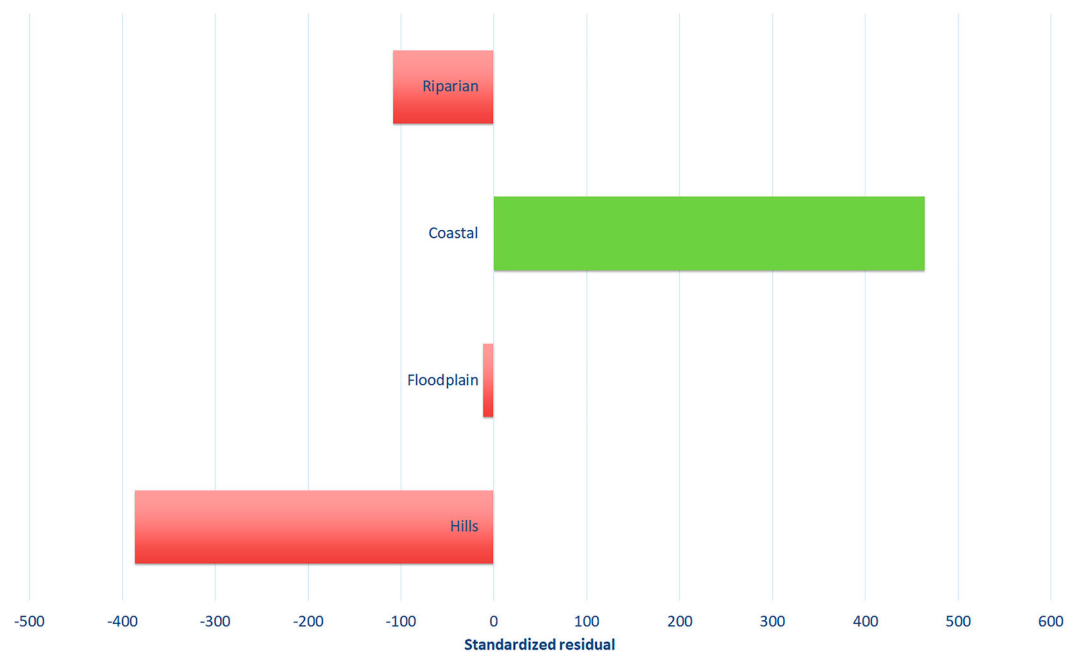
such forests in the Coastal and Wetland systems (Dune, Swale, Backswamps) and, even though the difference was less pronounced, in the Margin. Conversely, all other GMTs showed a frequency of FW that was lower than expected by random allocation. This, in the case of Plains (Plains, Reclaimed Plains, Levees, Flood basins), recalls a peculiar socio-cultural connotation. A similar result was obtained when looking at the Vegetation Series: Coastal Series were the only ones to show a frequency higher than expected by chance,

while Hills Series, Floodplain Series and Riparian Series showed a lower frequency of FW.

The FW can be referred to the following habitats of the Directive 92/43 CEE:

91E0\* Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*)

91F0 Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmion minoris*)



**Figure 3.** Correlation among the presence of Floodplain Woods (FW) and of Non-Floodplain Woods (NO-FW) (Figure 1) against the vegetation series (delimitation as in Figure 1(b)). Pearson’s Chi-squared test with simulated *p*-value (based on 2000 replicates).  $X^2 = 287,860$ ,  $df = NA$ ,  $p\text{-value} = 0.0004998$ . In green positive correlation; in red negative correlation.

**Table 2.** Surface area, number and their ratio of patches referred to habitats of Directive 92/43 CEE.

Habitat types	Area		Patches		Area/ Num. Patches
	Ha	%	Num.	%	
91E0* – Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> ( <i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> )	326.0	5.35	143	11.00	2.28
91F0 – Riparian mixed forests of <i>Quercus robur</i> , <i>Ulmus laevis</i> and <i>Ulmus minor</i> , <i>Fraxinus excelsior</i> or <i>Fraxinus angustifolia</i> , along the great rivers ( <i>Ulmion minoris</i> )	2400.0	39.36	504	38.77	4.76
Mosaic of 91E0*/91F0	779.0	12.77	68	5.23	11.46
9160 – Sub-Atlantic and medio-European oak or oakhornbeam forests of the <i>Carpinion betuli</i>	824.0	13.51	108	8.31	7.63
91M0 – Pannonian-Balkan turkey oak-sessile oak forests	207.0	3.39	19	1.46	10.89
92A0 – <i>Salix alba</i> and <i>Populus alba</i> galleries	1562.0	25.61	458	35.23	3.41
Total	6098.0		1300		4.69

91E0/91F0 Mosaic of the two habitats

9160 Sub-Atlantic and medio-European oak or oakhornbeam forests of the *Carpinion betuli*

91M0 Pannonian-Balkan turkey oak-sessile oak forests

92A0 *Salix alba* and *Populus alba* galleries

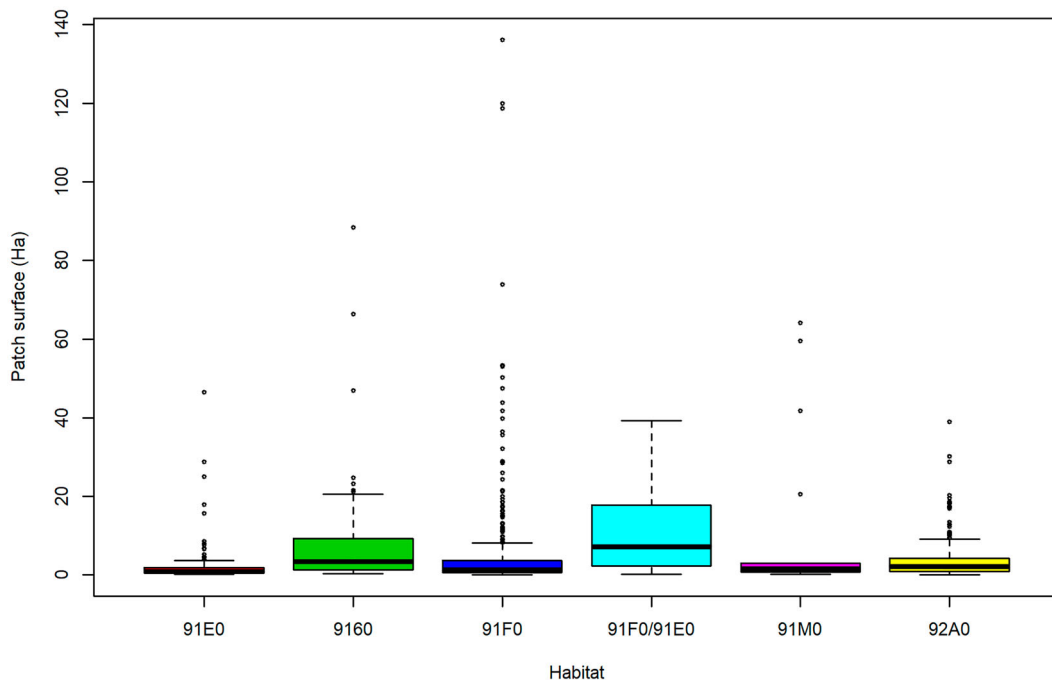
In Table 2 we report the area, number of patches and percentage of both area and number of patches, of habitats of the Directive 92/43 CEE occurring in 1300 patches of the FW for a surface area of 6098 ha (89.78% of the whole FW surface area). In Figure 4

the variation of the surface of the patches belonging to the Habitat is reported.

## 5. Discussion and conclusion

The FW of Tuscany can be considered a ‘vanishing vegetation type’: according to Mondino and Bernetti (1998) ‘the original forest of the plains and the wetlands was progressively eliminated with the agrarian transformations and had its final blow with the land reclamation of the Maremma ended in 1850’. Presently, a large part of these forests are in coastal or retro-dunal areas (see Table 2), whereas they are absent in the large plain areas of inland Tuscany (see the Map of Geomorphotypes in Main Map). The results of the test show that although the FW, as defined in the introduction, have a large potential area (see the Map of Vegetation Series in Main Map), in this area we found other types of woods or other types of vegetation, like plantations, tickets of neoformation of invasive alien species, under the typology NO-FW.

Fortunately, in the coastal areas several types of protected areas (National Parks, Regional, ANPIL (Area Naturali Protette di Interesse Locale), etc. and sites of the Natura 2000 network) are present, so some levels of protection are guaranteed. A large part of these areas is SAC (Special Areas for Conservation), according to the European 92/43 Habitat Directive. The patches referred to in the Habitat Directive have a total mean area of 4.69 ha, ranging from an average area of 2.28 ha in the habitat 91E0 to 11.4 ha in the mosaic of 91E0/91F0. We do not know the minimum patch size in an agricultural landscape (like that of



**Figure 4.** Box and whiskers – plots of the area of the habitats found in the Floodplain woods. Box plots show: median (strike), 25–75% quartile range (box), 5–95% percentile range (whiskers), out-layers °.

the plain of Tuscany) that can support true forested *coenoses*, but it is clear that the smaller the patch size, the higher the edge effect and the potential for alien invasive species movement (Alpert, Bone, & Holzapfel, 2000). Notwithstanding, the forested surface areas of Europe have increased each year since 1990 (European Environment Agency, 2015), but we have to ask ourselves if this process is really a good thing: if just over a third, of the actual FW of Tuscany, were present in the middle of the last century (personal observation), we deduce that the other patches are less than 50 years old, so can they be considered well-structured woods? Anyway the actual Floodplain Woods of Tuscany must be considered as Remnant Patches (Forman & Godron, 1981) and need intensive conservation.

According to Schindler et al. (2016) ‘floodplain ecosystems are a biodiversity hotspots and supply multiple ecosystems services’. Unfortunately, they are under threats for multiple uses from the unilateral anthropogenic point of view: agriculture, settlement and industrial infrastructures, mining and quarries, canalization for hydraulic regulation and/or navigation and so on. These activities alter the structure of the Floodplain Woods, simplifying their species diversity and facilitating the arrival and dispersion of alien species.

For these reasons, the Conservation of FW has received, in recent years, much attention in several European Countries thanks also to the habitat Directive that includes several habitats worthy of conservation connected to the floodplain.

Even if their majority is currently included in ZSC or in Parks and/or Protected Areas of local interest, they have a small surface area and this may not guarantee their conservation in the short- and medium-term, also in light of recent climatic changes. According to Mikac et al. (2018) the drought, determined by the increase of temperature and decrease of river water level, can induce severe stress on Floodplain Woods, especially on *Quercus robur*. The future of these Floodplain Woods will be strictly connected to the possibility of enlarging the sizes of these areas, and of including a mosaic of several stages of regeneration with meadows, scrublands, pre-woodland areas and mature forests: an ideal desirable situation that does not exist substantially at present.

## Software

The Program ESRI ArcMap 10.5 was used for both digitizing vegetation types and final graphic rendering of maps.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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