The forest of San Rossore (Tuscany, Italy): a call for its conservation through a multidisciplinary approach

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Brief presentation
The 'Estate San Rossore' extends for approximately 4,800 ha along the coast of north Tuscany (central Italy, 43°43'N and 10°16'E) on a sand dune system originated in about two thousand years through the accumulation of river sediments by sea winds (Fig 1).

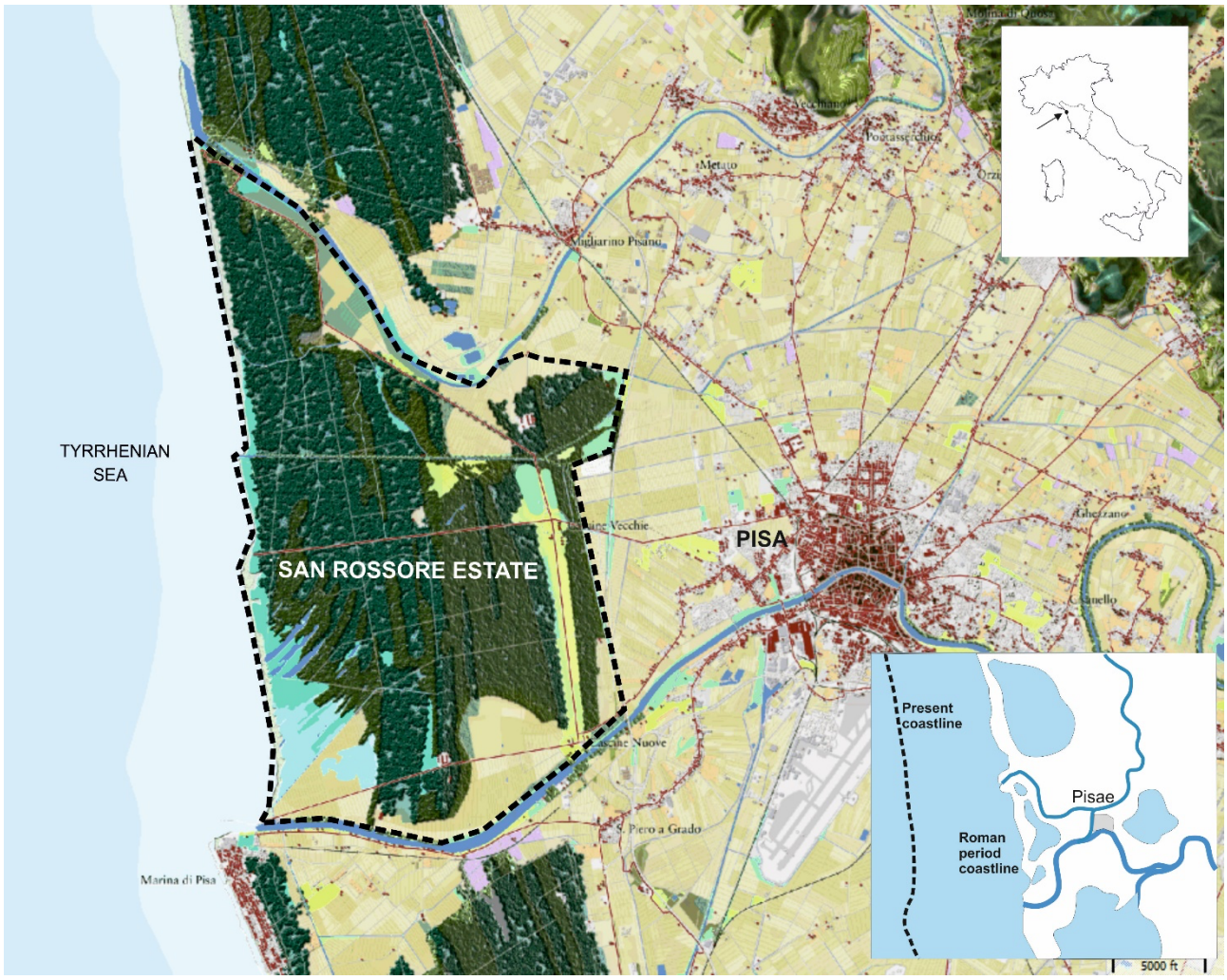

Fig. 1. The area where the San Rossore Estate extends. In the lower right the coastal shape about 2000 years ago.

The climate of the area is a hot humid Mediterranean (Csa, according to Köppen's classification) and the growing season lasts from March to October, with a summer stop. Due to its origin, however, the ground is a sequence of small reliefs ('tomboli') and dips ('lame'), which maintain a different humidity over the year, thus creating a variety of microclimates and habitats (Corti, 1955).
Human presence in the area date back to prehistory and, nowadays, the natural park is surrounded by important urban settlements. Up to Renaissance the forest essentially served as source of timber and fuel wood. Towards the end of 1600, under the rule of the Medici, stone pine (*Pinus pinea* L.) stands were planted on the old consolidated sand dunes, whereas towards the end of 1700, under the Tuscan

Grand Dukedom, strips of maritime pine (*Pinus pinaster* Ait.) were planted on the youngest dunes to protect the inner vegetation from the sea winds. In the same period, the deciduous oak (*Quercus robur* L.) forest patches were also sustained and implemented because of its high value wood.

Ecological value

The combination of natural processes and human activities has originated a variety of vegetation types, several belonging to priority habitats. The floristic inventory accounts for more than 600 plant species and comprehends relict species such as the fern *Osmunda regalis* L., the lian *Periploca graeca* L. and *Quercus robur*, which survived either the Ice Age or the following warm and drier conditions due to the wetter microclimates present in the area (Garbari, 2000; Landi and Angiolini, 2007). For its unique high landscape and biological value, the Estate of San Rossore is included in the World Network of Biosphere Reserves (UNESCO), as a part of the "Selve costiere di Toscana".

The mixed phytocoenoses of conifers, evergreen and deciduous broadleaves give rise to an extremely diverse plant landscape, rich in terms of floristic diversity and expression of the different stationary typologies of the Tuscan coast (Gellini et al., 1986).

The most representative vegetation types are (Tomei et al., 2004):

- conifer plantations of anthropogenic origin, *Pinus pinaster* along the coastline and *Pinus pinea* on the 'tomboli';
- sclerophyllous shrubs and forests dominated by the holm oak (*Quercus ilex* L.) on the 'tomboli', today often mixed with *Pinus pinea*;
- meso-hygrophilous broadleaved forests dominated by *Q. robur* L. and *Fraxinus angustifolia* subsp.*oxycarpa* (M. Bieb. ex Willd.) Franco & Rocha Afonso, mixed with *Carpinus betulus* L., *Populus alba* L. and *Alnus glutinosa* (L.) Gaertn. in the dips;
- wide forest clearings;
- marshes.

The forest covers approximately 3,500 ha of the Estate and naturally forms strips of evergreen and deciduous species alternating at a very short distance, strictly related to reliefs and dips (Fig. 2).

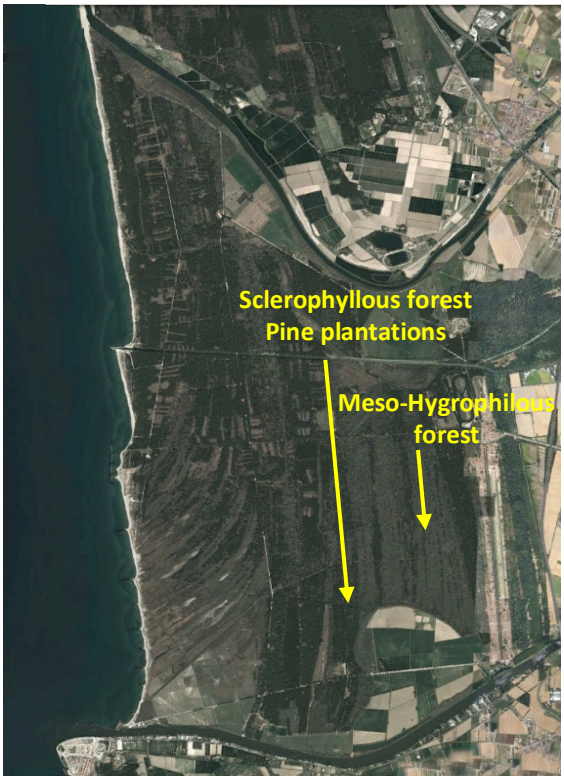

Fig. 2. Distribution of sclerophyllous and meso-hygrophilous forest types.

Starting from the seashore, the sequence of forest types is presented in figure 3.

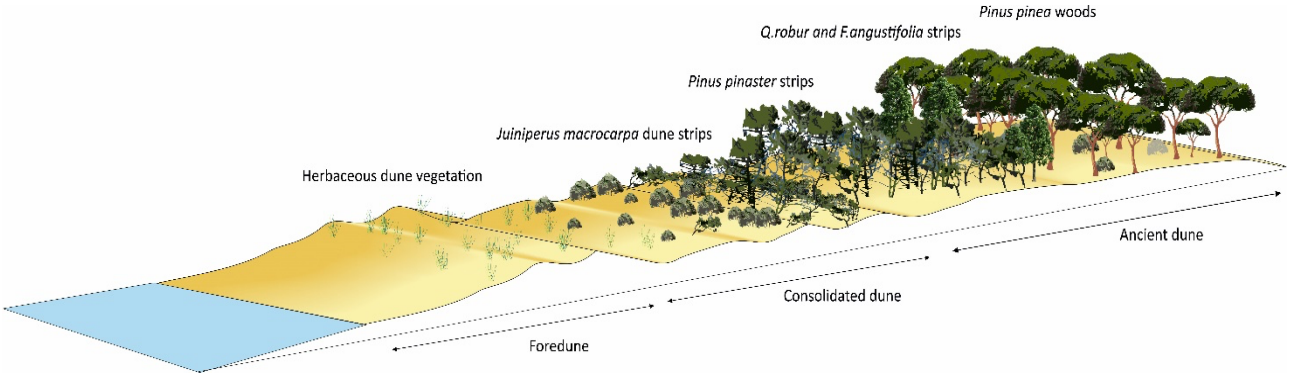

Fig. 3. Sequence of forest types.

Ecosystem vulnerability

The sandy soil is characterized by a very thin organic layer (Fig. 4) which is prone to erosion and mineralization once the integrity of the vegetation cover is disturbed (Table 1).

Fig. 4. Soil profile under sclerophyllous forests and in a cleared stand.

Table 1. Texture and chemical properties of the 0-10 and 10-20 cm soil layers of of about 100-year old *Pinus pinea* plantations (from Arduini et al. 2017).

Soil property	0-10 cm	10-20 cm
Sand (%)	-	95.2
Silt (%)	-	3.6
Clay (%)	-	1.2
pH (soil:H_2O 1:2.5)	4.7	5.4
Organic matter (%)	6.7	1.9
Total Nitrogen (‰)	10.4	3.1

The soil seed bank is generally poor and contains an appreciable proportion of alien species, which could reduce the natural regeneration of the vegetation after disturbance and change its composition in species (Arduini and Ercoli, 2012; Arduini et al., 2013).
Several species, among these the most representative of the forest types, are either out of their natural range (*Q. robur*) or belong to artificial stands (*P. pinea*). Their maintaining was, at least in part, supported by human activities. According to the current management plan, the aged stone pine plantations are clear-cut in strips and artificially re-planted, while the renewal of the other forest species is left to natural dynamics (Bertacchi and Lombardi, 2019).
However, the high wildlife pressure, especially wild boars and deer introduced for game in the past centuries, greatly reduce the reproduction ability of forest trees, especially the deciduous broadleaved, with *Q. robur* the most affected, but also *P. pinea*.
Touristic pressure is high in a great portion of the Estate, thus facilitating the passive introduction of alien species (Orlandi and Arduini, 2010).

Threats
In the foregone decades the forest of San Rossore underwent several threats:

- the progressive dieback of the forest front nearest to the seashore caused by both the massive coastal erosion (Bertacchi, 2017) and the foliar deposition of marine aerosol-borne pollutants (Fig. 5);
- the attack of insect pests: *Leptoglossus occidentalis* Heidemann on *Pinus pinea* and *Matsucoccus feytaudi* Ducasse on *Pinus pinaster* stands.

Fig. 5. Dieback of pine plantations in front of the sea due to polluted marine aerosols in the ‘70th.

In recent years, it was observed:

- an increased crash down of isolated trees in both the hygrophilous and the Mediterranean forest stands (Fig. 6 left);
- the dieback of entire *Fraxinus angustifolia* Auct. patches (Fig. 7).
- This dramatic aging is not balanced by effective recruitment, which lacks almost completely in the hygrophilous forest types.
- The openings in the forest canopy are often invaded by *Ailanthus altissima* (Mill.) Swingle (Fig. 6 right).

Fig. 6. Crash down of *Pinus pinea* in an aged stand (left) and invasion of *Ailanthus altissima* in canopy openings formed after the crash down of aged trees (right).

Fig. 7. Dieback of an entire *Fraxinus angustifolia* stand.

Possible causes of increased dieback

The crash down of aged trees could be attributed at least in part to the increased frequency and strength of windstorms, which is generally associated with climate change and, thus, expected to increase in the future.

However, the reason of the increased tree weakening is unclear and the involvement of multiple, interacting factors should be taken also into account. Among these:

- the infiltration of saline rich seawater in consequence of coastal erosion;
- the accumulation of pollutants in the soil;
- the attack of specific pathogens;
- changes in the seasonal fluctuations of soil humidity, due to either changes in the amount and distribution of rainfall or to changes in forest management.

To this regard, it could be hypothesized that the reduced maintaining of the artificial channels excavated to drain the soil of stone pine plantations in the past, could have reduced the water flux in the subsurface water table, thus prolonging the periods of soil waterlogging during the year. The exposure of tree roots to hypoxia during the growing season could have reduced tree vigor, thus increasing the susceptibility to diseases and windstorms.

Perspectives

The accelerated stand aging, which is not balanced by effective recruitment, can pose a serious threat to the preservation of the forest of San Rossore, thus causing the loss of its unique high landscape and biological value, for which it was named a Biosphere Reserves.

Accordingly, it is to presume that management is needed to maintain all forest types, not only stone pine plantations, at least artificially supporting the recruitment of forest trees.

To be effective, the management plan should be based on multidisciplinary investigations giving information on the factors driving the forest dynamics, which are the result of interactions between natural processes and human disturbance.

The forest of San Rossore represents a study model for the preservation of complex forest systems subjected to several pressures and could, therefore, be the object of multidisciplinary research projects.

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