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ARE ITALIAN STONE PINE FORESTS (*PINUS PINEA* L.) AN ENDANGERED COASTAL LANDSCAPE? A CASE STUDY IN TUSCANY (CENTRAL ITALY)

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*In Tuscany (central Italy), Italian stone pine forests (*Pinus pinea *L.) have characterized the coastal landscape for about five centuries. Coastal stone pine forests provide many goods and services, such as dune stability, protection of arable lands, biodiversity, wildlife habitat, space for tourism and recreation, landscape perception and aesthetic, wood and non-wood forest products. Since the middle of the 20th century this anthropogenic landscape has been diminishing due to changes in forest dynamics and land use. Nowadays, the quality and quantity of goods and services provided by coastal pinewoods are influenced by the adopted management styles and by decision-making factors which depend on temporary socio-economic needs that often veer from sustainable forest management criteria. The objectives of this study were: (i) to map the current distribution of stone pine forests along the Tuscan coast, (ii) to analyze land use and land cover changes between 1954 and 2010, and (iii) to describe the structure and principal dynamics of stone pine forests in this area. Results show that in 2010, stone pine forests amounted to 10 660 ha. Land use changes along the Tuscan coast reflect the trends reported on a national scale: urbanization, abandonment of agricultural areas, and expansion of forested areas. Pure stone pine forests have contracted between 1954 and 2010 while the frequency of mixed stone pine-broadleaf forests has grown as a result of successional dynamics, which have progressively led to a transformation of the coastal landscape. Results are discussed with the intention of providing knowledge to support management of the forest landscape along the Tyrrhenian coast.*

Key words: forest landscape; land use changes; coastal pine forests; forest dynamics; forest management; ecosystem services.
Parole chiave: paesaggio forestale; cambiamenti di uso del suolo; pinete costiere; dinamiche forestali; gestione; utilità ecosistemiche.

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1. INTRODUCTION

In Italy the surface area of Mediterranean pine forests amounts to 226 101 ha, of which 65 522 ha are maritime pine (*Pinus pinaster* Ait.) forests and 46 290 ha are Italian stone pine (*Pinus pinea* L.) forests, with Aleppo pine (*Pinus halepensis* Mill.) forests accounting for 104 734 ha. Stone pine is distributed mostly in Sardinia (12 676 ha), Tuscany (11 201 ha), Sicily (7581 ha) and Lazio (4790) (INFC, 2005).

In Tuscany, stone pine forests have characterized the coastal landscape for approximately five centuries. A large part of this association was planted to stabilize coastal sandy soils after reclamation works, begun by the Medici grand duchy in the 16th century and continued in the 18th and 19th century under the Lorena family (Cantiani and Scotti, 1988).

Since then pine forests have produced important goods and services that have contributed to the socio-economic development of the coastal area and also to the wellbeing of the inhabitants. The pine forests have stabilized dunes and protected agricultural lands from sea winds; provided wood products which, in some areas, continues as the transformation of wood into woodchips (Nardi Berti, 2006; RAFT, 2008; Neri and Piegai, 2009); produced pine nuts, a highly valued product by the food industry which has faced a crisis in Italy with the appearance of the western conifer seed bug (*Leptoglossus occidentalis* Heidemann) in 1999 (Tiberi, 2007); supported production of other non-wood products such as turpentine (Merendi, 1921) and truffles (*Tuber borchii* Vittad.) (ARSIA, 2006); and offered pasture and shelter for sheep and cattle.

Coastal pine forests provide important habitats for the conservation of plant and animal species of naturalistic interest (Pezzo, 2012; Biagioni *et al.*, 2015) and for this reason they are often inserted into sites of the Natura 2000 network (Angelini *et al.*, 2016).

These woodland associations have, over the centuries, carried out and continue to carry out historical-cultural, social, and landscape functions of increasing significance (Giacomini, 1968) in light of the fact that they have contributed to attracting intensive touristic-recreational activities (Ciancio, 2007; Auisio, 2013). Macchiaioli painters depicted them in the mid- to late-19th century as an identifying element of the Tuscan coast.

The functionality and persistence of stone pine forests is, however, threatened by both biotic and environmental adversities. Coastal erosion, which interests approximately 41% of the entire Tuscan coast (Regione Toscana, 2013) is a serious threat for pine forests facing the coast. Where the phenomenon is intense, the first area of erosion is the protective stretch of maritime pines with subsequent exposure of the stone pine canopy to sea winds which cause it to dry out, followed by direct deterioration of the trees themselves (Fanfani, 1973; Gatteschi and Milanese, 1988; Ciancio *et al.*, 2009a). Erosion can also lead to infiltration of seawater into the soil and salinization of the phreatic layer, causing stress to the pine forest and undergrowth, especially in interdunal areas

(Nocentini *et al.*, 2010). Reclamation canals, if they are not maintained efficiently, cannot properly regulate the outflow of water and in rainy periods standing water can accumulate, thus causing further stress to the forest floor. These facts make the pine forest-Mediterranean maquis system particularly vulnerable to attack by parasites. The principal phytopathologies include *Tomicus destruens* Woll, which is responsible for pine forest deterioration, the previously cited western conifer seed bug, responsible for the collapse of pine nut production (Salvadori, 2004), and *Heterobasidion irregulare* Garbel. & Otrosina, an agent of root rot in pines (Gonthier *et al.*, 2015).

The spread of alien species such as *Robinia pseudoacacia* L. in clearings, created when unstable trees fall (Maetzke and Travaglini, 2005), and the increased frequency with which wind storms have occurred in recent years in Tuscany (LaMMA, 2015) are additional critical points to support the protection of coastal pine forests.

Furthermore, the risk of fire along the coast is elevated, especially in summer and in areas where tourist access is free and concentrated. The pressure of tourism also causes problems of soil compaction, in particular where pine forest areas are improperly utilized for car parking in summer months.

In addition to the challenges mentioned thus far, it is necessary to consider the long-standing dilemma of which is the most appropriate silvicultural system for coastal stone pine forests. The classic silvicultural treatment of clear cutting with artificial regeneration, undertaken to optimize the production of fruits and/or wood with a 80-100 years rotation (Merendi, 1921), is considered to be impacting on the environment and landscape. It is the cause of numerous conflicts, especially in protected areas and landscapes, and one of the reasons behind a lack of active management of stone pine coastal forests in recent decades (Ciancio *et al.*, 2009b). In addition, in some areas, the use of pine forests for winter livestock grazing causes conflict between breeders and management agencies due to the disturbance that the animals cause to soil and maquis vegetation (Pezzo, 2012) and problems linked to in-forest foraging and the spread of alien species in the woodland system.

Abandonment of cultivation and progressive aging of these associations, aggravated by the results of a high tree density and the effects of cultivation that aimed, above all, to force production of pine cones and facilitate harvest (Bernetti, 1987; Gatteschi and Milanese, 1988), have unleashed natural dynamics that are gradually transforming the typical pine forest and landscape structure that had been created over the course of centuries. It is therefore urgent to define the best management systems to guarantee active conservation and sustainability of these important cultural landscapes and the combination of goods and services they can provide.

The present work examines the coastal stone pine forests of Tuscany with the aim of characterizing these associations in terms of distribution, stand structure, and developmental dynamics with the following specific objectives: (i) to map the distribution of coastal stone pine forests in Tuscany as of 2010; (ii) to analyze land

use and land cover changes along the Tuscan coast in the period 1954-2010; and (iii) to describe the structure and primary dynamics of coastal stone pine forests. The ultimate objective is to delineate a fact-based overview for reference purposes that both supports the formulation of alternative management approaches and considers the various territorial realities present along the Tuscan coast.

2. MATERIALS AND METHODS

2.1. *Study area*

We examined the strip of land within 2 km of the Tuscan coastline. In some sections, we extended the area 5 km inland to include the most distant pine forests inside the Migliarino San Rossore Massaciuccoli Regional Park located between Torre del Lago Puccini and Calambrone, the forests between Pincipina a Mare and the mouth of the Ombrone river, and the pine forests behind the Burano marsh. All together, the investigated area was 74 517.7 ha (Figure 1). The size of the surveyed area was determined so as to include the principal coastal associations of stone pine.

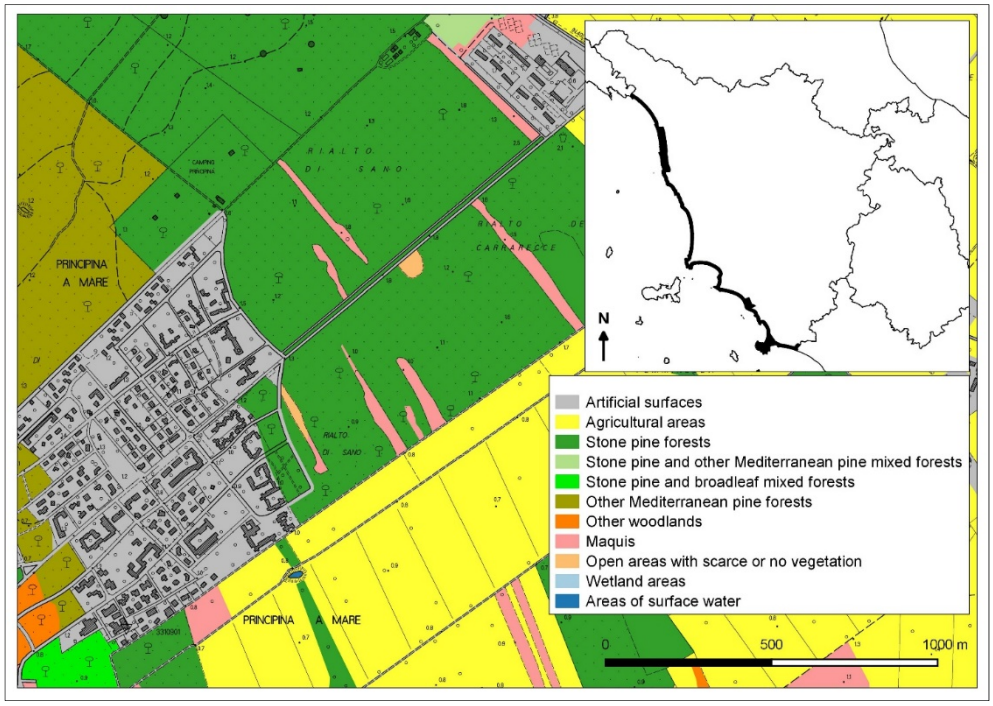

Figure 1 - Study area (in black in the upper right box) and detail of the 2010 land use map.

2.2. *Data*

The study was developed starting from the following spatial databases:

– the physical coastline in 2010 in vector format acquired online from the

Web Map Service (WMS) Geoscopio of the Tuscany Region (http://www502.regione.toscana.it/geoscopio/cartoteca.html#);
- AGEA digital orthophotos from 2010 (scale 1:10 000) in natural color and false color available online through WMS Geoscopio of the Tuscany Region (http://www502.regione.toscana.it/geoscopio/cartoteca.html#);
- Digital orthophotos from GAI flights in 1954 (scale 1:10 000) in grey tones available online through WMS Geoscopio of the Tuscany Region (http://www502.regione.toscana.it/geoscopio/cartoteca.html#);
- Topographic maps (CTR) (scale 1:10 000) available online through WMS Geoscopio of the Tuscany Region (http://www502.regione.toscana.it/geoscopio/cartoteca.html#);
- Land use map from 2007 (scale 1:10 000) in vector format acquired from the portal of the Environmental Monitoring and Modelling Laboratory (LaMMA) (http://www.lamma.rete.toscana.it/territorio/cartografia-tematica/uso-suolo);
- Forestry map of the Kingdom of Italy from 1936 (scale 1:100 000) (Milizia Forestale Nazionale, 1932) available online (Ferretti *et al.*, 2016) in vector format via specific webgis (http://www.sian.it/inventarioforestale/index.do?idNews=9);
- Forest vegetation map in vector format of the La Versiliana farm (scale 1:5000) (Ciancio, 2004), the Tenuta di San Rossore (scale 1:10 000) (Tomei *et al.*, 2003, 2004), the National Nature Reserve of Tomboli di Cecina (scale 1:10 000) (Ciancio, 2007), and the Pineta Granducale of Alberese (scale 1:10 000) (Nocentini *et al.*, 2010).

In addition, forest inventory data were utilized from 12 circular sample plots of 20 m radius (1256 m^2) available from the Department of Agriculture, Food and Forestry Systems of the University of Florence. The plots were equally divided among the coastal stone pine forest types described by Mondino and Bernetti (1998): three plots were located in the La Versiliana forest (Marina di Pietrasanta, Lucca) where "Lowland meso-hygrophilus stone pine forests" (Ciancio, 2004) with stand age >90 years is present; six plots were within the pine forest of Tomboli di Cecina (Marina di Cecina, Livorno) in stands of approximately 80-90 years of age, representative of two forest types, "Wooded dunes with stone pine and holm oak" (three plots) and "Meso-Mediterranean wooded dunes with stone pine" (three plots) (Ciancio, 2007); three plots were in the Pineta Granducale of Alberese (Marina di Alberese, Grosseto) where "Thermo-Mediterranean wooded dunes with stone pine" is present (Nocentini *et al.*, 2010). In each area, the diameter at 1.3 m (DBH) of all trees and shrubs having a DBH greater than 2.5 was measured by a calliper. We also measured the total height and the height to-base of the live crown by Vertex IV Hypsometer.

Considering that the coastal stone pine forests are associations with generally simplified structures, the inventory plots utilized can be considered sufficiently representative to portray a general picture of the historical pine forests in Tuscany.

2.3. *Land use classification in 2010*

The legend to the land use map from 2007, drawn by the LaMMA Consortium, refers to the classes identified in the Corine Land Cover (CLC) project. For woodlands, classes are divided to the III thematic level, distinguishing between broadleaf woodland, coniferous woodland, and mixed conifer-broadleaf woodland; the minimum mapping unit (MMU) for woodland classes is 0.2 ha while for others it is 0.5 ha.

The land use map from 2010, at a scale of 1:10 000, was classified by photo-interpretation of the AGEA digital orthophotos from 2010 and by consulting vegetation maps available in the data set. Effectively, polygons from the 2007 land use map, drawn by LaMMA, were updated. In particular, polygons classified as woodland and semi-natural environments in 2007 were reclassified to distinguish the following land use classes: stone pine forests, stone pine and other Mediterrranean pine mixed forests, stone pine and broadleaf mixed forests, other Mediterranean pine forests, other woodlands, maquis, open areas with scarce or no vegetation. Pure forest classes were distinguished from mixed classes on the basis of crowns cover, using a threshold of 75%. The polygons not classified as woodland in 2007 were reclassified in 2010 at the I thematic level of the CLC. For all classes present in the legend (Table 1), a MMU of 0.5 ha was used.

Table 1 - Legend of land use classes considered in the study.

Land use classes
1. Artificial surfaces
2. Agricultural areas
3. Italian stone pine forests
4. Italian stone pine and other Mediterranean pine mixed forests
5. Italian stone pine and broadleaf mixed forests
6. Other Mediterranean pine forests
7. Other woodlands
8. Maquis
9. Open areas with scarce or no vegetation
10. Wetland areas
11. Areas of surface water

2.4. *Land use classification in 1954*

Land use in 1954 was examined in relation to a sampling of 1113 photopoints which were selected by overlaying the study area with a grid of squares (1 km per side) and selecting one point in each cell at random. The photopoints were assigned to the classes from the land use legend (Table 1), photo-interpreting the digital orthophotos derived from the GAI flight in 1954, using as auxiliary information the 1936 Kingdom of Italy forestry map and verifying by video that the land use attributed to the photopoint respected the MMU requisite of 0.5 ha.

2.5. *Classification accuracy*

Accuracy of the 2010 land use classification was evaluated by visiting in the field a sub-sample group of 309 points extracted at random from the previously identified photopoint sample group (see section 2.4). Instead, accuracy of the 1954 land use classification was evaluated by repeating the photo-interpretation of the photopoints sample by a different technician. In both cases the overall accuracy of the classification was computed (Corona, 1999).

2.6. *Analysis of land use changes*

A multi-temporal analysis was performed to examine land use changes in the study area in the period 1954-2010. Toward this aim, the 1113 photopoints classified for 1954 were superimposed on the 2010 land use map and the usage class for the two years for each photopoint were compared.

2.7. *Structural characterization of coastal Italian stone pine forests*

For each sample plot the following dendrometric variables were determined: number of plants (trees and shrubs), basal area and volume per hectare, quadratic mean diameter (diameter of the tree with average basal area), mean height (height of the tree with quadratic mean diameter), dominant height (mean height of the 100 trees per hectare with the largest diameters), arithmetic mean of heights, arithmetic mean of height to-base of the live crown, standard deviation of diameters, standard deviation of heights. Volumes were estimated from the double entry volume equations developed by Tabacchi *et al.* (2011) for Italian forestry species. Data calculated for the single sample plot were then averaged and aggregated for forest type (Mondino and Bernetti, 1998): A - Lowland meso-hygrophilus stone pine forests; B - Wooded dunes with stone pine and holm oak; C - Meso-Mediterranean wooded dunes with stone pine; D - Thermo-Mediterranean wooded dunes with stone pine.

3. RESULTS

In 2010 the Tuscan coastal territory was characterized by approximately 42% woodlands and other semi-natural environments, 30% agricultural areas, 21% artificial areas, and the remaining 7% was occupied by wetlands and surface water. As a whole, coastal pine forests cover an area of 12 347.7 ha (17% of the surface of the study area). Forests of stone pine and stone pine mixed with other species amount to 9 633.3 ha (12.9% of the study area) and 1027.0 ha (1.4% of the study area), respectively; pine forests of other Mediterranean pines (*Pinus pinaster* Ait. and *Pinus halepensis* Mill.) cover an area of 1687.4 ha (2.3% of the study area). Other woodlands and maquis associations extend over approximately 11 727 ha (15.7% of the study area) and 5638 ha (7.6% of the study area), respectively (Table 2). An extract of the 2010 land use map is presented in Figure 1.

The overall accuracy of the classification of land use was 87% for 2010 and 91% for 1954.

Analysis of changes in land use with regard to the 1954 and 2010 photopoints indicates a marked expansion of artificial areas (+212%) and other woodland associations (+49%), and a reduction in agricultural areas (-41%). In addition to these changes, others worth note include a tendency toward an expansion of other Mediterranean pine forests (+71%) and areas of surface water (+38%), and a reduction of maquis areas (-32%) and open spaces (-42%). With regard to coastal stone pine forests, the results indicate a contraction of pure stone pine forests (-13%) and an increase in mixed stone pine and broadleaf forests (+433%). Stone pine and other Mediterranean pines mixed forests, and wetland areas resulted nearly unchanged during the period under consideration (Figure 2). The appearance of new stone pine forests was noted in 3% of the examined points.

Table 2 - Surface area (hectares and percent) of 2010 land use classes.

Land use classes	Surface area	
	Hectares	%
1. Artificial surfaces	15 845.1	21.3
2. Agricultural areas	22 459.7	30.1
3. Italian stone pine forests	9633.3	12.9
4. Italian stone pine and other Mediterranean pine mixed forests	485.8	0.7
5. Italian stone pine and broadleaf mixed forests	541.2	0.7
6. Other Mediterranean pine forests	1687.4	2.3
7. Other woodlands	11 726.9	15.7
8. Maquis	5638.1	7.6
9. Open areas with scarce or no vegetation	1250.7	1.7
10. Wetland areas	1339.0	1.8
11. Areas of surface water	3910.5	5.2
Total	*74 517.7*	*100.0*

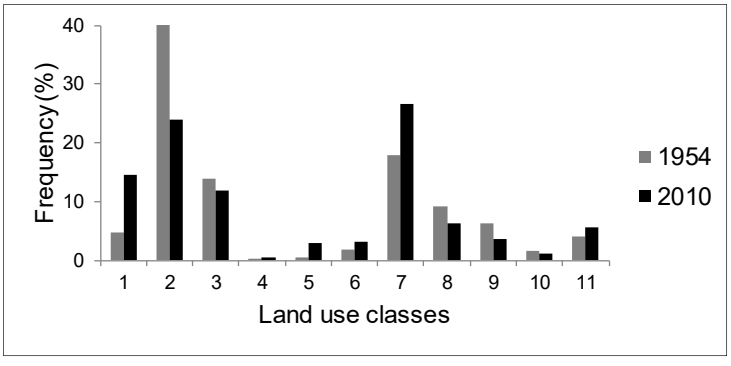

Figure 2 - Land use changes in the 1954-2010 period observed in a sample of 1113 photopoints (see Table 1 for descriptions of land use classes).

Table 3 - Number (Ntot), basal area (BAtot), volume (Vtot) per hectare and percentage distribution of the basal area per species (BAsp = stone pine basal area; BAho = holm oak basal area; BAma = maquis basal area; BAms = mesophilic species basal area) in coastal stone pine forest types (A = Lowland meso-hygrophilus forests; B = Wooded dunes with holm oak; C = Meso-Mediterranean wooded dunes; D = Thermo-Mediterranean wooded dunes); SD = standard deviation.

Type	Plot Num.	Age years	Ntot n/ha	BAtot m^2/ha	Vtot m^3/ha	BAsp %	Gho %	Gma %	Gms %
A	1	>90	979	35	424	45.1	27.6	0.0	27.3
	2	>90	1305	35	393	63.1	26.1	0.0	10.8
	3	>90	837	39	473	68.2	10.5	0.0	21.3
Mean		>90	1040	36	430	58.8	21.4	0.0	19.8
SD		-	240	2	40	12.1	9.5	0.0	8.4
B	1	93	597	42	333	96.0	4.0	0.0	0.0
	2	83	374	37	319	98.9	0.8	0.3	0.0
	3	85	248	37	339	99.2	0.5	0.3	0.0
Mean		87	406	39	331	98.0	1.8	0.2	0.0
SD		5	177	3	10	1.8	1.9	0.2	0.0
C	1	85	207	40	430	100.0	0.0	0.0	0.0
	2	85	247	38	364	100.0	0.0	0.0	0.0
	3	82	183	30	272	100.0	0.0	0.0	0.0
Mean		84	212	36	355	100.0	0.0	0.0	0.0
SD		2	32	5	79	0.0	0.0	0.0	0.0
D	1	-	207	14	97	100.0	0.0	0.0	0.0
	2	-	159	13	75	100.0	0.0	0.0	0.0
	3	-	80	6	42	100.0	0.0	0.0	0.0
Mean		-	149	11	71	100.0	0.0	0.0	0.0
SD			64	4	27	0.0	0.0	0.0	0.0

Coastal stone pine forests present different compositional and structural characters in relation to the forest type considered (Figures 3 and 4, and Tables 3 and 4).

The Lowland meso-hygrophilus stone pine forest is a forest type with high density of individuals (1040 plants/ha), both as trees and shrubs, and high compositional and size diversity. Stone pine, which contributes approximately 59% of the overall value of the basal area (36 m^2/ha), is present with even-aged individuals of large diametric dimensions (> 50 cm) with canopies that occupy the upper story of the stand, reaching heights of approximately 27 m. Site conditions favor the development of a dense layer under the pines of variously aged broadleaf individuals of holm oak and various mesophilic arboreal (pedunculate oak, sessile oak, Turkey oak, narrow-leafed ash, European hop-hornbeam, European alder, field elm, manna ash) and shrub species (common holly, bay laurel, common hawthorn, elmleaf blackberry) that are distributed more or less continuously throughout the vertical profile, reaching heights of 15 m and more. Forest standing volume is rather high, with values of approximately 430 m^3/ha.

Table 4 - Dimensional characteristics of stone pine (Dm = quadratic mean diameter; Hm = mean height; Hd = dominant height; SDD = standard deviation of diameters; SDH = standard deviation of heights; amH = arithmetic mean of heights; amHins = arithmetic mean of height to-base of the live crown) in coastal stone pine forest types (A = Lowland meso-hygrophilus forests; B = Wooded dunes with holm oak; C = Meso-Mediterranean wooded dunes; D = Thermo-Mediterranean wooded dunes); SD = standard deviation.

Type	Plot Num.	Dm cm	Hm m	Hd m	SDD Cm	SDH m	amH m	amHb m
A	1	70.9	29.2	29.1	4.9	3.0	29.1	17.4
	2	66.6	25.6	25.9	17.2	5.2	25.0	17.9
	3	57.2	25.7	25.6	7.0	2.7	25.6	16.7
Mean		64.9	26.8	26.9	9.7	3.6	26.6	17.3
SD		7.0	2.1	1.9	6.6	1.4	2.2	0.6
B	1	37.1	15.2	15.8	4.0	0.9	15.2	10.8
	2	38.3	16.4	17.2	4.5	1.5	16.4	10.8
	3	47.1	17.7	18.5	4.4	1.0	17.6	10.5
Mean		40.8	16.4	17.2	4.3	1.1	16.4	10.7
SD		5.5	1.3	1.4	0.3	0.3	1.2	0.2
C	1	49.8	20.3	20.9	6.2	1.1	20.3	10.1
	2	44.1	18.4	19.2	3.9	1.6	18.3	11.5
	3	45.8	18.0	18.1	6.5	0.9	18.0	10.9
Mean		46.6	18.9	19.4	5.5	1.2	18.9	10.8
SD		2.9	1.2	1.4	1.4	0.4	1.3	0.7
D	1	29.1	12.4	13.5	12.3	2.8	11.3	6.5
	2	31.7	11.2	11.7	7.3	1.8	10.9	4.9
	3	30.1	12.5	10.7	15.1	4.1	10.7	5.3
Mean		30.3	12.0	12.0	11.6	2.9	11.0	5.6
SD		1.3	0.7	1.4	4.0	1.2	0.3	0.8

Also the Wooded dunes with stone pine and holm oak is a forest type characterized by an elevated density of individuals (406 plants/ha) and a certain degree of species mixture. Pines, always coetaneous, make up approximately 98% of the overall basal area (39 m^2/ha) with diametric classes in the 30 to 60 cm range. The pine canopy is generally distributed as a single layer at about 16-17 m above a various dense uneven-aged layer of vegetation typical of the Mediterranean maquis, about 9-10 m in height and composed primarily of holm oak, isolated cork oak and shrub species (e.g., Italian buckthorn, Pistacia lentiscus, Phillyrea sp.). In this forest type, forest standing volume is about 330 m^3/ha.

The Meso-Mediterranean wooded dunes with stone pine is similar to the Wooded dunes with stone pine and holm oak and differ from the latter for the absence of holm oak and other sclerophyllous trees in the understory.

The Thermo-Mediterranean wooded dunes with stone pine instead presents structural characteristics which are well differentiated from the types described above. This type of pine forest is in fact less dense (149 plants/ha and 11 m^2/ha per basal area) and has lower standing volumes (approx. 70 m^3/ha) compared to other coastal pine forests. Furthermore, the pines which compose

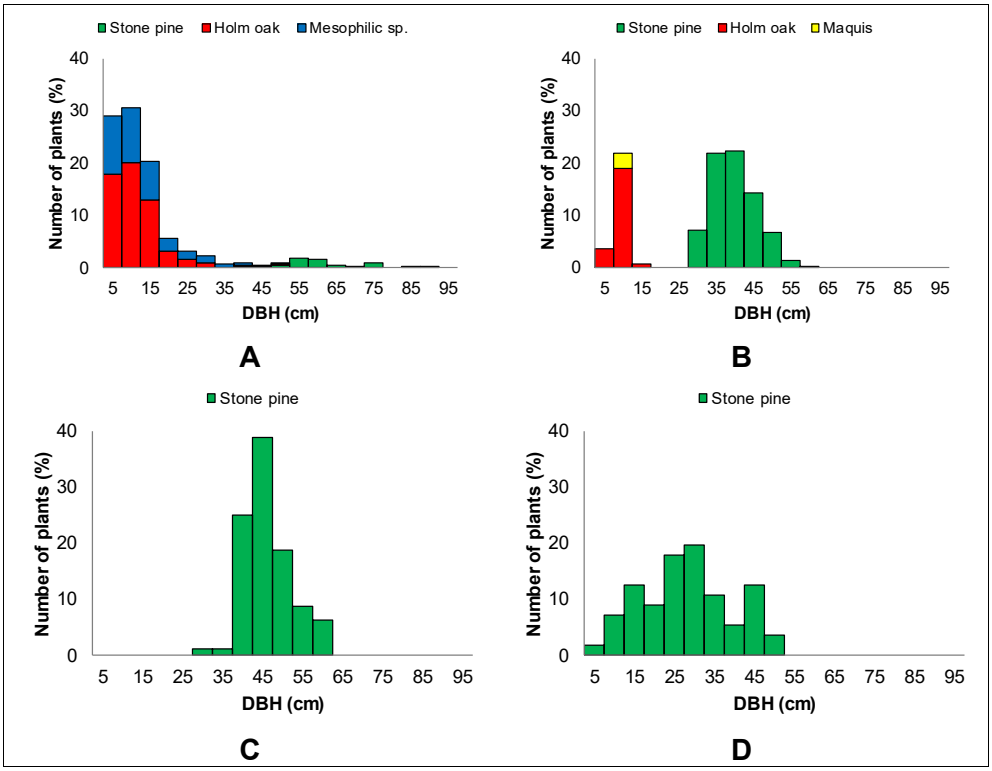

Figure 3 - Distribution (in %) of the mean number of plants in 5-cm diameter classes in coastal stone pine forest types (A = Lowland meso-hygrophilus forests; B = Wooded dunes with holm oak; C = Meso-Mediterranean wooded dunes; D = Thermo-Mediterranean wooded dunes).

it have smaller dimensions, both in terms of diameter and height. However, in the Thermo-Mediterranean wooded dunes with stone pine the pines have greater size diversity than the other examined pine forests, as indicated by the standard deviation values for diameter and height (Table 4) and the distribution of number of trees per diameter class (Figure 3). From this, it is possible to infer the presence of a certain number of young pines (diameter < 20 cm) and thus the presence of pines belonging to more age classes. In the understory, in addition to the species noted above for wooded dunes with stone pine, species which are more thermophilic such as juniperous sp., heather sp., common myrtle, rosemary and rockrose are present.

4. Discussion

The land use map produced in this study makes available for the first time in Tuscany a detailed cartographic tool (scale 1:10 000, MMU = 0.5 ha) that permits examination of the regional distribution of coastal pine forests with sufficient accuracy (overall accuracy = 87%), distinguishing pure from mixed stone pine forests and forest types dominated by other Mediterranean pines

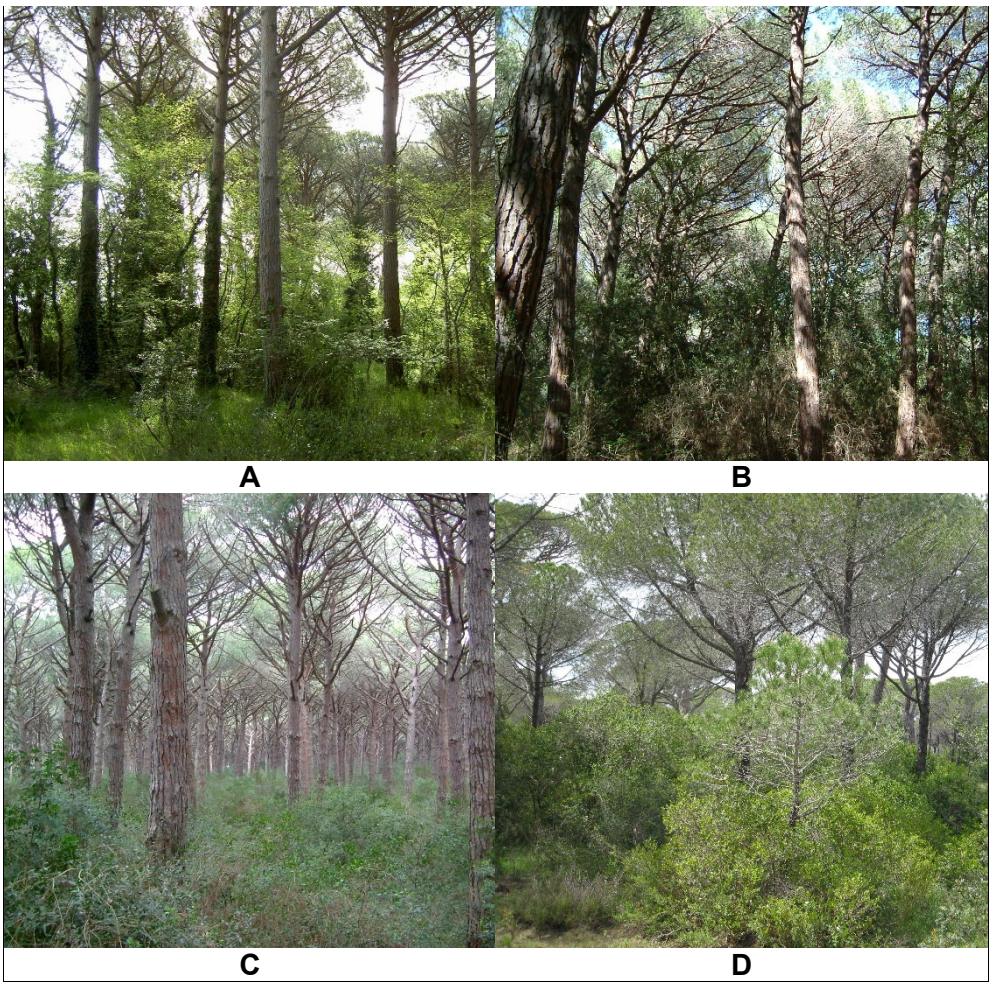

Figure 4 - Examples of coastal stone pine forest types: A = Lowland meso-hygrophilus forests; B = Wooded dunes with holm oak; C = Meso-Mediterranean wooded dunes; D = Thermo-Mediterranean wooded dunes.

present along the coast. The surface area of coastal pure and mixed stone pine forests was found to be 10 660 ha, a slightly lower value compared to the overall area of stone pine in Tuscany estimated by the National Forestry Inventory (INFC, 2005), which include pine forests in hilly areas inland. Stone pine forests have provided and continue to provide numerous goods and services. The importance attributed to pine forests has grown over the years, especially in connection with their role in touristic-recreational activities due to their landscape function and the role the pine wood-maquis system plays with regard to biodiversity conservation. Comparing the distribution of stone pine forests with the distribution of camping areas along the Tuscan coast, as reported by Google Maps, it emerges that in approximately 525 ha of pine forest that are important touristic-recreational structures. It can be noted that 81% of the overall surface area of stone pine forests is included in protected areas, for the most part Natura

2000 sites, but also regional natural parks and national nature reserves, with frequent cases of overlapping among these different types of protected area.

According to the National Forestry Inventory, in Tuscany Mediterranean pine forests are 73% privately owned, with the remainder on public property; only 19% of these areas have a detailed forest plan (INFC, 2005). Despite the importance attributed to coastal pine forests and to stone pine forests in particular, these associations can be considered as in a generalized abandoned state of cultivation. Even when there is a forest management plan, cultivation of these pine forests is in general limited to removing or pruning trees that are dangerous for visitors in frequented areas, phytosanitary fellings, and silvicultural interventions for forest fire prevention along roadways and in the understory. These operations, if conducted respecting the pine forest-maquis system, are necessary but not sufficient to guarantee the functionality of pine forests and their perpetuation.

The causes for abandoning cultivation are various and have been known for some time (Bernetti, 1987; Cantiani and Scotti, 1988; Gatteschi and Milanese, 1988); yet this situation has continued in Tuscany and other Italian regions for decades (Agrimi *et al.*, 2002; Puxeddu *et al.*, 2017). The risk, which we believe is in general poorly understood, is that of a gradual transformation of pine forests into woodlands dominated by species that grow spontaneously in coastal areas, such as holm oak, maquis associations, and mesophilic species in cooler and more humid environments, thus loosing the important cultural landscape.

This type of successional dynamic is underlined by the results of this study. Multi-temporal analysis revealed a reduction in pure stone pine forests, an increase in mixed stone pine and broadleaf forests, and an expansion of other woodland formations. The increase in surface water areas, linked with coastal erosion which contributed in part to reduce pine forest surface area, is also worthy of note. Urbanization, abandonment of agricultural areas, and expansion of forested areas along the Tuscan coast (Figure 2) are changes that reflect the trends pointed out at the national level (Marchetti *et al.*, 2012; Pompei *et al.*, 2015). As part of woodland expansion, stone pine planting carried out after 1954 are present in 3% of our survey points. These pine forests were planted mainly in previously agricultural areas and secondarily in areas occupied by maquis or open areas with scarce or no vegetation; the majority of these plantings were effectuated inland between Castiglioncello (Livorno) and Albinia (Grosseto), at the distance of more than 150 m from the coast.

Our results clearly show that the Lowland meso-hygrophilus stone pine forests is the pine forest type most greatly subjected to transformations in terms of specific composition. This dynamic is inevitable in stands established in environments where mesophilic species competition does not allow conservation of the pine forest, at least not without great energy input.

For Wooded dunes with stone pine and holm oak and Meso-Mediterranean wooded dunes with stone pine, our results suggest that successional dynamics proceed more slowly than in lowland pine forests. However, even in these cas-

es, aging of stands and lack of cultivation, together with excessive density of pine forests and phytopathologic problems, lead to a progressive stand instability. This in turn leads to a loss of single trees or groups of trees and consequently canopy openings, leaving space for maquis and holm oak. These situations must be monitored and, if necessary, timely interventions should be carried out to control the maquis and favor regeneration of the pine forest, either artificially or naturally (Ciancio *et al.*, 2009b). In areas of greatest fire risk, preventive control of the maquis can be useful also through intervention on the vertical canopy continuity since in these types pine canopy height is about 10 m (Table 4), near too the height reached by the understory.

Figure 5 - Examples of stone pine regeneration at the Pineta del Tombolo, Marina di Grosseto.

The Thermo-Mediterranean wooded dunes with stone pine are different from other types of coastal pine forests. Its structure is complex, the canopy cover is sparse, and it is made up of pines belonging to various age classes; the understory is richer in thermophilic species, and it is less dense and developed in height. During on-site inspections conducted in these pine forests, the presence of natural regeneration of stone pine was observed, for example in the Pineta del Tombolo at Marina di Grosseto (Figure 5) and in the Pineta Granducale of Alberese.

The capacity of stone pine to establish multi-strata structures and natural regeneration along the Italian coast has been demonstrated over time (Pavari 1955; Ciancio *et al.*, 1986) and not only in thermo-Mediterranean pine forests (Marchese, 1997; Ciancio *et al.*, 2009b; Di Filippo *et al.*, 2015). This silvicultural option has not been considered by the scientific community and forestry technicians, with the exception of few cases (Ciancio, 2007), while it merits greater attention at least as an experimental opportunity in alternative to the classic stone pine forest treatment which has a high impact on the environment and the landscape. On the other hand, the possibility of obtaining natural regeneration of stone pine today is made more difficult by the lack of seeds caused by the western conifer seed bug. It is therefore necessary to continue investigating this insect in order to develop efficient and sustainable ways to combat one of the major challenges that currently afflict coastal pine forests. Data on the production of stone pine nuts are not available for Tuscany, but data for all of Italy show that the production of stone pine cones has reduced by 10% every year, going from 80 000 tons collected in 1995 to 13 000 tons collected in 2006 (Tiberi, 2007).

5. Conclusions

Three primary objectives were targeted in this study: to map the distribution of coastal stone pine forests in Tuscany, to analyze land use changes along the Tuscan coast in the period 1954-2010, and to examine the structure and main dynamics of coastal stone pine forests.

Multi-temporal analysis of land use has evidenced changes along the Tuscan coast that reflect the main trends reported on a national scale: urbanization, abandonment of agricultural areas, and expansion of forested areas.

The pure stone pine forests have contracted during the period under study while the frequency of mixed stone pine-broadleaf forests has grown. These changes are the result of successional dynamics which, with a lack of active forest management in the pine forests, have progressively led to modifications in the structure of pine stands and consequently to a transformation of the coastal landscape.

Our results provide a knowledge base for political decision-makers that will be useful in planning urgent operations to re-launch sustainable management

of coastal stone pine forests through diversified silvicultural systems tailored to the different environmental and structural characteristics of the stands and current socio-economic conditions along the Tuscan coast. To increase this knowledge, we believe that further research on the spatial distribution of structural types of stone pine forests in Tuscany can profit by the use of new technologies such as airborne laser scanning data. In addition, the research should be supplemented by surveys on both natural regeneration of stone pine and users' perception on the ecosystem services provided by stone pine forests and the awareness that the dynamics involved can significantly alter the landscape present along the Tuscan coast.

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RIASSUNTO

*Le pinete litoranee di pino domestico (*Pinus pinea *L.) sono un paesaggio costiero in via di estinzione? Un caso di studio in Regione Toscana*

In Toscana le pinete di pino domestico (*Pinus pinea* L.) caratterizzano il paesaggio culturale costiero da circa cinque secoli. Nel corso del tempo è stata riconosciuta alle pinete litoranee la capacità di fornire numerose utilità ecosistemiche, tra le altre, la stabilizzazione delle dune, la protezione delle aree agricole dai venti marini, biodiversità e habitat, spazi per attività turistico-ricreative, qualità percettiva del paesaggio, produzione di frutti e legno. Dalla metà del XX secolo, questo paesaggio di natura antropogenica è stato modificato ed in parte eroso, ed ha iniziato a trasformarsi a causa di dinamiche gestionali e vegetazionali, dei cambiamenti di uso del suolo e degli effetti del cambiamento globale. Oggi la qualità e la quantità delle utilità ecosistemiche fornite dalle pinete è condizionata sia da fattori biotici sia dagli stili di gestione adottati e da altri criteri di scelta dipendenti da esigenze socio-economiche temporanee volti a preferire alcuni aspetti che mal si coniugano con i criteri di gestione forestale sostenibile. Gli obiettivi di questo studio sono: (i) mappare la distribuzione delle pinete costiere di pino domestico in Toscana, (ii) analizzare i cambiamenti di uso e copertura del suolo lungo il litorale toscano e (iii) descrivere la struttura e le principali dinamiche delle pinete costiere di pino domestico. Nel 2010 le pinete litoranee di pino domestico ammontano a 10.660 ha. I cambiamenti di uso del suolo sulla costa toscana rispecchiano i trend principali segnalati a scala nazionale: urbanizzazione, abbandono delle aree agricole, espansione delle superfici forestali. Le pinete pure di pino domestico hanno fatto registrare una contrazione nel periodo 1954-2010 mentre è cresciuta la frequenza delle pinete di domestico miste a latifoglie. Tali cambiamenti sono il risultato di dinamiche successionali che stanno progressivamente trasformando il paesaggio costiero. I risultati ottenuti sono discussi per fornire una base di conoscenze utili per la gestione del paesaggio forestale lungo il litorale tirrenico.

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