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Anthropogenic influences on the condition of *Pinus pinea* L. and *Quercus robur* L. in Pineta san Vitale (Ravenna, Italy)

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Abstract

The industrial plants and the harbor of Ravenna had strong influence on the northward neighboring coastal pinewood Pineta san Vitale. This was shown in 1973, when the crown density of *Pinus pinea* (L.) was declining with a north-to-south gradient of decreasing distance to industrial plants. Now – over 40 years later – exhaust filter and wastewater systems have been installed to reduce pollution. But have these improvements an observable effect, regarding the crown densities and therefore the health conditions of the adjacent pinewood? Our analysis of trees shows once again, crown densities of *P. pinea* decline significant in correlation with a smaller distance to the industrial zone, and also crown densities of *Quercus robur* L. decline with a strong tendency. Therefore industrial filter system improvements seem to be not sufficient. The subsidence caused soil salinization of the region was additionally tested to be an independent factor for defoliation. In this regard, negative consequences on the crown density of *P. pinea* were found to a high extent. Finally our results show, coastal forests as natural reserves of international importance are influenced by many – often anthropogenic caused – impacts. The need of further improvements in filter systems and also an ongoing critical view on effects of urban and industrial surroundings on natural areas under human pressure is strengthened in the common sense of nature protection.

Introduction

As a southern part of the "Parco Regionale del Delta del Po" Pineta san Vitale (Ravenna, Italy) (fig.1) is protected by Natura 2000 (Montanari 2010) and listed as an important bird area (Heath et al 2000). It is surrounded by further important naturalistic wetlands called Valle Mandriole, Punto Alberete and Bardello. East of Pineta san Vitale the lagoon Pialassa Baiona is located which is separated from the sea by a small split of land and was manmade in the seventeenth century (Zingaretti and Pezzi 2011). Nowadays, it is listed by the Convention of Ramsar (Ramsar Convention Secretariat 2013) as "wetland of international importance".

Close to the natural areas in the south of Pineta san Vitale, there are industrial plants and the harbor of Ravenna. The Industry of Ravenna has mainly developed in the late 50s (Matteucci et al. 2005) and contains petrol industry (due to large natural gas reserves in front of the coast) and chemical industry (production of synthetical gum like PVC, elastomeres, latex, stiren-butadien-gum and others, but also the production of fertilizers, insecticides and emplastics). Furthermore, there are plants for food and feedingstuff industry, metal processing, cement production and different industries directly connected to the harbor like yards, forwarders and warehouses (Rubbi 2010).

At the harbor of Ravenna, high concentrations of particulate matter, ozone and NO_2 (last one with values over 40 mg/m³) were measured (Lucialli et al. 2007).

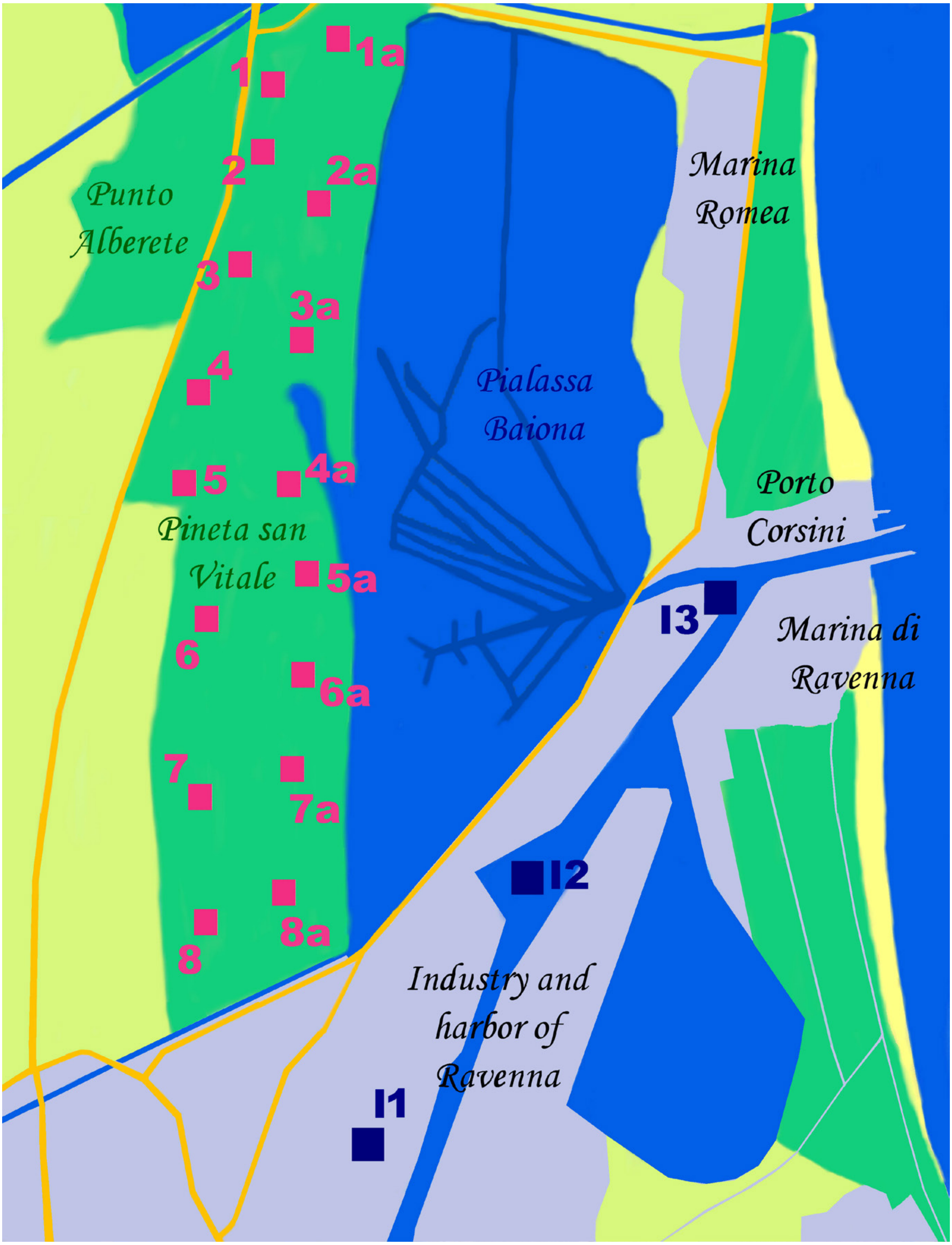

Fig. 1: Map of Pineta san Vitale with the study sites (violet squares) and the chosen points in the industry to measure the mean distance (I1, I2, I3, blue squares)

The Mediterranean-typical south-east winds (scirocco) transport the pollutants from the industrial zone to Pineta san Vitale (Scossirolli 1973). The harmful effect of ozone and other exhaust gases on plants is already confirmed in different studies (Paoletti 2006, Thomas 1961, Tkacz et al. 2008), although the sensitivity for pollutants is depending on the plant species and can be influenced by many further factors (Bussotti and Gerosa 2002, Paoletti 2006).

Additionally, the whole region is affected by land subsidence as a result of continual groundwater pumping and gas production (Antonellini et al. 2008, Mollema et al. 2013, Teatini et al. 2005). The ecological difficulties arising from this contain increasing soil salinity, enhanced by different other factors like evaporation and influx of saltwater or - in the case of Pineta san Vitale - hyper saline lagoon water (Mollema et al. 2013). In some areas there are salt concentrations up to 22 g/l (Antonellini et al. 2008), which is a multitude of what many plants can tolerate.

Under these aspects it seems obvious that the condition of the trees in Pineta san Vitale is getting worse. Already in 1973 Scossiroli described the industrial influences on Pineta san Vitale and its vegetation. His results included the declining abundance of lichens and increasing crown transparency of *Pinus pinea* (L.) from north to south. The harbor of Ravenna developed since then by installing a lot of environmentally friendly exhaust filters and wastewater systems (Rubbi 2010). If these improvements had positive implications on the vegetation was not known until today. As crown density of a tree is directly related to its health and can be used as a good parameter to improve mortality models (Dobbertin and Brang 2001) we investigated the defoliation once again 40 years after Scosirollis studies by using modern methods and statistical analysis.

Material and Methods

We examined 320 randomized pine (*P. pinea*) and oak trees (*Quercus robur*) concerning their crown densities in Pineta san Vitale. In the park we used 16 study sites that were placed equally from north to south. 8 of these plots were in the east of the park, the rest of them were located in the west (fig. 1). The distance from each plot to the industrial area of Ravenna was measured by using GPS-Data and Google Earth. As the industrial plants and the harbor cover a certain area, we set in total 3 points for measuring the average distance to the plots in the park. Therefore, one point in the east, one in the middle and one in the west of the industrial area were chosen (fig. 1). The salinization at each plot in the park was estimated using piezometer data (or even average data of the nearest piezometers) of B. Giambastiani (2007) and the salinity map of Antonellini et al. (2008) (fig. 1).

At each plot we analyzed 10 pine trees (*P. pinea*) and 10 oak trees (*Q. robur*). Crown density was estimated on site according to the classification of Mizoue (2001). Subsequently, 4 photos of the crown were taken, if possible from different directions. On the basis of these pictures a second, more exact crown density measurement was performed on the computer using the ImageJ1.45s analysis software (http://imagej.nih.gov/ij; provided in the public domain by the National Institutes of Health, USA). Therefore, every picture was measured 2 times. The first measure expected a hypothetical full crown with 100% foliage. The second measure was manually arranged and encircled the real foliage (fig. 2). The measures were recorded in a table and the real foliage was divided by the hypothetical one. The results (i.e. the calculated crown densities) were used for statistics.

To amplify the results of the crown density study, the conditions of *Q. robur* acorns were also tested. The weight of the fruits was analyzed, based on the seedling-size effect, which suggests a better competitiveness of great fruits, germinating with a greater seedling (Quero et al. 2007). To determine the mean weight of the acorns we collected coincidentally 100 fruits at each plot in October 2013. The cups were removed and the remaining fruits were completely dried in a drying furnace. The dry weight was measured with a precision balance. For this purpose, we pooled 10 acorns together in each case to get a meaningful statistical result.

As the germination success of fruits is essential for tree reproduction and spreading, the rate of parasitism in acorns was measured to analyze whether the defense of fruits and, thus, the defense of trees might be reduced by changing environmental conditions. Infestation was determined by counting the holes in the acorns originated by parasites. We distinguished between no parasitism (no hole), parasitized by beetles (e.g. *Curculia glandium, Curculia venosus* or *Curculia pellitus*) (great, round hole), and parasitized by moths (e.g. *Cydia splendana, Cydia amplana* or *Pammenne fasciana*) (small hole) after Goßner (2005). Acorns that could not be classified because of defects by other factors like small mammals or mechanical damage where noted as "unknown" and not used in our statistical calculations.

Finally, the quality of deadwood at the different

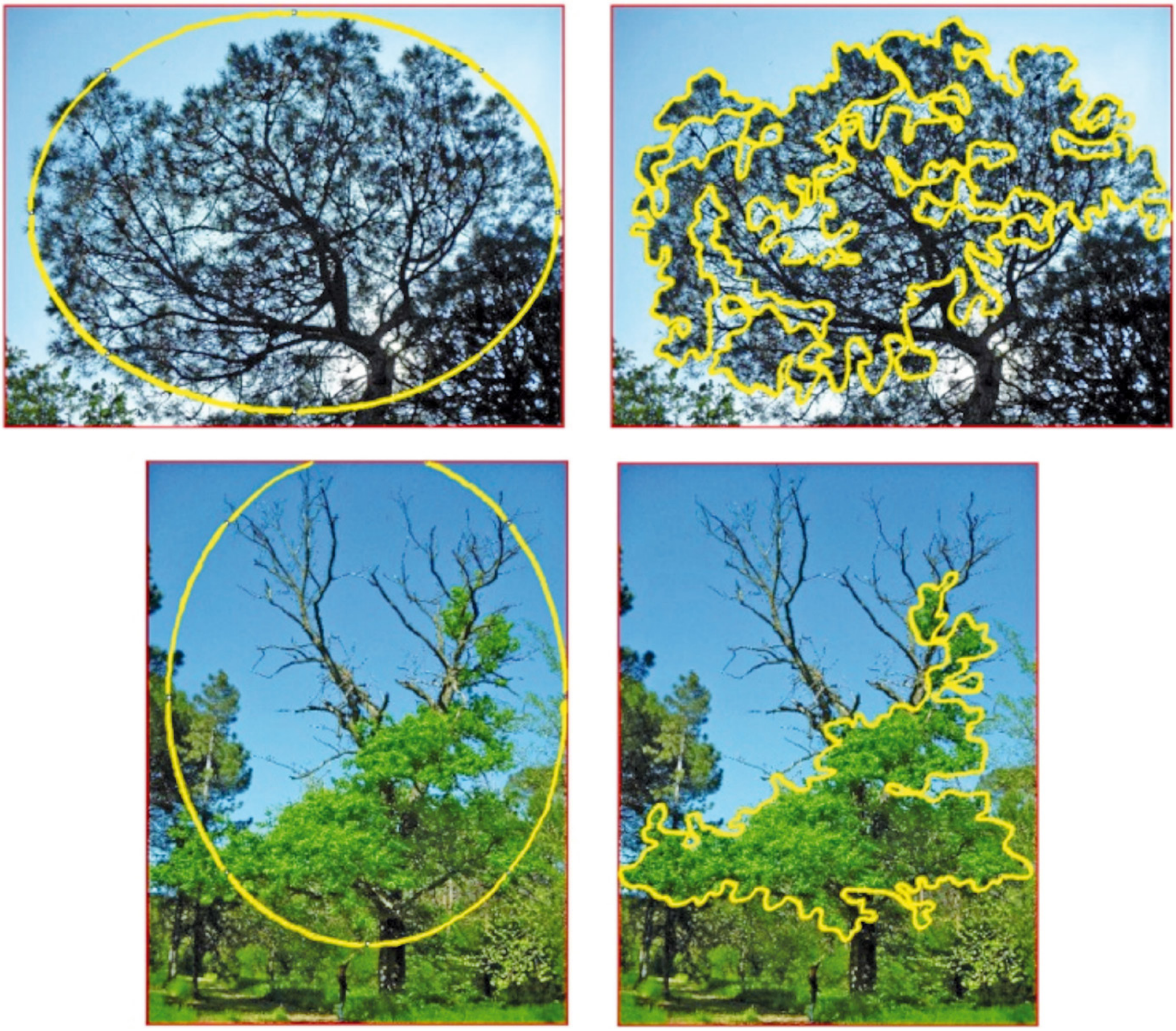

Fig. 2: Different crown images and their treatments in Image J. On the left the hypothetical 100%-foliage crown is expected. On the right the real foliage is encircled.

study sites was documented. Deadwood is an often used parameter to characterize an ecosystem and should thus not be unregarded in Pineta san Vitale. To analyze the quality of deadwood, we used the classification of Stokland et al. (2005). Per plot, we characterized 10 randomized deadwood objects.

For statistics and graphics the program R (www.r-project.org) was used. Statistical significance was tested using a linear model summary-order in R (summary(lm(x~y))).

Results

The differences between estimated and measured crown densities were small (*P. pinea*: $p = 0.0006978$; *Q. robur*: $p < 0.00001$). Only ImageJ data were used for statistical analysis.

Our results confirm that mean crown densities from *P. pinea* and *Q. robur* were declining by trend or even significantly within smaller distance to the industrial zone (*P. pinea*: $p = 0.03$; *Q. robur*: $p = 0.07$) (fig. 3A). Concerning the acorns, there was no significance, neither for the weight ($p = 0.68$) nor for the parasitation ($p = 0.53$) (fig.3B and 3C). Only by using one centralized point (fig. 1, I1) to measure the distance to the industrial area tendencies for higher parasitation ($p = 0.1$) and lower weight ($p = 0.06$) occur the nearer the industrial plants were located.

With increasing salinity, the crown density of *P. pinea* was declining almost highly significant ($p = 0.003$) (fig. 3D). Other examined factors like the crown density of *Q. robur* ($p = 0.14$), the weight of acorns ($p = 0.45$) or the parasitism rate ($p = 0.30$) did not correlate with salinization (fig. 3D, 3E and 3F).

Within the deadwood-analysis the most remark-

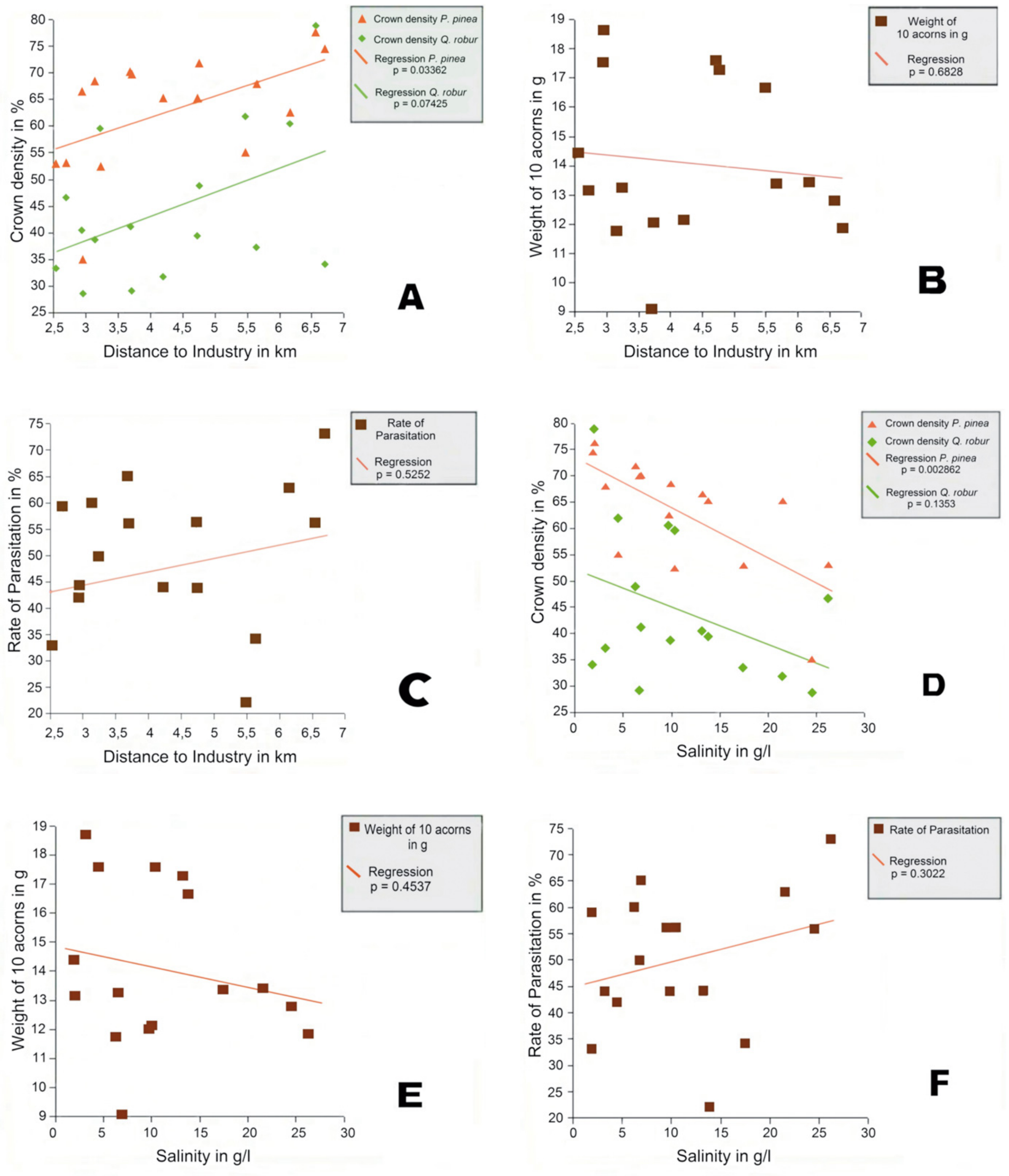

Fig. 3: Correlation between the distance to Industry and Crown density (A), acorn weight (B), parasitation of acorns (C). Correlation between soil salinization and Crown density (D), acorn weight (E) and parasitation of acorns (F).

able thing was the presence of many standing dead, dried trees. At some study sites, the total percent of snags was up to 80%. On average, 37% of the studied dead wood findings were trees, presumably dried and killed by salt stress. The rest of deadwood findings were fallen branches and logs, caused by rotting or mechanical stress.

Discussion

So did filter improvements really ameliorate forest health condition? In fact, our results are very similar to those of Scossirolli (1973). Crown transparency increases in most cases with increasing soil salinity and decreasing distance to industry. Nevertheless, there are many other factors influencing Pineta san Vitale. Hence, every single influence plays a special role as well as the combination of all surrounding conditions like agricultural management of surrounding fields, exhaust emissions or seaspray. Among the scientifically best analyzed factors, there are air pollution and subsidence induced soil salinization (Antonellini et al. 2008, Giambastiani 2007, Lucialli et al. 2007, Mollema et al. 2013).

Defoliation and the declining crown density are short-term responses of trees, thus, reactions that are immediately visible after a negative influence on the habitat (Tkacz et al. 2008). The crown densities of both examined species were declining significantly or by trend, the nearer the industrial plants were located. So air pollution could be one of the important factors causing the damages. For instance, some waste gases could interact with phytohormones initiating senescense processes or abscission. Also cuticular waxes, stomatal opening and closure processes, pathogene defense and many other aspects can be negatively influenced by pollutants (Hock and Wolf 2005). But for the achievement of a clearer result there is the need of further examinations with more trees and better methods. For example, crown density is a parameter composed of 2 main aspects: the density of foliage and the area that is covered by leaves (Mizoue 2001). Pictures only can show the leaf area; density though is difficult to get using our methods. We tried to keep the error small by taking the photos from different directions plus accurate evaluating with ImageJ. But in some cases, ground vegetation made it impossible to get the photographs from every direction. In this regard, it would be much better to use modern laser scanning methods like used in Naesset (2002) or Solberg et al. (2006). Also the influences on other tree species and the species composition is still unknown - not to mention the influences on multi-dimensional relationships of the whole forest structure and the ecosystem.

With regard to the acorns, a tendency was recognized by using a central point in the midst of industrial plants (fig. 1, I1). There was no correlation when all parameters for distance where tested together. The production of fruits, fruit weight and their defense are depending on many different factors (Ducousso et al. 1993). So it is difficult to discuss whether there are influences caused by the industry of Ravenna or not. Factors like sea spray or different light conditions could also have positive or negative effects on the plants and their fruits, so that pollution influences e.g. of point I2 and I3 (fig. 1) could be compensated or strengthened. The tendencies concerning the distance to point I1 (fig. 1) could indicate a possible influence of pollutants. Also the composition of waste gases could have different influences on fruits and fruit production. The reason why fruits and germs are influenced is still not known and contains a lot of complex issues. For example, epicuticular waxes of fruits - that play an important role as mechanical defense against herbivory - can be harmed by ozone and other pollutants (Shepherd and Griffiths 2006). Therefore, pollutants from the industry of Ravenna could possibly explain why parasitation rates increase in the south of the park. Not only epicuticular waxes on fruits in Pineta san Vitale need to be analyzed, but also their germination rates and many other aspects. Our results only show a weak tendency so far so that further studies are of great interest.

Concerning the soil salinity, only the crown densities of *P. pinea* showed an almost highly significant result. For *Q. robur*, we did not find any correlation between salinity and crown density. In Pineta san Vitale there occur 3 morphologically very similar species difficult to distinguish: *Q. robur*, *Quercus petraea* ((Matt.) Libl.) and *Quercus pubescens* (Willd). According to Dupouey and Badeau (1993) *Q. robur* can mostly be separated easily from the other 2 species, but sometimes there are hybrid forms between *Q. petraea* and *Q. robur*. So it cannot be completely excluded that also some *Quercus* hybrids or even other *Quercus* species like *Q. petraea*, a species that is better adapted to dry and warm habitats (Bacilieri et al. 1995), were recorded at our crown density study. Hence it might be possible that these trees had a better crown condition influencing our results. Nevertheless, on average crown densities were only about 44% foliage that might be explained by the salt sensitiveness of the mainly studied *Quercus* species. Even low salt concentrations of 20 mMol/l - that means about 1.2 g/l NaCl- lead to remarkable stress reactions in *Q. robur* seedlings (Sehmer et al. 1995). *P. pinea* seedlings for example react only at a salt concentration more than twice as high (about 50 mMol/l – 2.9 g/l NaCl) (Sidari et al. 2008). Although seedlings are probably more sensitive to salt stress than adult trees, publications show that *Q. robur* is more salt sensitive than *P. pinea*. Therefore, low mean crown densities of *Q. robur* (on average 44.39%) at all study sites probably indicate that salt concentrations all over the park are yet intolerable (fig.3D). For *P. pinea* only high concentrations lead to a remarkable crown transparency whereas lower concentrations are weakly tolerated.

Also deadwood correlates to high salt concentrations in the soil. Dead standing trees mostly seem to have been killed by drought / salt stress. Especially at salt-hotspots there were many trees that were recorded to be dead. With on average 36.8% at each plot, drought and salt stress seem to be the most common reasons for deadwood in the park. These results might be influenced by a sampling error, as standing dead trees are more conspicuous than fallen and decayed branches. Additionally, branches are occasionally taken out of the park, e.g. used as firewood. Nevertheless, these dead trees indicate once more, that high soil salinity is influencing the park in a very destructive way.

Finally, our results show that there are negative influences impairing the condition of trees in Pineta san Vitale. But also other unknown factors could play an important role. The negative influences of industrial plants and their wastewaters, for example, were already confirmed in the neighboring lagoon Pialassa Baiona, showing high concentrations of different heavy metals like cadmium, copper, mercury, lead and zinc, but also other compounds like polystyrene, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (FS) (Matteucci et al. 2005). These chemical pollutants could possibly also influence the trees in Pineta san Vitale and, therefore, our results.

Conclusion

The studies of Scossirolli (1973) are once again confirmed and strengthened by statistical analysis, although the harbor of Ravenna developed since then by installing a lot of environmentally friendly exhaust filters and wastewater systems (Rubbi 2010). The reasons for the bad tree conditions in the south of the park are very complex and cannot be reduced to one or two factors, but air pollution and salinization play an important role as composed in the following main points:

Defoliation of *P. pinea* and *Q. robur* in Pineta san Vitale is declining significantly or by trend in correlation with the distance to the industrial plants of Ravenna.

Also acorns show increasing parasitation and decreasing weight the nearer the factories are located.

The salinity in the soil caused by the industrial plant-induced subsidence seems to be responsible for the significant decline of *P. pinea* crown density and correlates with the distribution of deadwood in the park.

But even if Pineta san Vitale probably cannot be rescued (Mollema et al. 2013), it shows that protection should not stop within a national park border. Also industrial plants, cities, streets and all other anthropogenicly used areas need to be managed in an environmentally friendly way. By furthermore developing filter and wastewater systems, reducing pollution and establishing a sustainable economy, many natural systems can be saved.

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