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Research paper

Ozone dynamics in a Mediterranean Holm oak forest: comparison among transition periods characterized by different amounts of precipitation

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Abstract - Tropospheric ozone (O_3) is one of the most toxic compounds for plants in the atmosphere. The large amount of anthropogenic O_3 precursors in the urban areas promote O_3 formation, thus making Mediterranean forests located in periurban areas particularly vulnerable to this pollutant. O_3 flux measurements have been carried out using the Eddy Covariance technique over a Holm oak forest located 25 Km from Rome downtown, inside the Presidential Estate of Castelporziano (Italy).Two transition periods - early Spring and late Fall - in two consecutive years were examined. The uncommon low precipitation recorded in both transition periods in 2012 allowed to evaluate the influence of water availability on O_3 fluxes during seasons which are not commonly affected by drought stress. Overall, the forest canopy showed to be a net sink of O_3, with peak values of mean daily O_3 fluxes of -8.9 nmol $m^{-2}s^{-1}$ at the beginning of flowering season and -4.6 nmol $m^{-2}s^{-1}$ at the end of Fall. O_3 fluxes were partitioned between stomatal and non stomatal sinks using the evaporative/resistive method based on canopy transpiration in analogy with an Ohm circuit. By comparison of the two years, water availability showed to be an important limiting factor during Spring, since in this season plants are more photosynthetically active and more sensitive to water availability, while in Fall, under conditions of low stomatal conductance, the dependence on water availability was less appreciated.

Keywords - ozone fluxes, O_3, Holm oak, Mediterranean forest, Eddy Covariance, drought stress, pollution

Introduction

Tropospheric ozone (O_3) is a significant environmental problem as it affects human health (Anenberg et al. 2010) and decreases carbon sequestration potentials of forest ecosystems (Fares et al. 2013a). It is also an important greenhouse gas, with a radiative forcing of 0.35–0.37 W m^{-2}, responsible for 5% - 16% of the global temperature increase since preindustrial time (Foster et al. 2007).

O_3 is produced in the atmosphere by photochemical reactions between anthropogenic and biogenic volatile organic compounds (VOC) and nitrogen oxide (NO_x), high irradiance and temperature occurring in the Mediterranean regions promote O_3 formation more than in other area (Paoletti 2006). O_3 removal from forest ecosystems is attributed to both stomatal and non-stomatal sinks, which include deposition on cuticles and soil surface as well as O_3 depleted by gas-phase reactions (Kurpius and Goldstein 2003, Cieslik 2004). The majority of O_3 deposition is often attributed to non-stomatal O_3 sinks (Fowler et al. 2009), especially during the summer season when stomatal conductance is reduced under conditions of drought stress and high vapour pressure deficit (Gerosa et al. 2009).

The objective of this study is to quantify O_3 removal during two transition periods: before the beginning of the driest season, from March 20 to April 14 (early Spring) and before the coldest season, from November 11 to December 6 (late Fall) in a Mediterranean Holm oak forest. O_3 flux dynamics were compared between the uncommonly dry early Spring and late Fall of 2012 with the more wet periods of 2013 in order to highlight whether water availability can have a significant effect on ozone fluxes.

Materials and Methods

Study site description

The study site, named "*Grotta di Piastra*" (41°42' N, 12°21'E), is located within the Castelporziano Estate, 25 km SW from the centre of Rome, Italy. This site is a wild coastal rear dune ecosystem, 1.5 km from the seashore, covered almost prevalently by an even-aged evergreen Holm oak forest (*Quercus ilex* L.). The forest main height was 14 m and the Leaf Area Index (LAI) was 3.69 m^2leaf m^{-2}ground,

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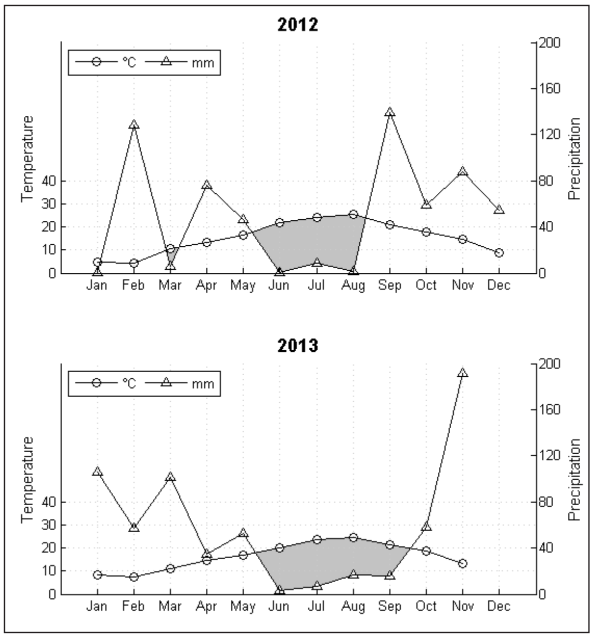

Figure 1 - Bagnouls-Gaussen diagrams for 2012 and 2013. Circles are monthly average temperature (°C) while triangles are monthly cumulated precipitation (mm). Shaded area represent drought period.

measured using a LAI 2000 instrument (Li-Cor, USA). The soil has a sandy texture and low water-holding capacity. The climate is typically Mediterranean: precipitation occurred mainly in Fall and Winter, whereas Summers were hot and dry (Fig. 1). Averaged in the year 1999-2010, annual precipitation was 789.3±230.6 mm and mean monthly temperatures range between 7.3°C and 23.3°C. The wind regime was characterized by winds from the sea (S-SW) blowing during the morning, and winds from the inland (N-NE) in the afternoon.

Meteorology and flux measurement

Measurements were carried out in 2012 and 2013 in early Spring and late Fall, from day of the year 79 to 104 and 315 to 340 of each year.

Air temperature, precipitation, relative humidity, net solar radiation, wind direction, soil humidity and soil temperature were recorded every minute and averaged for 30 min intervals with a Davis vantage pro meteorological station (Davis Instruments Corp. CA, USA).

Flux measurement equipment was installed at 19.7 m height at the top of a scaffold tower. A tri-dimensional sonic anemometer (Gill Windmaster) was used to measure instantaneous wind speed and temperature fluctuation. H_2O and CO_2 concentrations were measured with a closed-path infrared gas analyzer (LI-7200, Li-Cor, USA). O_3 fast measurements were performed by a chemiluminescence methods which uses coumarin dye reaction with O_3, thanks to a customized instrument developed by the National Oceanic and Atmospheric Administration (NOAA, Silver Spring, MD, Bauer et al. 2000). The chemiluminescence detector was calibrated against 30 min average O_3 concentrations from a UV ozone monitor (Thermo Scientific, mod. 49i). Data were recorded at 10 Hz for all gases using a data logger (CR-3000, Campbell Scientific, Shepshed, UK).

H_2O, CO_2, O_3, latent and sensible heat fluxes were calculated according to the eddy covariance technique:

$$F_c = \overline{w' c'} \qquad (1)$$

where w' and c' are deviations from the 30 minute means of vertical wind velocity and gas concentration, respectively. The method is extensively described in Goldstein et al. (2000) and Fares et al. (2012).

O_3 fluxes were partitioned between stomatal and non-stomatal trough several steps: first stomatal conductance for water (G_{sto}) was calculated from latent heat flux by inverting the Penmann–Monteith equation according to the evaporative/resistive method (Monteith 1981, Fares et al. 2013b, Gerosa et al. 2009). O_3 stomatal conductance (G_{O3}) was calculated from G_{sto}, by correcting for the difference in diffusivity between O_3 and water vapor (Massman 1998). O_3 stomatal fluxes were calculated multiplying G_{O3} by O_3 concentration, assuming a constant vertical flux between the measurement height and the top of canopy and negligible intercellular O_3 concentration (Laisk et al. 1989). The remaining fraction of the O_3 flux is considered as non-stomatal deposition and includes all other deposition pathways.

Fluxes are expressed per unit of ground area per second, positive fluxes indicate upward transfer of mass and energy from the ecosystem to the atmosphere, and negative fluxes indicate transfer from the atmosphere into the ecosystem.

Results and discussion

Meteorology and energy fluxes

Periods examined in this work are both transition phases between a cold and wet season and a dry and warm season, when usually drought stressed does not occur: average in the year 1999-2010, mean precipitation were 61.3±24.6 mm in April and 130.1±54.4 mm in November. Early Spring and late Fall (2012) were dry respect to values collected in 2013 (Fig. 2): 8.0 mm in 2012 versus 58.4 mm of 2013 in the early Spring and 71.4 mm of 2012 versus 160.8 mm of 2013 in late Fall.

Figure 3 shows 2012 and 2013 mean daily course of temperature (°C), net radiation (W m^{-2}), latent heat flux (LE, W m^{-2}), sensible heat flux (H, W m^{-2}) and vapour pressure deficit (VPD, kPa) for the two

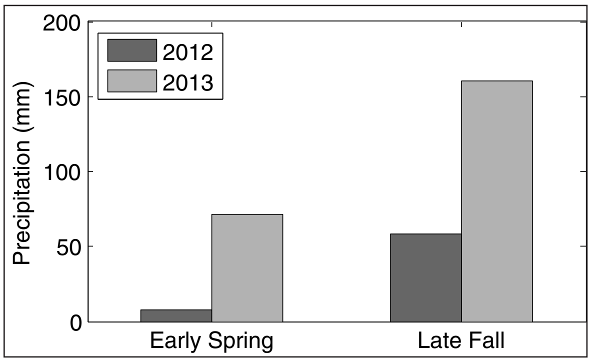

Figure 2 - Cumulated precipitation (mm) from March 20 to April 14 (Early Spring) and from November 11 to December 6 (Late Fall).

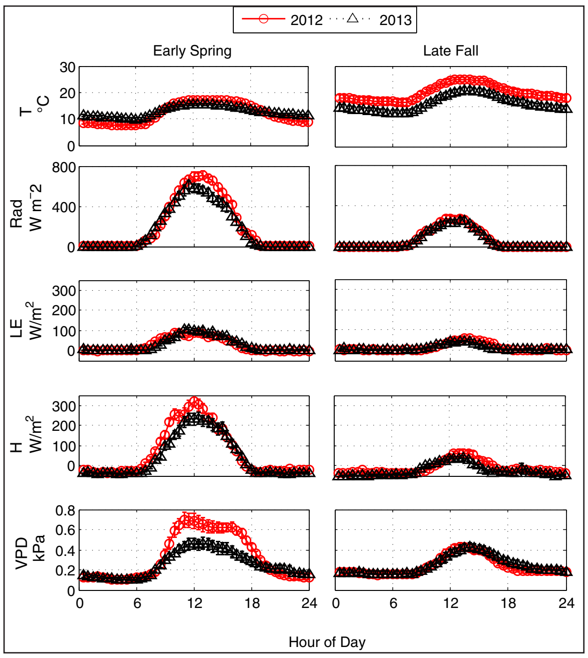

Figure 3 - Averaged daily values (± standard deviation) of temperature (a), net radiation (b), latent heat flux (c), sensible heat flux (d) and vapour pressure deficit (e) for the periods from March 20 to April 14 (Early Spring) and from November 11 to December 6 (Late Fall).

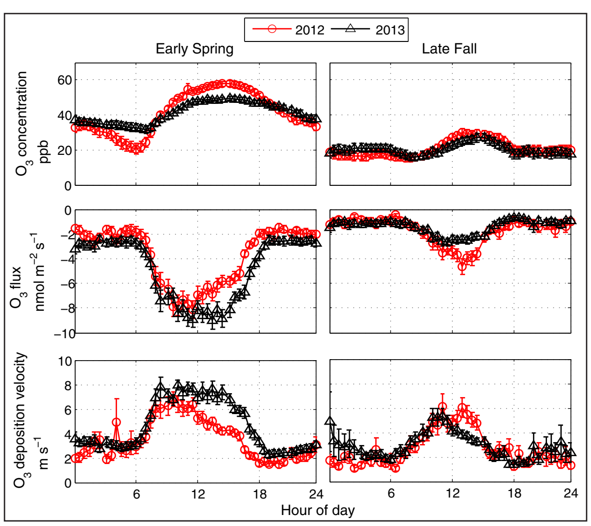

Figure 4 - Averaged daily values (± standard deviation) of ozone concentration (ppb), ozone fluxes (nmol m^{-2} s^{-1}) and deposition velocity (m s^{-1}) at the site in 2012 and 2013 early Spring and late Fall.

periods. Early Spring mean temperature was similar across the two years (12.1±4.2°C and 12.6±2.9°C for 2012 and 2013, respectively) while 2013 late Fall was colder than the 2012 one (13.4±3.9°C and 10.6±4.2°C for 2012 and 2013, respectively). Late Fall night temperatures were higher than those recorded in early Spring 2012. Daytime cloudiness in 2013 early Spring was 19% higher than 2012. H reflected the solar radiation trend. During the early Spring hottest hours LE flux intensities were 16% lower in 2012 than 2013, as expected considering the scarcity of precipitation occurred in 2012. Interestingly, the relation is inverse in late Fall (LE fluxes were 23% minor in 2013 than 2012) suggesting that the water availability did not represent a limiting factor during Fall.

O_3 concentration at the site

No significant differences were observed between mean O_3 concentrations at the top of the canopy for the two years in early Spring (41.4±16.4 ppb and 41.5±10.8 ppb for 2012 and 2013, respectively) neither in late Fall (20.7±13.3 ppb and 20.3±12.8 ppb for 2012 and 2013, respectively). For both periods, O_3 concentration was higher in the warmest hours of the day and decreased during the night (Fig. 4). Overall, O_3 concentration was lower in the late Fall period according to the dependence of O_3 on air temperature (Kurpius and Goldstein 2003, Fares et al. 2010, Finlayson and Pitts 1997). The land-sea wind regime at the site also affected O_3 concentration. Figure 5 shows daytime (a) and nighttime (b) wind direction and O_3 concentration. During the day wind blew prevalently from the sea (S-W), carrying air masses to the forest, while during night wind blew from the city (N-E), transferring polluted air plumes to the forest site, as previously reported by Fares et al. (2009). Air coming from the city was previously characterized by low O_3 concentrations due to the fast reactions with anthropogenic pollutants like nitrogen oxides (NO_x, Finlayson and Pitts 1997). This may explain the average low concentrations of O_3 in Castelporziano as compared with periurban area north of Rome (Fares et al. 2009 and 2013b). Moreover, during the few times that wind circulation diverged from its typical pattern (Fig. 5 a, b), O_3 concentration at night was higher, thus confirming that that air masses not directly coming from the urban areas are less depleted in O_3 concentration.

O_3 fluxes and deposition velocity

O_3 fluxes to the forest reached the maximum values during the central hours of the day both in early Spring and in late Fall. The peak values of mean daily O_3 fluxes in early Spring were -8.1±0.7 nmol $m^{-2}s^{-1}$ and -8.9±0.6 nmol/m²s for 2012 and 2013 respectively, while in late Fall they were -4.6±0.7 nmol $m^{-2}s^{-1}$ and

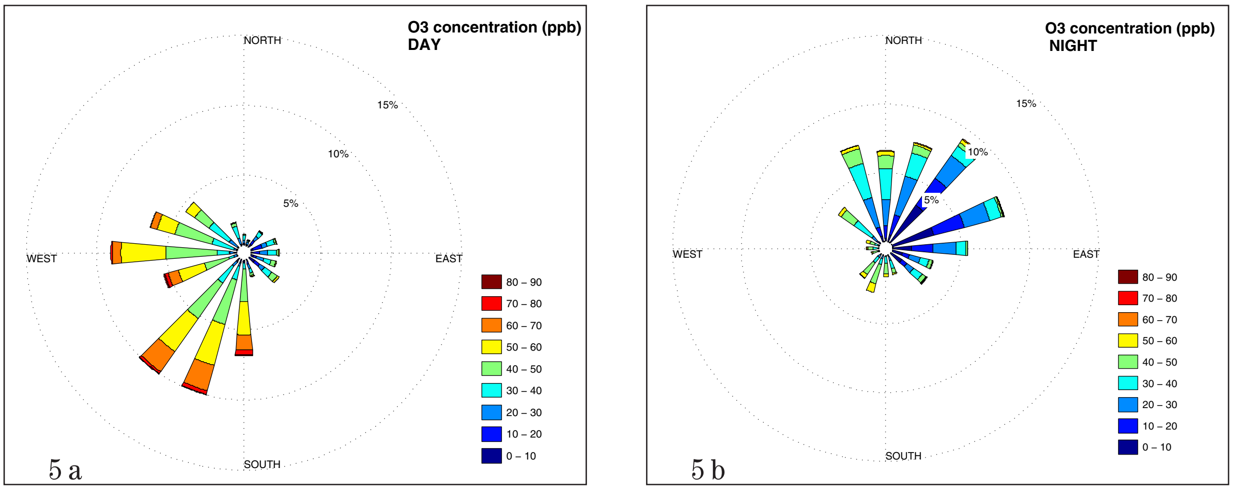

Figure 5 - Wind roses of daytime (a) and nighttime (b) wind directions and ozone concentration (ppb). The frequencies at which the wind blew from each direction is represented by the radial thickness of each slice, while ozone concentration is represented by the color of the filled area. Data are from February 2012 to November 2013.

Table 1 - Summary statistics of O_3 fluxes. For each periods is reported: mean O_3 flux ± standard error, 25th percentile, 75th percentile, skewness, number of observations (n) and percentage of valid observations (N).

Time period year	season	O_3 flux (nmol m^{-2} s^{-1}) mean±se	25th perc.	75th perc.	skewness	n	N (%)
2012	early Spring	-3.92±0.12	-5.88	-1.2	-1.14	991	81
	late Fall	-1.7±0.08	-2.80	-0.01	-1.7	1021	86
2013	early Spring	-4.92±0.10	-7.00	-2.29	-0.92	1123	99
	late Fall	-1.35±0.04	-1.95	-0.09	-1.69	1025	99

-2.5±0.3 nmol $m^{-2}s^{-1}$ for 2012 and 2013, respectively. Late Fall O_3 fluxes for both years were about half of the fluxes measured in early Spring. A summary statistics of O_3 fluxes is reported in Table 1.

A strong correlation between O_3 fluxes and O_3 concentrations was observed in both study periods (Fig. 4), with the exception of the hottest hours of the day in 2012 early Spring. O_3 deposition velocity (flux normalized by concentration) in this period was reduced by 23.6%. We ascribe this behaviour to the reduction in stomatal O_3 fluxes, as previously hypothesized given the dependence of stomatal conductance on moisture content. Stomatal conductance was indeed lower in early Spring 2012 during the central hours of the day (Fig. 6).

O_3 deposition velocities were lower in late Fall than in early Spring for both years (Fig. 4). This indicates that not only O_3 concentration controls the flux magnitude but also plant phenology, which determines low stomatal conductance in Fall, played a leading role in controlling O_3 flux. In order to better understand seasonal effects on O_3 fluxes during Spring and Fall, these were partitioned between stomatal and non-stomatal fluxes (Fig. 7) for measurements performed in 2013 (data for 2012 not available).

In agreement with dynamics of stomatal conductance shown in fig. 6, stomatal contribution to the total O_3 flux was different during the two seasons, with higher stomatal fluxes in Spring, while non-stomatal O_3 fluxes were similar in the two seasons. This result confirmed the predominant role of stomatal control on O_3 removal from the atmosphere in dependence on water availability in a photosynthetically active season (Spring). Therefore in Fall, under conditions of low stomatal conductance, the dependence on water availability was less appreciated.

Individual contribution of stomatal and non-stomatal sinks to total O_3 fluxes also varied during the day. Night values of non stomatal fluxes could have several contributors: gas-phase reaction with VOC and NOx (Finlayson and Pitts 1997), and surface deposition. The latter is probably responsible

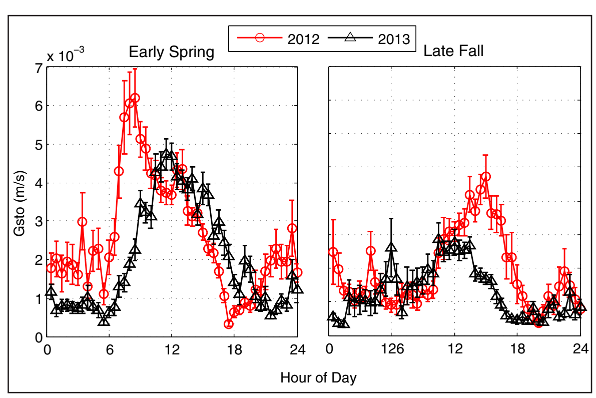

Figure 6 - Averaged daily values (± standard deviation) of stomatal conductance (Gsto, m/s) at the site in 2012 and 2013 early Spring (a) and late Fall (b).

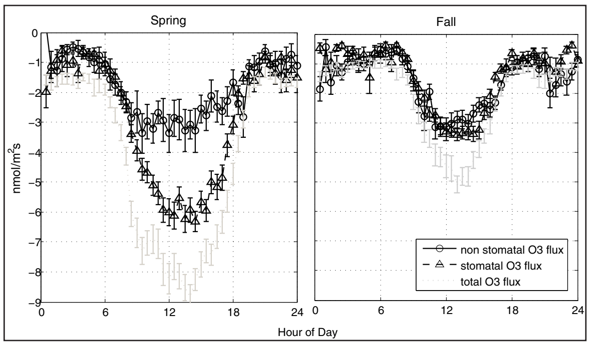

Figure 7 - Averaged daily values (± standard deviation) of total O_3 flux, stomatal O_3 flux and non stomatal O_3 flux measured during 2013 Spring (a) and Fall (b).

for the observed high nocturnal non-stomatal fluxes in Fall, when leaf surface wetness and air humidity have been shown to increase O_3 deposition (Zhang et al. 2002, Altimir et al. 2005).

Conclusion

O_3 fluxes were measured in an periurban Mediterranean evergreen Holm oak forest during transition periods in two different years, characterized by different amount of precipitation.

During the measurement periods, not commonly affected by drought stress, O_3 flux was found to be reduced under conditions of low water availability, when stomatal sink contribution is typically higher. The non-stomatal ozone deposition proved to be an important sink of tropospheric ozone in this Holm oak ecosystem, current studies are aimed at partitioning these non-stomatal sinks between different contributors (e.g. NOx, VOCs, surface deposition).

Overall, our results indicate that the Castelporziano evergreen forest represents a net sink of O_3. This type of ecosystem service must be taken into account while evaluating the complex of the benefits that forest ecosystems can provide to urban and peri-urban areas.

Currently, O_3 fluxes are still measured at the site. A large temporal series will help to elucidate deeply the contribution of the environmental control factors on ozone dynamics.

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Research paper

Growth performance of selected eucalypt hybrid clones for SRWC in central and southern Italy

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Abstract - Eucalypt short-rotation woody crop (SRWC) is becoming an attractive option for energy biomass in Mediterranean dry environments. The present study is aimed at assessing growth performance of selected eucalypt hybrid clones for SRWC in three Italian sites (Massama, Sardinia; Mirto, Calabria; Rome, Latium) compared with *Eucalyptus camaldulensis*, the most commonly cultivated eucalypt species in Italy. The study identified eucalypt clones with stable and high performance between several alternatives. Results pointed out the declining growth performance observed in the second rotation compared with the first cycle. This is due to the cultivation model, age rotation and harvesting method adopted, which negatively affect the available soil nutrients' content. The clone/site interaction as for basal area growth at the three investigated sites, suggests a significantly different clones' performance among sites. Viglio and Velino clones showed the best overall performance and are suggested to be used over the large scale SRWC in central and southern Italy.

Keywords - agroforestry, bioenergy, Eucalyptus, clones, Italy

Introduction

Eucalypt was cited, for the first time in Italy, by Graefer (1803, in Agostini 1953) in the "Reggia di Caserta" royal botanical garden. By that time eucalypts spread, as ornamental tree and botanical curiosity, in gardens and parks of southern Italy. In central Italy, the first plantations were established by Trappist Fathers in the second part of XIX century near Rome and in Maremma (southern Tuscany). In the same period, plantations were established in Sicily and Sardinia respectively by Railway State Company and Mine Company for sleepers and mine supports (Gemignani 1988). Between 1920 and 1950, big works of marsh reclamation were made, and eucalypts were planted for shelterbelts in Sardinia (Arborea), Latium (Agro Romano and Pontino) and Apulia (Pavari et al. 1941, Bassi 1951, Giuliani et al. 1951, Susmel 1951).

Large reforestation programs took place in southern Italy during the 1950s for soil protection purposes and especially during the 1980s for the production of paper mill raw material. The most used eucalypts species were *Eucalyptus globulus* Labill. ssp. *bicostata*, *E. globulus* Labill. ssp. *globulus*, *E. occidentalis* Endl, *E.* x *trabutii* M. Vilm., *E. camaldulensis* Dehnh. and *E. viminalis* Labill. The area of eucalyptus plantations in mid 1980s was estimated at 72,000 hectares, of which 54,000 ha in pure stands and 18,000 ha in mixed stands (Boggia 1987). Productivity varies depending on the species and sites. As an example, *E. globulus* ssp *globulus* and *E. occidentalis* productivity range respectively between 10 and 35 m^3 ha^{-1} $year^1$ (Avanzo 1964, Ciancio et al. 1981, Bronzi et al. 1987) and between 3 and 8 m^3 ha^{-1} $year^1$ (Gemignani 1988). Cultivation density averaged 1,100 to 1,600 plants per hectare with 3 x 3 m or 3 x 2 m spacing. The most used rotation ages encompass 10-12 years for 3-4 harvests.

Eucalypt short rotation woody crops (SRWC) is becoming an attractive option for energy biomass in Mediterranean dry ecosystems. Research programs have been activated to evaluate the feasibility of this option (Facciotto et al. 2007, Facciotto et al. 2009), to producing ligno-cellulosic biomass in very short time (2-3 years). Uses of Eucalypt biomass include energy production as alternative method to the conventional ones that use fossil fuel (coal and oil) originating greenhouse gases (Dallemand et al. 2008). Two cultivation models were identified as the most productive and suitable options for central and southern Italy: (i) 5,000-5,500 plants ha^{-1} for 3-4 rotation cycles lasting 2-3 years and (ii) 1,100-1,600 plants ha^{-1} for 2 rotation cycles lasting 5-6 years. Deep soils, irrigation or a superficial water table during dry periods and fertilization especially

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Table 1 - Selected soil characteristics at the three experimental fields in central and southern Italy.

Site	Mirto, Calabria			Rome, Latium			Massama, Sardinia		
	lat. 39°36' (N) long.16°46' (E) elev.10 m			lat. 41°55' (N) long.12°21' (E) elev. 81 m			lat. 39°57' (N) long. 08°36' (E) elev.15 m		
Soil depth (cm)	0-30	30-60	60-90	0-30	30-60	60-90	0-30	30-60	60-90
Sand (%)	30.00	64.09	25.00	63.00	65.00	66.00	50.07	64.64	56.18
Loam (%)	61.47	35.97	59.49	16.00	16.00	14.00	11.87	9.97	12.40
Clay (%)	18.53	19.94	20.51	21.00	19.00	20.00	38.05	25.39	31.42
pH in H2O	7.62	8.03	8.01	7.50	7.70	7.70	7.88	8.03	8.28
Organic matter (%)	5.57	0.92	0.51	1.03	0.22	0.22	0.94	0.36	0.44
Total Ca (%)	3.96	3.14	2.53	Trace	Trace	Trace	8.19	13.57	17.61
Active Ca (%)	0.12	1.47	0.48	-	-	-	2.86	3.65	4.19
Total N (%)	-	-	-	0.06	0.02	0.02	0.08	0.04	0.04
P (ppm)	4.00	2.00	2.00	8.00	5.00	5.00	-	-	-
K (ppm)	31.00	49.00	63.00	622.00	641.00	649.00	-	-	-
Mg (ppm)	-	-	-	490.00	510.00	575.00	-	-	-
Na (ppm)	-	-	-	251.00	375.00	391.00	-	-	-

at the planting time and after the harvest, are being considered necessary to get valuable growth rates (Facciotto et al. 2007, Facciotto et al. 2009). *Eucalyptus camaldulensis* Lake Albacutya is, at the moment, the best choice for eucalypt plantations in Mediterranean climate in central and southern Italy (Gemignani 1968, Lacaze 1970). Mughini (1997, 2000) described a few eucalypt hybrid clones selected for SRWC with higher growth rate than *E. camaldulensis*.

Based on these premises, the aim of this paper is to compare the growth performance of selected clones with *E. camaldulensis* in three sites of central and southern Italy (Rome, Latium; Massama, Sardinia; Mirto, Calabria). A clonal test to 5,500 plants ha^{-1} and 1,600 plants ha^{-1} was established at all sites (including *E. camaldulensis* as a control). Sectional Area (SA) and percent Survival (S) to the end of each rotation cycle were evaluated as growth performance indicators.

Materials and methods

Study sites

The climate of the three experimental sites is typically Mediterranean. A dry period of 3-4 months (June-September) was observed with summer rainfall averaging 59, 54 and 12 mm in Mirto, Rome and Massama (1961-1990). The three sites received 585 mm, 840 mm and 616 mm of rainfall concentrated in autumn-winter time. Summer water deficit limits plant growth if irrigation is not provided. Selected soil characteristics at the three sites are shown in Table 1.

Planting materials

The eucalypt hybrid clones used in the experimental fields are reported in Table 2. *E. camaldulensis* Lake Albacuya, the most common eucalypt species cultivated in Italy was used as control. *E. camaldulensis x E. globulus* subsp *bicostata*, *E. camaldulensis x E. viminalis*, *E. camaldulensis x E. grandis* hybrid clones were selected during the 1990s for biomass plantations. These clones were obtained by controlled cross pollinations using *E. camaldulensis* mother trees, selected in the Lake Albacutya provenance seed orchard (established near Rome), and pollens collected from the best trees of the provenance tests of *E. viminalis* and *E. globulus* subsp *bicostata*. *E. grandis* pollens were collected from Morocco secondary provenances. Among the 900 hybrid seedlings obtained by the above mentioned crosses, 100 clones were selected on the base of rooting ability (> 90%). Clones were tested in optimum, cold and drought conditions and the best 15 were selected for growth performance. The planting materials used in the three experimental fields were 6-8 months years-old rooted cuttings and seedlings respectively for hybrid clones and *E. camaldulensis* (Mughini 1997, 2000).

Crop method

Three experimental plots were established in spring 2004. Before planting, chemical weeding using glyfosate was performed, after soil plowing at 30-40 cm depth. Each plant was fertilized with 40 g of slow-release fertilizer (9 + 20 + 8 + 3.0 MgO + 0.1 B). Chemical weeding was applied after plantation using Oxyfluorfen (0.50-0.70 liter ha^{-1} active ingredi-

Table 2 - Control and eucalypt hybrid clones used at the three experimental fields.

Clone/control	Species/hybrid
E. cam	*E. camaldulensis*
14	*E. camaldulensis x E. globulus ssp bicostata*
20	*E. camaldulensis x E. globulus ssp bicostata*
22	*E. camaldulensis x E. globulus ssp bicostata*
40	*E. camaldulensis x E. globulus ssp bicostata*
44	*E. camaldulensis x E. globulus ssp bicostata*
45	*E. camaldulensis x E. globulus ssp bicostata*
13a	*E. camaldulensis x E. globulus ssp bicostata*
Velino	*E. camaldulensis x E. globulus ssp bicostata*
Viglio	*E. camaldulensis x E. globulus ssp bicostata*
65	*E. camaldulensis x E. grandis*
81	*E. camaldulensis x E. viminalis*

ent). Until the rotation age, the soil was disked 2-3 times during the growing season (10 cm depth) for weed control and to prevent fire risk.

Experimental design

Plants (rooting cuttings and seedlings) were planted at two densities: (i) 5,500 plants ha^{-1} and (ii) 1,600 plants ha^{-1}. In the first case, the inter-rows distance was 3 m and the intra-row distance between plants was 0.60 m, the elementary plot for each accession (clone or control) being made by 20 plants in a single row. In the second case, the inter-rows distance was 3 m and the intra-row distance between plants was 2 m, the elementary plot for each accession being made by 6 plants in a single row. Each test was established with completely randomized design with each accession replicated 5 times as a minimum.

Statistical analysis

Only tests providing complete datasets collected at the end of the rotation cycle were performed. In each test, the diameter at breast height (dbh) and S of all the plants were measured each year in autumn. Dbh was measured with a digital caliper taking two orthogonal measurements. Dbh was converted to SA (cm^2) of stem/shoot using the equation $\pi(dbh/2)^2$. Plot SA for each accession was derived by summing the SA of every plant in each plot. The plot accession S was calculated for each plot. Plot accession SA and S were analyzed through ANOVA with the aim to verify: (i) accession x rotation interaction (SA and S accessions at the end of first and second rotation cycle of Mirto site 5,500 plants ha^{-1}); (ii) accession x site interaction (SA and S accessions at the end of the first rotation cycle in the three tests with 5,500 plants ha^{-1}) and (iii) SA and S accessions at Mirto site with 1,600 plants ha^{1}. Data were tested for normality and homoschedasticity of residuals.

Results and Discussion

Accession x rotation interaction

Differences between SA accessions and rotations (Table 3) are significant ($p < 0.01$) while accession x rotation interaction was found not significant. S differed significantly between accessions ($p < 0.01$). Results suggest that percent survival did not influence SA in the first and second rotation. On the contrary, results indicate that accessions show different performances being quite stable in the two rotations. SA differed however between the first and second rotation; the SA of the first rotation was found greater than the second rotation (427.6 cm^2 and 335.4 cm^2, respectively). This pattern was reported also by FAO (1979) and Mora et al. (2000) and clashes with what observed for poplar and willow SRWC, SA increasing with rotation (Paris et al. 2011). Species, pedo-climatic conditions, cultivation models and harvesting system may influence this pattern.

Limiting factors to growth rate in the second rotation in Mirto are the cultivation model, rotation age and harvesting system which reduce the available nutrients in the soil. In the adopted cultivation model, plants were fertilized only at the planting time but not in the following years and after harvest. The harvesting system used for SRWC (modified forage harvester) collects the whole plant, including branches, leaves and bark. This operation removes, according to Mora et al. (2000) more than 70% of the nutrients. Moreover, according to a recent study carried out in clonal plantations in Congo (Laclau et al. 2000), the rotation age used in our tests (2 years) coincides with the period where nutrients are supplied by uptake from soil reserves, preventing the intense nutrients recycling that characterizes the period from the third year to the rotation age. As a matter of fact, a rotation age of 7-10 years is recommended in conventional plantations (660 to 1,600 plants ha^{-1}) to maintaining soil fertility, whilst the most suggested harvesting system removes only the logs leaving bark, branches and leaves in the field (Laclau et al. 2003).

In Italy, this cropping system cannot be implemented in SRWC with 2-3 years rotation age since fertilization is an expensive operation and cultivation is no profitable without public incentives (Facciotto et al. 2003, Sperandio 2004, Manzone et al. 2009). In northern Europe irrigation with urban pre-treated waste-water was introduced to address this problem in poplar and willow SRWC (2-3 years rotation age) (Dallemand et al. 2008, Dimitrou et al. 2005). The same method was successfully applied to

Table 3 - Combined ANOVA for stem/shoot sectional area (SA) and percent survival (S) between accessions and rotations (first and second rotation) and between accessions and sites in the sites with 5,500 plants ha^{-1} (ns: not significant, ** $p < 0.01$).

Variable		SA	S			SA	S
Source of variance	df	MS	MS	Source of variance	df	MS	MS
accessions	11	58,187.8**	740.883**	accessions	11	26,257.2**	537.54**
rotations	1	18,6819.7**	309.375ns	sites	2	893,579.8**	14,779.31**
accessions x rotations	11	9,701.06ns	40.057ns	accessions x sites	22	18,277.90**	252.612**
residual	64	19,877.93	113.67	residual	116	5,837.85	115.78

Table 4 - ANOVA for stem/shoot sectional area (SA) and percent survival (S) in the first rotation of accessions at 1,600 plants ha^{-1} density.

Variable		SA	S
Source of variance	**df**	**MS**	**MS**
Accessions	11	3,998.367**	761.720**
Residual	32	729.258	110.240

eucalypt plantations in Northern Africa countries, Australia and USA (Myers et al. 1998, Rockwood et al. 2004).

Accession x site interaction

A significant difference in percent survival between accessions and rotations was found, it suggesting that S could influence SA performance between sites. This is especially true in the case of Rome site, where S is only 61.7% (Table 4). The SA average (Table 5) is similar in Massama and Rome (189 cm^2 and 169 cm^2, respectively) and higher at Mirto (427.6 cm^2) with a statistically significant difference ($p < 0.01$). The difference should be due to: (i) the presence of a superficial water table (1-2 m depth) in Mirto and (ii) the severe galls makers insects (*Ophelimus maskelli* Ashmead and *Leptocybe invasa* Fisher & La Salle) attacks occurred in 2004 and 2005 (Arzone et al. 2000, Viggiani et al. 2001 and 2002, Bella et al. 2002, Bagnoli et al. 2004, Laudonia et al. 2004, Laudonia 2006, Protasov et al. 2007).

Some clones showed SA lower than *E. camaldulensis* (clone 13a in Massama; clone 45 in Rome; clones 81, 13a, 65 and 45 in Mirto). These results clash with those obtained in a previous study (Mughini 2000). The accession x site interaction suggests that clones and the control show interactive performance with environmental conditions. The same results were obtained in Portugal (*E. globulus* clones), Morocco (*E. grandis*, *E. tereticornis*, *E. rudis x E. camaldulensis*, *E. grandis x E. camaldulensis* clones) and Brazil (Borralho et al. 1992, Nunes et al. 2002, Belghazi et al. 2008).

In Mirto, the difference in the SA observed between accessions at the first rotation was significant (Table 6). The observed SA ranged between 376.98 cm^2 (clone 22) and 2020.18 cm^2 (clone 14). Only clone 22 showed a SA value lower than the control.

Selection of the most productive clone

The more productive and stable clone at all sites was identified as the best clone. Clone x site interaction may indicate a separate site selection, which can be assumed in the case of different economic importance of eucalypt raised in the three areas. Clones showing a good overall performance across sites should be selected with practical advantages in breeding programs and nursery and commercial management (Borralho et al. 1992, Nunes et al. 2002). Stable clone selection has been adopted recently in Spain in the case of poplar clones selection for SRWC (Sixto et al. 2011). The following methodology was adopted to select the most stable and productive clone: (i) the five clones showing higher SA than the control at all sites; (ii) the five clone and control performances observed at each site to analyze phenotypic plasticity and (iii) the two most suitable clones were identified.

Viglio and Velino were identified as the most productive and stable clones. The same results were

Table 5 - Means and standard error (in brackets) of stem/shoot sectional area (SA) of *Eucalyptus* clones and the control (*E. camaldulensis*) tested at the three experimental fields in central-southern Italy.

Site	Massama (Sardinia)	Rome (Latium)	Mirto (Calabria)		
Age	**R3S3[1]**	**R3S3**	**R2S2**	**R4S2**	**R6S6**
Plants density per hectare	**5,500**	**5,500**	**5,500**	**5,500**	**1,600**
Clone	**cm^2**	**cm^2**	**cm^2**	**cm^2**	**cm^2**
22	155.42 (21.51)	142.65 (57.57)	428.13 (56.09)	357.67 (170.40)	376.98 (90.63)
E. cam	150.89 (52.24)	107.48 (4.76)	358.40 (29.72)	273.98 (32.50)	537.69 (74.79)
81	180.71 (39.65)	173.64 (33.12)	277.42 (37.56)	247.05 (37.24)	608.27 (34.10)
13a	148.95 (23.31)	150.23 (45.77)	313.06 (17.43)	338.88 (31.72)	861.95 (163.64)
65	320.92 (29.90)	246.00 (25.16)	323.41 (8.51)	276.13 (29.72)	869.01 (166.10)
45	221.76 (28.91)	98.31 (30.68)	308.02 (52.36)	218.63 (48.98)	889.44 (80.10)
20	166.26 (13.38)	200.74 (37.21)	523.22 (49.13)	291.40 (39.54)	1053.58 (218.96)
40	156.54 (17.71)	170.43 (29.62)	594.85 (35.00)	492.71 (94.12)	1108.56 (169.63
44	163.42 (19.44)	182.42 (21.06)	466.87 (57.99)	367.83 (71.13)	1244.62 (226.65)
Velino	195.46 (39.35)	203.87 (39.21)	499.39 (55.05)	320.97 (57.86)	1267.98 (238.20)
Viglio	279.95 (46.95)	207.74 (26.81)	523.22 (114.20)	336.62 (159.54)	1456.87 (483.00)
14	181.38 (48.53)	159.54 (23.31)	510.91 (49.77)	456.38 (144.53)	2020.18 (270.29)
Average	189.11 (10.54)	168.91 (10.30)	427.60 (19.78)	335.44 (26.00)	1015.67 (80.80)
Velino *vs E.cam*[2]	29.54 %	89.68 %	39.34 %	17.15 %	135.82 %
Viglio *vs E. cam*[3]	85.54 %	93.28 %	45.99 %	22.86 %	170.95 %

[1] R3S3:roots 3 years old and stem/shoot 3 years old; [2] Velino *vs E.cam:* % of SA of Velino greater than *E. camaldulensis;* [3] Viglio *vs E.cam:* % of SA of Velino greater than *E. camaldulensis*.

Table 6 - Mean and standard error (in brackets) of percent survival of Eucalyptus clones and the control (*E. camaldulensis*) tested in central and southern Italy.

Site	Massama (Sardinia)	Rome (Latium)	Mirto (Calabria)		
Age	R3S3[1]	R3S3	R2S2	R4S2	R6S6
Plants density (per hectare)	5,500	5,500	5,500	5,500	1,600
Clone	%	%	%	%	%
22	88.75 (5.15)	48.75 (8.00)	75.00 (6.45)	67.50 (7.50)	44.33 (5.67)
E. cam	75.00 (9.79)	62.50 (1.44)	97.50 (1,44)	97.50 (1,44)	95.80 (3.29)
81	93.33 (1.67)	70.00 (2.24)	81.25 (7.74)	77.50 (8.78)	83.25 (4.25)
13a	97.50 (1.71)	70.00 (10.80)	98.75 (1.25)	98.75 (1.25)	100.00 (0.00)
65	95.00 (2.04)	62.50 (4.33)	82.50 (2.50)	80.00 (0.00)	91.50 (8.50)
45	96.00 (2.92)	42.00 (6.44)	72.50 (9.24)	66.25 (11.06)	70.75 (7.88)
20	98.33 (1.05)	53.75 (7.47)	95.00 (2.04)	80.00 (4.56)	91.50 (4.91)
40	100.00 (0.00)	63.00 (7.00)	91.25 (2.39)	91.25 (1.25)	91.50 (4.91)
44	91.67 (6.41)	72.50 (6.61)	88.75 (4.27)	88.75 (5.15)	87.25 (4.25)
Velino	96.25 (2.39)	77.50 (4.33)	93.75 (2.39)	93.75 (2.39)	95.75 (4.25)
Viglio	93.75 (2.39)	60.00 (4.56)	80.00 (5.00)	75.00 (0.00)	75.00 (8.00)
14	93.00 (4.36)	60.00 (8.90)	95.00 (3.54)	90.00 (7.07)	83.25 (6.74)
Average	93.77 (1.33)	61.67 (2.16)	88.18 (1.83)	84.43 (2.25)	85.41 (2.51)

[1] R3S3: roots 3 years old and stem/shoot 3 years old

found also considering separately the performance of the first rotation for the three tests with a density of 5,500 plants ha^{-1}. Notably, the identified clones do not represent the best choice in all tests; clone 14 performs better than Viglio and Velino at Mirto (in both first and second rotation with both 5,500 plants ha^{-1} and 1,600 plants ha^{-1}).

Conclusions

The present study identified eucalypt clones with stable and high performance between several alternatives. Results pointed out the declining growth performance observed in the second rotation compared with the first rotation. This result depends on cultivation model, age rotation and harvesting method adopted, which negatively affect the available nutrients in the soil. The significant clones/control x site interaction for SA performance at the 5,500 plants ha^{-1} sites suggests that some clones showed a different performance among sites. This result is important for clone selection. Viglio and Velino clones showed the best overall performances and are suggested to be used over the large scale SRWC in central and southern Italy.

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Research paper

Increasing wood mobilization through Sustainable Forest Management in protected areas of Italy

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Abstract - The European Community has long recognized the need to further promote renewable energy. Under the overall objective to support and enhance sustainable management, the promotion of the use of forest biomass could help to mitigate climate change by substituting fossil fuel, increasing carbon stock in wood products and improve energy self-sufficiency enhancing security of supply and providing job opportunities in rural areas. To what extent Italian forests can satisfy an increased wood demand, without compromising the others Ecosystem Services (ESs) remains an open question. Our aim was to assess the potential supply of woody biomass from the network of protected areas in Italy considering the felling constraints. We estimated the theoretical annual potential increment from forest inventory data performing a correlation with the Corine Land Cover 2006 at the IV level with a 1:100,000 resolution elaborated in a GIS (Geographic Information System) environment. The average annual potential increment at national level available for felling was 4.4 m^3ha^{-1}. Within the network of protected areas (EUAP and Natura 2000), the average annual increment, available to felling, was 0.98 m^3ha^{-1}, respectively 0.81 m^3ha^{-1} from coppice and 1.14 m^3ha^{-1} from non-coppice forests. Based on data obtained from this study, the availability of wood materials could be increased of almost 20 % at national level by pursuing an active management within the network of protected areas. In Italy, the actual level of resource utilization is rather low; increasing felling together with the implementation of an active management within protected areas could allow satisfying, theoretically, the Italian wood consumption.

Keywords - wood mobilisation, protected area, Sustainable Forest Management, woody biomass, supply

Introduction

In recent years, the use of forest biomass for energy purposes has gained outstanding importance due to its role in the reduction of fossil fuel dependence, the diversification of the products deriving from forests (Lamers et al. 2013), the climate change mitigation and in providing job opportunities in rural areas. Within the 2020 strategy (http://ec.europa/europe2020/) for a smart, sustainable and responsible growth, forest biomasses play a crucial role in the achievement of objectives.

The woody biomass accounts about half of Europe's renewable-energy consumption, in its various forms, from sticks to pellets to sawdust, as well as it is the more widespread renewable fuel used (Economist, April 6th 2013).

In 2010, the total supply of all woody resources in the EU 27 was about one billion cubic meters where of almost 70% came from forest and 30% from outside the forest (Mantau et al. 2010). Currently, more than half of the wood harvested from European forests is used for industrial processing purposes and future increases in the demand for timber would require forest managers to increase future management intensity (Sohngen et al. 1999). The type of management within protected areas can influence the amount of increment that may be harvested. The choice between different forest management practices is a crucial step. A Forest Management Approach (FMA) provides a structure for decision-making, including a range of silvicultural operations throughout the stand development phases (PEER 2011). Dunker et al. (2012) proposed five FMAs by placing the management goal and decisions along a gradient of intensity of intervention with the natural process. The strategic management choices of where to conserve nature, and where to produce wood are often done at the management unit level (PEER 2011).

Most of European forests are managed (MCPFE 2007) and thus offer the possibility to improve their adaptation ability by human intervention (Köhl et al. 2010). Nevertheless about 25% of the European forest area is subject to management constraints to secure the Ecosystem Services (ESs) such as nature conservation, soil protection, water supply or recreation (MCPFE 2003), but also timber production. In Italy forests account for about 10.9 million hectares corresponding to 37% of the land area and are mainly located in hill and mountain ranges. The forest area available for wood supply

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is about 8.08 million hectares (FOREST EUROPE, UNECE and FAO, 2011). According to the National Statistics Agency (Istituto Nazionale di Statistica - http://agri.istat.it - visited 07/2013), the national average harvested volume from forests amounted to almost 7.6 million cubic metres (21% of total annual volume increment) in 2001, of which about 67% was fuelwood.

Not all forest and Other Wooded Land (OWL) are available for wood supply, and this reflects the forests multifunctionality: as well as providing economic resources, the forests are important for both the environment and the community.

To what extent Italian forests can satisfy an increased wood demand, without compromising the others ESs remains an open question. Main concerns are biodiversity protection and carbon neutrality (Muys et al. 2013). Maintaining biodiversity in forested areas can be achieved through an adequate network of Protected Areas (PAs) and by the implementation of a silvicultural management, which integrates conservation and production functions (Parviainen and Frank 2003). Establishing PAs is a common conservation strategy pursued for the aim of biodiversity conservation, but it is also an important opportunity to safeguard the others ESs provided by forests (Cash et al. 2006, Turner et al. 2007, Nelson et al. 2008, Egoh et al. 2009, Pettorelli et al. 2012, Willemen et al. 2013). Biological and landscape diversity protection measures can result in a range of possible impacts on the economic use of forest resources. These PAs are subject to national and/or regional legislation that may dictate some restrictions on forest management (Verkerk et al. 2008), for example, on the future land use options (Norton-Griffiths and Southey 1995).

In Italy, the Law (MATTM 2010) protects 27.5% of the forest area, with a higher incidence in some regions of central and southern Italy. The NATURA 2000 network sites (SCI and SPA) include 22.2% of the national forest area (INFC 2005).

In this study, extensions and annual volume increment of the Italian forest area have been estimated with the aim of determining how PAs and others areas subject to different forms of protection weigh upon the annually available wood amount. The target was to identify concrete measures for wood mobilization in PAs. Extension and biomass volumes available for felling were estimated in three steps:

a. assessment of forest extensions with different types of protection and silvicultural treatments through CLC 2006 (Corine Land Cover - 2006) (ISPRA 2010) and INFC (Italian National Forest Inventory - 2005) data;
b. calculation of the annual increment of forest types through the correspondence between INFC and CLC 2006 data;
c. assessment of the potential felling amounts in the network of PAs in Italy and determination of the annually available wood within the PAs supposing the implementation of an active management.

The volume of wood that cannot be harvested from these PAs was assessed estimating the unconstrained potentials for wood fellings (i.e. disregarding all forms of protection or limitations to mobilize these resources) and by reducing this potential by applying felling restrictions to the protected areas (Verkerk et al. 2008).

Materials and Methods

General approach

The paper is based on capturing a large set of data and information on Italian forests and elaborating it in a GIS (Geographic Information System) environment in the CLC 2006 resolution (1:100,000) at the IV level (ISPRA 2010). For this study OWL classes (322, 323, 324 CLC classes) were not considered. The analysis mainly focused on the CLC classes typically considered as "Forest" (311, 312, and 313).

In the first step, the forest extensions were determined by overlapping the PAs network areas with CLC 2006 (ISPRA 2010). Each CLC 2006 forest polygon was classified according to the silvicultural system (coppice/non-coppice), as reported by the Italian National Forest Inventory 1985 (ISAFA 1988). A Protection Index (I_{PW}: Index of Protection Wood - ratio between protected forest area and total forest extension) was calculated at regional and national level for each type of protection, silvicultural system and CLC class.

In the next step, a correlation between the forestry categories listed within INFC (2003) and the IV level CLC forest classes was carried out to calculate the increments of each identified forest categories (Table 1) on the basis of INFC annual increment data. The correlation between INFC and CLC categories was performed considering the vegetation description of each category according to the inventory classification of forest vegetation (INFC 2003) and the description of the vegetation categories within CLC 2006 (http://sia.eionet.europa.eu/CLC2000/classes/index_html).

In the last step, the felling potential and restriction within the network of PAs were determined. Figure 1 reports the methodology applied to develop the objectives of the research.

Table 1 - Correlation table between the forests categories INFI and IVth level CLC.

Inventory Category (INFC 2005)	CODE INFC	CLC 2006 CLASSES	CODE CLC 2006	Correspondence with INFC code
Larch and Stone pine (L. decidua, P. cembra)	1	Holm-oak and cork-oak forests	3111	15;16;17
Norway spruce (P. abies)	2	Deciduous oak forests	3112	9;10
Fir (A. alba)	3	Mesophilous broad-leaved forests	3113	12
Scots pine and mountain pine (P. sylvestris, P. mugo)	4	Chestnut forests	3114	11
Black pines (P. nigra, P. laricio, P. leucodermis)	5	Beech forests	3115	8
Mediterranean pines (P. domestica, P. marittima, P. halepensis)	6	Igrophilous forests	3116	13
Others coniferous forest	7	Non Native broad-leaved forests	3117	14;19;18
Beech (F. sylvatica)	8	Mediterranean pine forests	3121	6;7
Temperate oaks (Q. petrea, Q. pubescens, Q. robur)	9	Mountain and oromediterranean pine forests	3122	4;5
Mediterranean oaks (Q. cerrid, Q. frainetto, Q. trojana)	10	Silver fir and spruce forests	3123	2;3
Chesnut (C. sativa)	11	Larch and Arolla pine forests	3124	1
Hornbeam and Hophornbeam (Carpinu spp., Ostrya Carpinifolia)	12	Non Native coniferous forests	3125	20
Hygrophilous forests	13	Mixed forests dominated by Holm oak	31311	25%(15;16;17)+ 75%(6; 7; 9; 10; 14)
Others deciduos broadleaved forests	14	Mixed forests dominated by deciduous oak	31312	25%(9;10)+75% (6; 7; 14; 15; 16; 17)
Holm oak (Q. Ilex)	15	Mixed forests dominated by mesophilous broad-levead	31313	25%(12)+75%(5; 7; 14)
Coark oak (Q. suber)	16	Mixed forests dominated by chestnut	31314	25%(11)+75%(5; 7; 14)
Other evergreen broadleaved forests	17	Mixed forests dominated by beech	31315	25%(8)+ 75%(3; 4; 5; 7; 14)
Poplar plantations	18	Mixed forests dominated by igrophilous species	31316	25%(13)+75%(6; 7; 14)
Other broadleaved plantations	19	Mixed forests dominated by non native broad-leaved	31317	25%(14; 18; 19) +75%(6; 7; 14)
Coniferous plantations	20	Mixed forests dominated by mediterranean pine	31321	25%(6; 7)+ 75% (7; 9; 10; 14; 15; 16; 17)
		Mixed forests dominated by mountain and oromediterranean pines	31322	25%(4; 5)+ 75%(2; 3; 7; 8; 14)
		Mixed forests dominated by silver fir and spruce	31323	25%(2; 3)+ 75%(4; 5; 7; 8; 14)
		Mixed forests dominated by larch and Arolla pine	31324	25%(1)+ 75%(2; 3; 4; 5; 8; 14)
		Mixed forests dominated by non native coniferous	31325	25%(20)+ 75%(7; 14; 19)

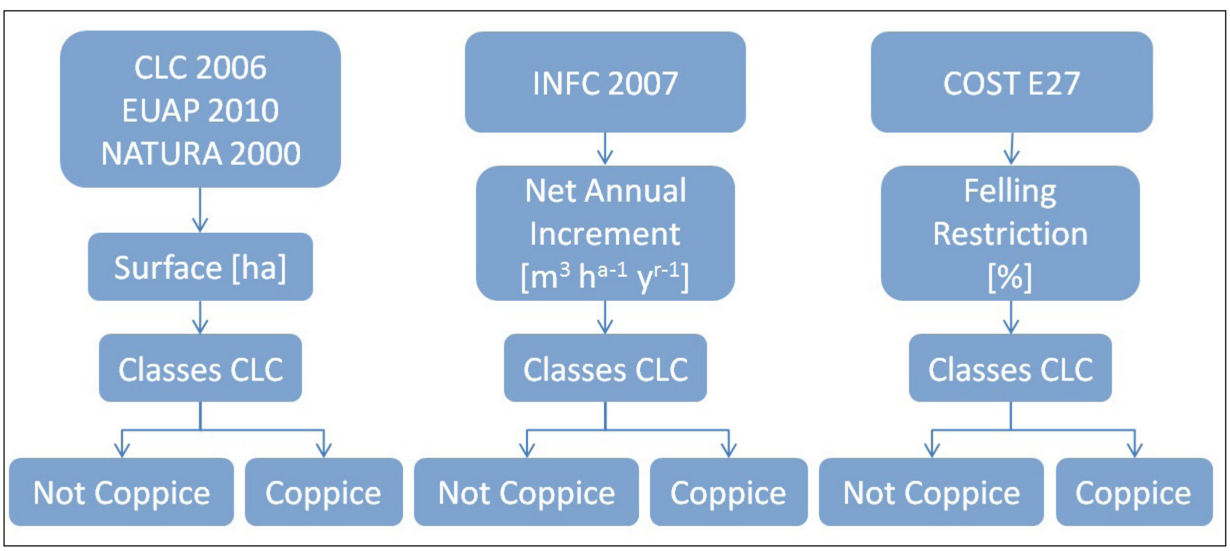

Figure 1- Schematic approach for determining the potential annual increment available and not.

Network of Protected Areas

The EUAP (Official List of the Protected Areas - MATTM 2010) areas and Natura 2000 sites made up the network of PAs used in this research. EUAP areas include 24 National Parks, 144 State Natural Reserves, 134 Regional Natural Parks, 365 Regional Natural Reserves and 171 Other Natural Protected Areas. Natura 2000 (Habitat directive 92/43/CEE) land sites (2011 Update - www.eea.europa.eu) consist in 2,549 Special Areas of Conservation (SAC) and include 2,269 Sites of Community Importance (SCI) and 600 Special Protection Areas (SPAs).

Table 2 - Comparison between the MCPFE classes, EUAP, Natura 2000, EEA and the applicable felling restrictions.

	MCPFE Classes	EUAP	Natura 2000	EEA	Restriction
Management Objective 1 "Biodiversity Conservation"	1.1 No Active Intervention	Zone A PNZ	-	A	1
	1.2 Minimum Intervention	-	-		A 2
	1.3 Conservation Through Active Management	Zone B-C-D PNZ, PNR, RNS, RNR, AANP	Natura 2000	A	3

The identified PAs network belong to the main classification of Protected Forest Areas (PFAs) at European level as they fulfilled the three general principles outlined in the MCPFE (Ministerial Conference on the Protection of Forests in Europe) guidelines (MCPFE 2002).

The MCPFE guidelines distinguish two classes of forest management in the PFAs. The first one focuses on biodiversity and is split up in three subclasses; 1.1: no active intervention; 1.2: minimum intervention; and 1.3: conservation through active management (Table 2). The second one focuses on landscapes protection and specific natural elements. The PAs network areas are included in the first class with a differentiation of the sub-classes based on the parks zonation and/or management plans.

The EUAP areas include also the CDDA (Common Database on Designated Areas) list, coordinated by EEA (EEA 2007). Regarding National Parks within EUAP, the national law established as a planning tool, the zoning of territory (Law 394/91). Based on this law, Ciancio et al. (2002), define four classes different for management degree. Zone A: the goal is the preservation regardless of the naturalness degree; zone B: preservation is realized through systemic silviculture; zone C: in addition to systemic silviculture classical silviculture can be used; zone D: the choice of silvicultural system is broader. The extension of zone A in the national parks refers to INFC (2005) data, and being evident the conservation objective, we supposed a non-coppice system in these areas.

The partial overlapping between EUAP areas and NATURA 2000 sites was considered in data processing.

This network of PAs falls within the network of High Conservation Value Forest (HCVF) defined by the Forest Stewardship Council (FSC) that represent about 40 % of the total Italian forest extension (Maesano et al. 2014).

Felling Potential

The felling potential reflects the theoretical maximum volume that is available for harvesting. There are several approaches to estimate the maximum felling potential, but the most straightforward is the Net Annual Increment (NAI) method (Verkerk et al. 2008). NAI has to be considered an upper limit, because annual felling should not exceed the annual increment to ensure long-term sustainability (MCPFE 2003). The potential increment for the whole network of PAs was calculated for each forest type, administrative region and silvicultural system according to the INFC (2005) data of the NAI.

Felling Restrictions

Data on felling restrictions in forests protected for biodiversity aims were collected from the COST Action E27 study on PFAs in Europe (Frank et al. 2007). In COST Action E27 restriction are given on a scale of 1-4, where: 1- activity is strictly prohibited; 2 - activity is usually prohibited, but with some exceptions or conditions; 3 - activity is usually allowed, but with some exceptions or conditions; 4 - activity is allowed with no restrictions. Based on the restriction scale, the limitation levels were: 1 - 0% of the potential can be harvested; 2 - 33% of the potential can be harvested; 3 - 67% of the potential can be harvested; 4 - 100% of the potential can be harvested (Verkerk et al. 2008). Table 2 shows the felling restriction applied in the network of PAs.

Results

Network of Protected Areas

The forest area inside the network of PAs was about 2.6 million hectares compared with 7.8 million hectares of Italian forest area (CLC data). This is equivalent to an I_{PW} of 33.6% made up of 15.96% (about 1.23 million hectares) of coppice and 17.64% (about 1.37 million hectares) of non-coppice forests.

Considering separately the two forms of protection that partially overlap, the EUAP areas represent an I_{PW} of 17.64% (about 1.37 million hectares) composed of 8.06% (about 0.63 million hectares) of coppice and 9.58% (about 0.74 million hectares) of non-coppice forests; while the NATURA 2000 sites represent an I_{PW} of 29.72% (about 2.3 million hectares) with 14.33% (about 1.1 million hectares) of coppice and 15.39% (about 1.2 million hectares) of non-coppice forests. At regional level, the highest value of I_{PW} was in Campania region with 3.32%, while the smallest one was in Valle d’Aosta with 0.14%. Regarding silvicultural system, in coppice forests the I_{PC} (Index of Protection Coppice) varied from 2.25% in Campania to 0% in Valle d'Aosta, while in non-coppice forests the I_{PNC} (Index of Protection Non-Coppice) ranged from 1.74% in Calabria to 0.14% in Valle d'Aosta (Tab. 3).

Considering the CLC classes, the more repre-

Table 3 - Protection indices at regional scale for the areas EUAP, Natura 2000 and EUAP+Natura 2000 . Legend: I_{PC}: Index of protection coppice; I_{PNC}: Index of protection non-coppice; I_{PW}: Index of protection wood.

Territorial District	EUAP + NATURA 2000			EAUP			NATURA 2000		
	I_{PC}	I_{PNC}	I_{PW}	I_{PC}	I_{PNC}	I_{PW}	I_{PC}	I_{PNC}	I_{PW}
Abruzzo	0.96%	1.26%	2.22%	0.73%	0.99%	1.71%	0.95%	1.24%	2.18%
Basilicata	0.61%	0.97%	1.57%	0.46%	0.90%	1.36%	0.52%	0.66%	1.18%
Calabria	1.09%	1.74%	2.83%	0.92%	1.36%	2.28%	0.77%	1.00%	1.77%
Campania	2.25%	1.06%	3.32%	1.76%	0.88%	2.64%	1.93%	0.80%	2.73%
Emilia Romagna	1.11%	0.38%	1.48%	0.46%	0.19%	0.65%	1.05%	0.36%	1.42%
Friuli V.G.	0.11%	0.79%	0.90%	0.03%	0.34%	0.37%	0.11%	0.76%	0.86%
Lazio	1.52%	1.03%	2.54%	0.58%	0.49%	1.08%	1.43%	0.86%	2.29%
Liguria	0.91%	0.34%	1.25%	0.15%	0.07%	0.22%	0.87%	0.32%	1.19%
Lombardia	0.61%	1.06%	1.67%	0.18%	0.35%	0.53%	0.59%	1.00%	1.60%
Marche	0.77%	0.24%	1.01%	0.44%	0.13%	0.56%	0.64%	0.20%	0.83%
Molise	0.44%	0.36%	0.80%	0.07%	0.13%	0.20%	0.44%	0.36%	0.80%
Piemonte	0.55%	0.99%	1.54%	0.28%	0.39%	0.67%	0.48%	0.95%	1.43%
Puglia	0.66%	0.52%	1.18%	0.43%	0.29%	0.72%	0.59%	0.50%	1.09%
Sardegna	0.63%	1.02%	1.65%	0.28%	0.22%	0.49%	0.56%	0.93%	1.49%
Sicilia	0.35%	1.25%	1.61%	0.33%	0.76%	1.09%	0.31%	1.14%	1.45%
Toscana	1.83%	1.02%	2.85%	0.62%	0.59%	1.21%	1.64%	0.94%	2.59%
Trentino Alto Adige	0.12%	1.52%	1.64%	0.04%	1.04%	1.08%	0.12%	1.34%	1.46%
Umbria	0.84%	0.25%	1.09%	0.17%	0.07%	0.24%	0.76%	0.23%	0.99%
Valle d'Aosta	0.00%	0.14%	0.14%	0.00%	0.08%	0.08%	0.00%	0.14%	0.14%
Veneto	0.60%	1.69%	2.29%	0.12%	0.32%	0.44%	0.58%	1.67%	2.25%
Italy	15.96%	17.64%	33.6%	8.06%	9.58%	17.64%	14.33%	15.39%	29.72%

sentative was the deciduous oak forest (3112), which covers 0.55 million hectares, equal to I_{PW} of 7.14%. According to silvicultural system, the classes with the highest diffusion in coppice forests were the beech forests (3115) with an I_{PC} 4.49% (0.35 million hectares) while in non-coppice forests the deciduous oak forests (3112) with an I_{PC} 2.90 % (0.23 million hectares).

Felling potential

At national level, the potential annual increment was about 35 million cubic meters, of which 42.42% derived from coppice and 57.58% from non-coppice forests. The highest annual increment of coppice forests was found in the Toscana region with 19.8%, equal to about 2.8 million cubic meters, while the Trentino Alto Adige represented the largest annual increment in non-coppice forests with 18.58% amounting to about 3.7 million cubic meters. The CLC classes with the highest annual increment were respectively the 3114 (chestnut forests) for coppice forests with 12.03% (about 4.1 million cubic meters) and the 3123 (silver fir and spruce forests) for non-coppice forests with 14.12% (about 4.9 million cubic meters) (Tab. 4).

The potential annual increment within the network of PAs amounted to about 11.7 million cubic meters, equivalent to 33.79% of the total annual increment divided in 13.53% for coppice forests (about 4.7 million cubic meters) and 20.26% for non-coppice forests (about 7 million cubic meters). The CLC classes with the highest annual increment were beech forests (3115) with 5.16% of the total annual increment (about 1.1 million cubic meters) in coppice forests, while silver fir and spruce forests (3123) with 4.17% (about 0.9 million cubic meters) in non-coppice forest (Tab. 4).

The potential annual increment distinguished by the form of protection and CLC classes was reported in Table 4.

Felling restrictions and available wood

The availability of wood in the network of PAs depends on the type of protected area and on the silvicultural system. The felling restriction affected the Zone A of the national parks, involving 1.19% (0.09 million hectares) of the forest extension and 1.09% of the national annual increment.

The annual increment unavailable within the network of PAs represents 11.88% (about 4.1 million cubic meters) of the total annual increment. However, the annual increment available through active management represents 21.9% of the total annual increment, amounting to about 7.6 million cubic meters (Tab. 5).

At national level, beech forests (3115) class was the one with the higher available annual increment (5.6% - 1,940,000 cubic meters) (Fig. 2). This is easily explainable, because the beech forest in Italy is one of the most widespread forest type representing 12% of the national forests (INFC 2005 data).

General overview of the results split up by silvicultural system showed that the annual increment was respectively 3.8 m^3ha^{-1} in coppice forests and 5.1 m^3ha^{-1} in non-coppice forests. Within the network of PAs the available annual average increment was 0.98 m^3ha^{-1} (0.81 m^3ha^{-1} in coppice and 1.14 m^3ha^{-1} in non-coppice forests). Considering the two forms of protection, the available annual average increment was 0.51 m^3ha^{-1} in EUAP areas (0.42 m^3ha^{-1} in coppice, 0.60 m^3ha^{-1} in non-coppice) while 0.9 m^3ha^{-1}in Natura 2000 sites (0.74 m^3ha^{-1} for coppice and 1.06 m^3ha^{-1} for non-coppice).

Table 4 - Share of the potential annual increment within the EUAP areas, Natura 2000 and CLC 2006. Legend: I_{CC}: Increment Current Coppice; I_{CNC}: Increment Current Non-Coppice; I_{CW}: Increment Current Wood.

	EUAP + NATURA 2000			EAUP			NATURA 2000			CLC 2006		
CLC 2006 Classess	Ic_C	Ic_{NC}	Ic_W	Ic_C	Ic_{NC}	Ic_W	Ic_C	Ic_{NC}	Ic_W	Ic_C	Ic_{NC}	Ic_W
3111	1.02%	0.90%	1.92%	0.54%	0.39%	0.93%	0.87%	0.70%	1.57%	2.22%	2.52%	4.74%
3112	2.46%	2.20%	4.66%	1.15%	1.37%	2.52%	2.23%	1.77%	4.00%	9.15%	7.49%	16.63%
3113	1.61%	1.02%	2.63%	0.70%	0.60%	1.30%	1.46%	0.94%	2.40%	6.00%	2.56%	8.56%
3114	2.60%	0.73%	3.33%	1.18%	0.49%	1.67%	2.29%	0.51%	2.80%	12.03%	2.42%	14.45%
3115	5.16%	3.36%	8.52%	3.09%	2.29%	5.38%	4.86%	3.12%	7.98%	9.86%	5.29%	15.15%
3116	0.03%	0.27%	0.31%	0.01%	0.12%	0.12%	0.03%	0.24%	0.27%	0.14%	1.16%	1.30%
3117	0.07%	0.16%	0.23%	0.05%	0.07%	0.11%	0.05%	0.15%	0.20%	0.37%	1.13%	1.50%
3121	0.00%	1.35%	1.35%	0.00%	0.68%	0.68%	0.00%	1.26%	1.26%	0.00%	2.99%	2.99%
3122	0.00%	1.06%	1.06%	0.00%	0.75%	0.75%	0.00%	0.78%	0.78%	0.00%	2.61%	2.61%
3123	0.00%	4.17%	4.17%	0.00%	1.65%	1.65%	0.00%	3.91%	3.91%	0.00%	14.12%	14.12%
3124	0.00%	1.08%	1.08%	0.00%	0.53%	0.53%	0.00%	1.05%	1.05%	0.00%	2.81%	2.81%
3125	0.00%	0.03%	0.03%	0.00%	0.01%	0.01%	0.00%	0.03%	0.03%	0.00%	0.19%	0.19%
31311	0.07%	0.20%	0.27%	0.05%	0.14%	0.18%	0.05%	0.14%	0.20%	0.14%	0.34%	0.48%
31312	0.10%	0.32%	0.42%	0.05%	0.19%	0.23%	0.08%	0.26%	0.34%	0.42%	1.08%	1.50%
31313	0.09%	0.17%	0.26%	0.03%	0.07%	0.11%	0.08%	0.15%	0.23%	0.73%	0.85%	1.57%
31314	0.08%	0.08%	0.16%	0.03%	0.04%	0.07%	0.06%	0.06%	0.12%	0.54%	0.49%	1.03%
31315	0.22%	0.64%	0.87%	0.13%	0.38%	0.50%	0.17%	0.59%	0.76%	0.71%	1.62%	2.32%
31316	0.00%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.01%	0.01%	0.00%	0.02%	0.03%
31317	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.05%	0.09%
31321	0.00%	0.48%	0.48%	0.00%	0.25%	0.25%	0.00%	0.43%	0.43%	0.00%	1.65%	1.66%
31322	0.01%	0.96%	0.97%	0.01%	0.68%	0.69%	0.00%	0.69%	0.69%	0.02%	2.97%	2.99%
31323	0.01%	0.83%	0.84%	0.00%	0.30%	0.30%	0.01%	0.81%	0.81%	0.06%	2.55%	2.61%
31324	0.00%	0.21%	0.21%	0.00%	0.06%	0.06%	0.00%	0.21%	0.21%	0.00%	0.60%	0.60%
31325	0.00%	0.02%	0.02%	0.00%	0.01%	0.01%	0.00%	0.02%	0.02%	0.00%	0.07%	0.07%
Italy	13.53%	20.26%	33.78%	7.01%	11.04%	18.05%	12.26%	17.80%	30.06%	42.42%	57.58%	100.00%

Table 5 - Annual increments available and not within the EUAP areas and Natura 2000.

	Wood Unavailable [m3]			Wood Unavailable [%]		
	Coppice	Not Coppice	Total	Coppice	Not Coppice	Total
EAUP (PNZ - Zone A)	0	380870	380870	0.0%	1.1%	1.1%
EUAP (Zone B-C-D PNZ, PNR, RNS, RNR, AANP)	806106	1144084	1950190	2.3%	3.3%	5.6%
EUAP (Total)	806106	1524954	2331060	2.3%	4.4%	6.7%
Natura 2000	1409644	2046279	3455923	4.0%	5.9%	9.9%
EUAP + Natura 2000	1555447	2584103	4139550	4.5%	7.4%	11.9%
	Wood Available [m3]			**Wood Available [%]**		
	Coppice	Not Coppice	Total	Coppice	Not Coppice	Total
EAUP (PNZ - Zone A)	0	0	0	0.0%	0.0%	0.0%
EUAP (Zone B-C-D PNZ, PNR, RNS, RNR, AANP)	1636640	2322836	3959476	4.7%	6.7%	11.4%
EUAP (Total)	1636640	2322836	3959476	4.7%	6.7%	11.4%
Natura 2000	2862004	4154566	7016570	8.2%	11.9%	20.1%
EUAP + Natura 2000	3158029	4473231	7631260	9.1%	12.8%	21.9%

Discussion

At national level, 88.4% of the forest area was available for forest logging (Gasparini and Tabacchi 2011) and the share of net available annual increment was 39.5% in 1990, 33.1% in 2000 and 26.3% in 2005 (EUROSTAT 2012). The average increment potential available for felling at national level was 4.4 m^3ha^{-1}.

According to EUROSTAT data (http://epp.eurostat.ec.europa.eu/), European countries have a large margin to increase logged wood volumes. Italy has a level of wood mobilization among the lowest ones in Europe. Considering the very low level of harvesting, a large majority of harvested volumes comes from production forests outside protected areas. Therefore, there is a potential to enhance wood supply in a sustainable way, for energy and raw materials for industry, encouraging wood mobilization (Muys et al. 2013). In contrast, due to the global economic crisis there was a rising interest in fuelwood, resulting in an increase of fuelwood imports of about 26% in Italy annually. Italy is the first importer country of firewood in Europe.

Increasing the consumption of the wood sustainably produced and boost the bio-energy in countries all over Europe could lead economic, environmental and geopolitical gains (FOREST EUROPE 2010). There are many credible reasons to move away from fossil fuels, including the reduction of the dependence on foreign petroleum, maintaining forest management infrastructures, and encouraging conservation of forest work (Gunn et al. 2012). Moreover, the biomass has several other well-recognized benefits

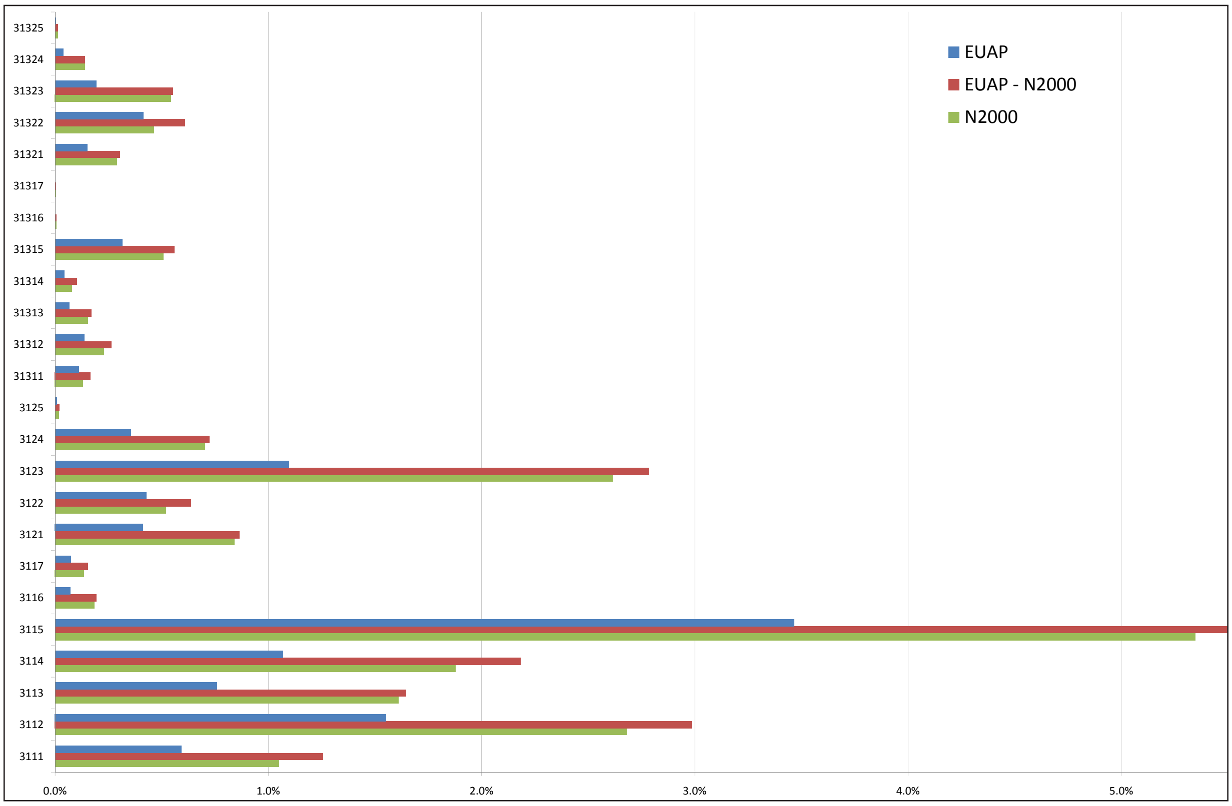

Figure 2 - Annual increments available for each CLC class within the protected areas through an active management of the territory.

such as improved security of supply, contributing to improve air quality and creation of new jobs and businesses - many of them in rural areas (Ragwitz et al. 2006).

Forests represent a combination of important ecosystems that provide habitat for numerous species, regulate water cycles, clean air and provide timber for economic use (Maes et al. 2011).

The forest growing stock, the increment and fellings could be considered directly ecosystem services indicators for sustainability of ecosystem services over time, to ensure that the long-term benefit flow of services is represented (Maes et al. 2011). Mobilizing more wood is an effort of the whole forest sector. There is a potential to enhance wood supply in a sustainable way, for energy and raw materials for industry. In line with the policy commitments all over Europe and in particular in light of the EU renewable energy targets, wood mobilization should be further encouraged in countries all over Europe (FOREST EUROPE 2010).

Conclusions

This paper assessed the amount of wood that is technically available in the protected areas by active management of the forest resources. To assess the felling potential in the network of PAs, the unbounded available wood was evaluated and divided into the two silvicultural systems (coppice, non-coppice). This upper limit does not take into account management restrictions due to biological and landscape diversity protection that may apply in PFAs and does not take into account other environmental, social and economic factors that may limit the felling potential. The research provides the dataset and suggests the rationale for wood mobilization in areas usually considered of close to strict environmental protection. Wood harvesting can be undertaken without compromising other forest functions if it is made in a sustainable way, in other words, without compacting soil, causing soil erosion, or disturbing the reproductive cycle of plants or animals.

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http://ojs-cra.cilea.it/index.php/asr

Project reporting

Re-use of wastewater for a sustainable forest production and climate change mitigation under arid environments

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Abstract - Over the last decades biotic and abiotic constrains together with human actions are determining a substantial environmental pressure, particularly in dry lands as the south of the Mediterranean region. From very long time, indeed, simultaneous drivers such as demographic growth, climate change and socio-economic factors are weakening the previous homeostasis between human needs and natural resources on the regional scale. Resulting pressures are determining environmental degradation and increase of desertification risk for the arid and semiarid lands. Water quality and availability are both crucial points limiting people well-being and livelihoods in the same context. Scarcity of fresh water and heavy and mismanaged production of wastewater are the main factors affecting water resources. Increasing pollution of soil and ground waters reduces the possibility of sustainable development of local communities with relevant social consequences. The FAO's supporting program in north Africa aims to: a) develop new and cheaper phytotechnologies (e.g. constructed wetland system; innovative treatment system for reuse of waste water for fertigation); b) treat wastewater for water quality protection; c) promote land recovery by means of sustainable multipurpose forestry; d) adopt bioengineering interventions to stop slopes erosion and protect urban, and semi-urban infrastructures; e) create pilot demonstrative areas to test multi-purpose sustainable agroforestry systems. Within this frame, an integrated approach was designed to promote innovative sustainable water management and multipurpose forestry, in order to mitigate the effects of climate change, promote land recovery, and improve the livelihoods of local population. The present paper aims to provide an overview of the FAO project GCP/RAB/013/ITA. Particularly, two pilot studies are shown and discussed.

Keywords - phytotechnologies, arid environment, wastewater, sustainable development, forest and agroforestry systems

Introduction

The Mediterranean Basin with its climatic peculiarities is extended on three continents. It is densely populated (507 million people on 2010) and extremely rich of natural and cultural heritage. It constitutes an "ecoregion", where both social and economic developments are closely related to somewhat limited natural resources and vulnerable environments (FAO 2013).

After thousands of years of co-evolution between ecosystems and societies, human activities are determining substantial environmental pressure, with a large social-environmental imbalance between the northern and southern regions. Such disparities are exacerbated by climate change effects. These are causing an increase in intensity and frequency of the cyclical period of aridity and of extreme events such as wind duster and water bombs (IPCC 2012). The simultaneous action of biotic, abiotic and socio-economic factors is the main driver of land degradation and of increasing risk of desertification (Bennadji et al. 1998).

In arid and semi arid areas the soil is scarcely productive. In this context, forests can play a crucial role in promoting and restoring the water cycle on the regional scale (David et al. 2011, Matteucci et al. 2011).

Forests in drylands are an invaluable multipurpose resource of fodder for livestock, fuel-wood (e.g. 58% of all the energy consumption in Africa), non-wood and fiber products and biomass (FAO 2013). They also provide a wide range of environmental services (ESs) such as protection from soil erosion, addition of organic matter, increased water retention and biodiversity. ESs are particularly relevant for agricultural activities and desertification control. Afforestation and reforestation activities in arid and semi-arid lands are functional to soil rehabilitation/restoration. Forests increase carbon

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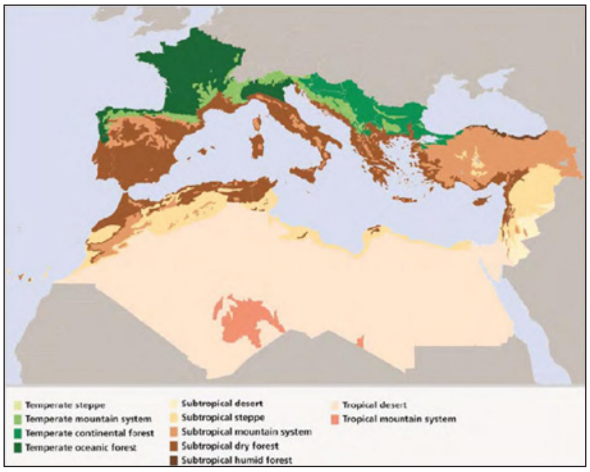

Figure 1 - Steppes and deserts dominates the southern Mediterranean countries. Source: Derived FAO and JRC, 2012 and Iremonger and Gerrand, 2011.

sequestration and storage, generate employment opportunities, provide recreational and landscape value (FAO 2013).

Water quality and availability represent crucial limiting factor for human well-being and livelihoods in arid and semi-arid lands.

The southern Mediterranean countries generally are dominated by steppes and deserts (Fig.1). Such environments are fragile and exposed to degradation and desertification processes.

Northern Africa, is affected by different problems heavily related to the new social and economical development. The population growth of the last decade highlighted the limits of available natural resources. The effects of global change together with new agricultural techniques (e.g. pivot irrigation), unsustainable water and soil management, land use changes led to an overexploitation of natural resources. All this is endangering the fragile balance between human needs and natural resources.

Especially in arid and semi-arid lands, the low availability of fresh water and the mismanaged production of wastewater are main factors affecting use and availability of water resources. Contamination of soil and ground waters biases, finally, any sustainability in the processes of local development.

A contribution to sustainability relies on the use or re-use of non-conventional water resources. Urban waste water can be properly treated and used for forest and agroforestry systems in rural, urban and peri-urban areas. This would increase the availability of wood, firewood, biomass, food and ecosystem services.

Over the last three years FAO Forestry has implemented new activities on the use of non conventional waters in forestry and agroforestry systems of arid zones in some Mediterranean countries. Through a collaboration with the Italian Ministry of Foreign Affairs, FAO launched the GCP/RAB/013/ITA project "*Forest restoration in Algeria, Egypt, Morocco and Tunisia using treated wastewater to sustain smallholders' and farmers' livelihoods*". In this project Scientific Italian Institutions (DIBAF-University of Tuscia, University of Basilicata, National Research Council CNR and Consiglio per la Ricerca e sperimentazione in Agricoltura CRA) in collaboration with the FAO Forestry Department have designed and developed pilot projects in Maghreb countries, innovative methodologies for a sustainable and cheaper use of urban wastewaters.

The project is an important example of participatory approach to the formulation of cooperation projects. Indeed, the project plan directly derives from the needs and requests of the four North African countries involved: Algeria, Egypt, Morocco and Tunisia. These countries specifically requested the Italian expertise to re-use treated wastewater for the restoration of forestry and agro-forestry systems of arid zones.

Project objectives

The main aim was the use of non-conventional waters for irrigation of multipurpose wood plantations for tree crops' production, orchards, fuel-wood and wooden biomass. In particular, the project proposed an integrated approach specifically aimed to: a) reduce pollution of natural water resources (development of new and cheaper phytotechnologies for wastewater treatment); b) mitigate climate change, promote the recovery of degraded areas, reducing contamination risks of ground water and soil; c) improve the living conditions of the local population through forestry and agroforestry sustainable activities, taking into account needs and traditions of local people.

Materials and Methods

The methodologies adopted by the project to treat wastewater are mainly two: constructed wetlands (phytotechnology approach) and a modified version of the standard wastewater treatment system, planned to reduce the energy inputs and preserving the nutrient load useful to the plants (fertigation approach).

Constructed wetlands

Natural wetlands act as bio-filters, removing sediments and pollutants from the water; constructed wetlands are designed to emulate these features. Vegetation in a wetland provides a substratum (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. The plants remove about 70% to 90% of pollutants (biotic and abiotic), and provide carbon for micro-organism particularly by fine root turnover. Constructed wetlands are largely recognized as effective for primary and secondary urban and agricultural wastewater treatment (Kadlek 1996, US_EPA 1999), and are considered by the World Health Organization (WHO) an effective and cheap way to meet its microbiological guideline for wastewater reuse (WHO 1989). These systems are made up of ponds placed in sequence, filled with specifically selected plants, shrubs and vegetation for their ability to filter impurities from the water. The treated water is then let settle in storage basins. Since the system only uses natural phytotechnology solutions it also appears to be more sustainable and economically-viable for rural communities. The application of this system in Algeria and Tunisia has been designed by researchers of the University of Tuscia, Italy.

Innovative treatment for reuse of waste water for fertigation

Innovative "secondary" treatment for wastewater systems reduces the microbial load to acceptable limits, maximizing the release of useful substances (e.g. Nitrogen and Phosphorus), which can be used in agroforestry systems to provide nutrients and organic matter in the soil. According to this innovative approach a methodology was developed by the University of Basilicata, Italy, after a testing phase on olive trees. From these previous pilot studies, it has emerged that properly controlled modifications of a conventional treatment plant, together with an accurate monitoring scheme which adjusts the provision of organic matter and nutrients to the irrigated soil, is a cost-effective system that maximizes the amount of “good” organic matter available for irrigation, while minimizing health risks.

Main activities supported in the project countries

In response to the specific requests of the participating countries the project is supporting

- In Morocco, the establishment of 10 hectares of palm grove that will be part of the green belt of the town of Marrakech (31°42’3.02”N – 8°3’37.25”W). The green belt will have several functions including agro-silvo-pastoral activities and to act as buffer zone between the main landfill and the urban area. The plantation is irrigated by the innovative treatment for reuse of wastewater for fertigation designed by University of Basilicata, and realized in collaboration with University of Marrakech. Both CNR and CRA have provided further support in the development of the plantation. This plantation will be included into the larger project for the development of "green belt" to protect the city against soil erosion, desertification and to create a functional zone for the development of agroforestry activities. At the same time, the use of fertigation techniques will ensure an increase of soil fertility and carbon storage capacity of the soil.
- In Egypt the project provided the drafting of the first forestry management plan of Serapium forest (30°29’24.41”N -32°13’59.77”E, Ismailia district), which is a 25 years old plantation irrigated with treated wastewater. The Serapium plantation (129 ha) was realized using different species (*Eucalyptus citriodora Hook.*, *E. camaldulensis Dehnh.*, *Casuarina equisetifolia L.*, *Cupressus sempervirens L.*, *Khaya senegalensis* (Desr.) A. Juss, and others) adapted to hot environments and characterised by a high wood productivity. The forest management plan has been drawn taking into account the possibility of making this forest eligible for a possible market for carbon credits. The work is being carried out by the Under-Secretariat for Afforestation and Environment of the Ministry of Agriculture, the Department Forestry University of Alexandria and other relevant Egyptian institutions, under the technical coordination of FAO and with the support of the University of Monaco (Germany) and University of Tuscia (Italy).
- In Tunisia the project activities have been implemented in Ouechtata, a rural village in northern Tunisia, close to the coast (36°57’27.51”N – 9°00’7.29”E). The activities concern the design of a constructed wetland, planned to reduce the pollution of a water reservoir used for agricultural needs, at low cost and in sustainable way. Furthermore, the design of a fertigation system for olive trees and biomass production in Hafouz (inside village of southern Tunisia, 35°38’13.21”N – 9°42’28.44”E) is planned to reduce the cost of management of the already existing wastewater treatment plant. The activities were conducted in close cooperation among the project partners (FAO, University of Tuscia and University of Basilicata) and the national Forestry General Direction.
- In Algeria the FAO project supported the completion of an already existing pilot area in the Oasis of Brézina (33°5’38”N – 1°15’3.40”E). The project was developed in the context of the Italian cooperation (Ministry of Economic Development - MISE, Ministry of Foreign

Affairs - MAE), by the University of Tuscia (IT) and University of Mascara (ALG). The reuse of the wastewater produced by the local community was tested for the irrigation of forestry and agroforestry systems, after treatment by means of the constructed wetland technology. A second activity was the design of constructed wetlands to reduce the pollution of the local river and of the palm plantations, as well to fight the erosion processes in the oasis of Taghit (30°55'3.06"N – 2°2'2.22"W).

Pilot applications of phytotechnologies to realize productive and protective forest systems in southern Mediterranean countries: two case studies.

Phytotechnologies use plants to remediate various media impacted with different types of contaminants (Vangronsveld et al. 2009, Otte and Jacob 2006). In different sites in north Africa, the integrated systems to reduce water and soil pollution have been designed and developed (treating the urban waste water by constructed wetland). At the same time, these systems are planned to promote land rehabilitation (planting trees according to multipurpose scheme and local needs). Below, two pilot applications carried out in Algeria are explained briefly.

First case study

Oases are the main spots of human development in desert areas. Biotic and abiotic constraints together with human actions determine the fragile equilibrium of the ecosystem that is threatened by desertification.

In the oasis of Brézina an integrated, sustainable model for the oasis protection, recovery and development has been recently realized, also considering the advantages related to carbon credits market through the Clean Development Mechanism (CDM) of the Kyoto Protocol. Brézina oasis is located in the pre-Saharan region (800 m a.s.l.), 85 Km south of the county (*wilaya*) town of El Bayadh, Algeria. Brézina is characterized by a pre-Saharan arid climate, with an annual mean temperature of 20 °C; diurnal variation of 11 °C; annual rainfall rarely exceeds 100 mm (NASA 2007); low atmospheric humidity (around 40%); high solar radiation (16.56 MJ $m^{-2}day^{-1}$) and high wind speed. During the April dust storms, the average wind speed grows until 5.9 m s^{-1} (Kasbadji Merzouk 2000). The *Seggueur* ephemeral river, which surrounds the oasis at the southern side (Masini et al. 1988), is the main source of water for the palm plantation and for the traditional agricultural productions, performed under the palm cover of the oasis.

The main problems which afflict Brézina oasis are related to the groundwater depletion resulting from increasing urban population, excessive retention of *Seggueur* river by the dam realized upstream of the oasis, and climate change. All these are causing severe damages of the palm grove and the risk of groundwater contamination due to the outflow of untreated wastewater.

The main goal was to face the challenge from two different perspectives. The first concerns the adoption of a new water management model, inspired to the collection, recycle and reuse of urban wastewater. The second proposes a new agroforestry strategy in order to stimulate both alternative economic chains and environmental restoration. The recent Oasis growth suggested to design a system optimised for the local conditions and easily expandable. For this reason the pilot project was designed as a modular system, able to be replicated in parallel or in series to match increased wastewater flow rate or pollution, respectively. The modular approach implies the definition of a minimum flow rate of wastewater. Such a minimum quantity is collected, treated and, finally, reused through a single process. The wastewater pilot system was designed to fill a good quality of output and to reduce the infiltration and evapotranspiration losses using constructed wetlands. A further target was to build up a simply operated and flexible system, in terms of effluent quality produced (Mara 1999).

Two parallel natural treatment chains compose the system, as illustrated in Figures 2-3-4:

1) CW B is a constructed wetland with horizontal superficial flow, being composed by three cells alternating aerobic (cell 1 and cell 3) to anaerobic process (cell 2) (Fig. 3).
2) CW A is a constructed wetland with horizontal sub superficial flow composed by three separated cells where mainly aerobic processes are triggered (Fig. 4).

Both treatment chains are connected with a storage basin necessary to homogenize the flow rate variation during the day and to provide minimal water storage. For the constructed wetland were chosen two different mixes of plant species (Fig. 5):

- MIX 1: *Phalaris arundinacea* L., *Juncus* spp., *Phragmites* spp., *Typha* spp., optimal for reduced water depth and resistant to short periods of dryness.
- MIX 2: *Myriophyllum* spp., *Thypha* spp., optimal to favor anaerobic processes.

The synergistic effect of hydraulic design, the plant species selection and the related fine root biomass promotion, improve the process of ab-

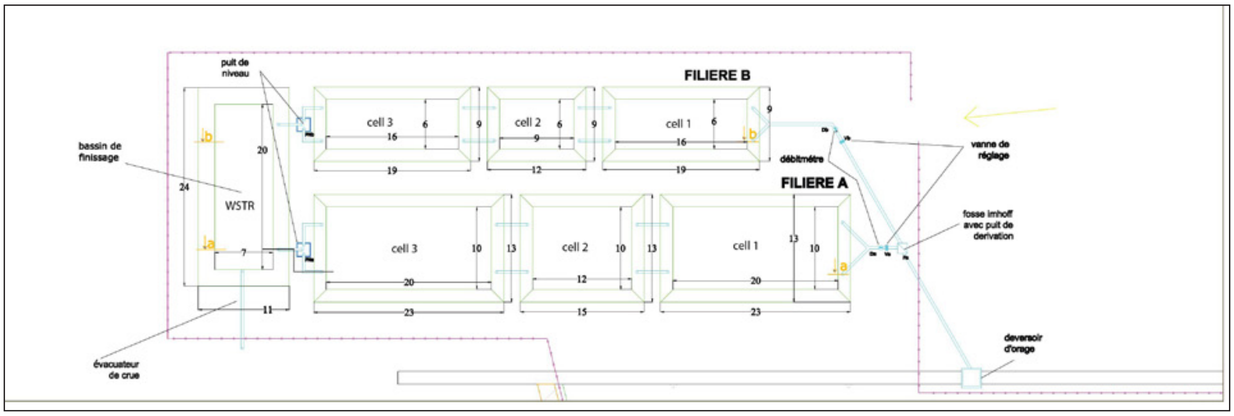

Figure 2 - Oasis of Brézina (Algeria) – waste treatment system: plan.

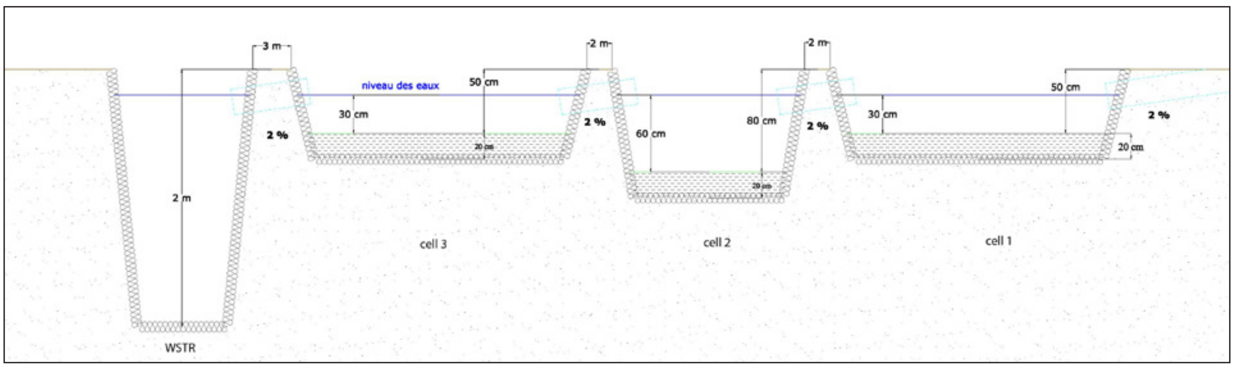

Figure 3 - Oasis of Brézina (Algeria) – CW B section: a constructed wetland with horizontal superficial flow. Cell 1 is designed to provide preliminary sedimentation with a water level up to 30 cm, the vegetation is emergent with a density of 90%. Cell 2 is designed to provide anaerobic digestion of Cell 1 effluent, water level never exceed 60 cm and the vegetation is submerged with a density of 20%. Cell 3 is designed to complete the water treatment of Cell 2 effluent trough aerobic process. Water level is up to 30 cm and vegetation is emergent with a density of 90%. WSTR (Water Storage Treatment Reservoir).

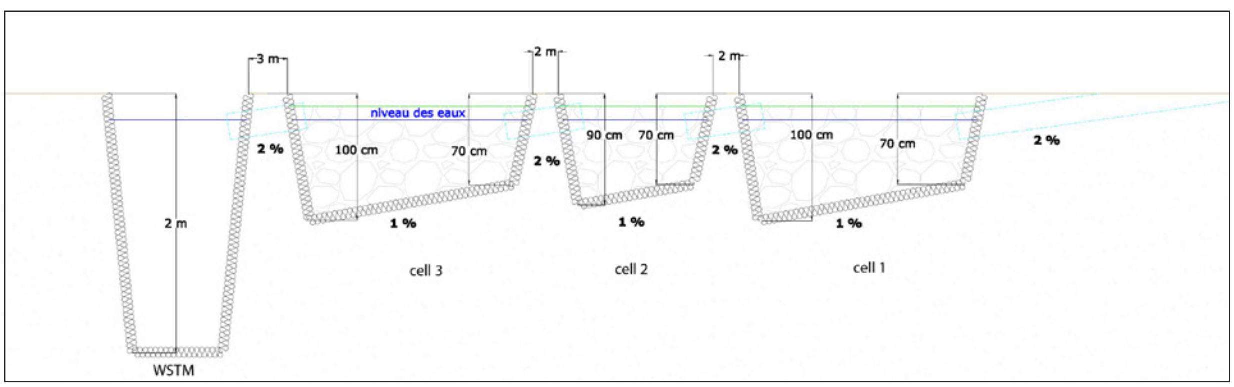

Figure 4 - Oasis of Brézina (Algeria) – CW A section: a constructed wetland with horizontal sub superficial flow composed by three separated cells where mainly aerobic processes are triggered. WSTR (Water Storage Treatment Reservoir).

sorption, sedimentation and inactivation of major pollutant as BOD5 (biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period), TSS (total suspended solids), nitrogen, phosphorus and *Escherichia coli*.

The treated wastewater is efficiently reused into the forest agroforestry plots, using drip irrigation. The forest specie selection maximizes both environmental and economical improvement through marginal land restoration, no-food products, and potential revenue from carbon sequestration (Fig. 6).

In the forest plantation four experimental systems were tested.

Figure 5 - Oasis of Brézina (Algeria) – view of the constructed wetlands in October (2013).

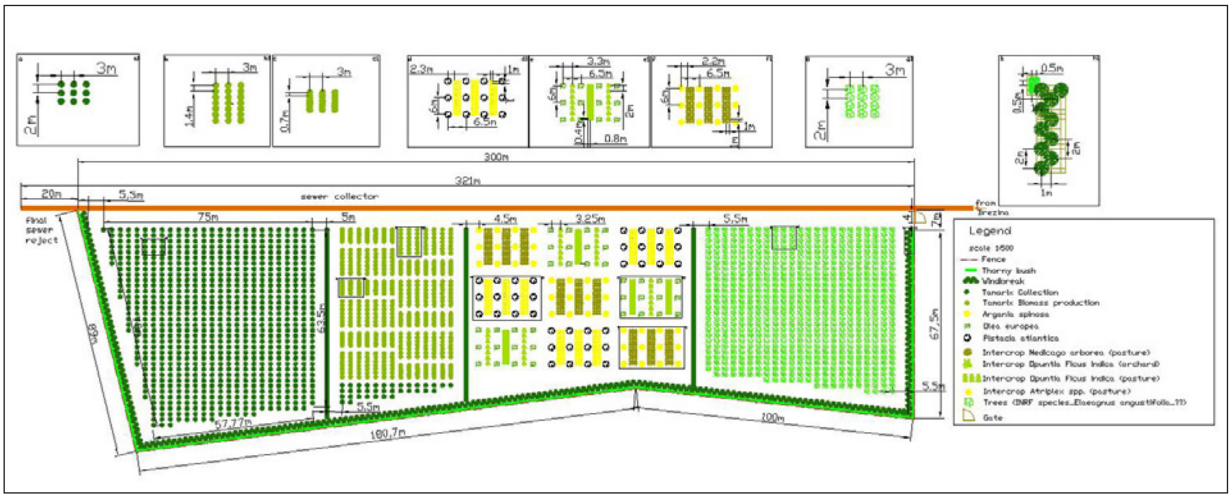

Figure 6 - Oasis of Brézina (Algeria) –agroforestry testing plots: species (wood and forage), densities (biomass) genotypes evaluation.

1. *Tamarix* spp. collection to compare different species and populations for plant breeding.
2. *Tamarix* spp. plantation for biomass production under short rotation regime to evaluate productivity, inter-annual growth rates, wood quality also for bioethanol production, environmental benefits.
3. Plantation of different species with a relevant ecological and economical value to produce forage, wood and non-wood products (e.g., *Argania spinosa* L., *Pistacia atlantica* Desf., *Olea europaea* L.). The trees were planted at a distance of 6 m, on 7 m spaced rows; the inter row will be planted with forage intercrop species: *Atriplex* spp., *Medicago arborea* L., and *Opuntia ficus-indica* (L.) Mill.
4. Experimental comparison on field for genotype evaluations of *Populus* spp. in order to select suitable plant material for forestry plantations in arid and semi-arid lands.

Second case study

Along with the objective of preserving oasis ecosystems, Algeria has opened several national programs for environmental protection and local development, as the one for Taghit Oasis. This program is focused on the identification of measures able to protect the environmental resources and cultural heritage, promoting a sustainable development of a vulnerable area, transformed by human activities for centuries, at present under the pressure of new societal drivers. From this perspective, the oasis of Taghit represents a small-scale experiment to test new approaches for environmental protection in the frame of the sustainable development of the Oasis.

In Taghit the project aims to reduce the impact of wastewater on the principal river, where the palm cultivation is managed in combination with agro-pastoral activities. In fact, as consequence of an increasing wastewater discharge and of increasingly frequent events of flooding, the fertile riparian area results polluted and the palm trees damaged. Taghit is located in sub-Saharan area, near the Moroccan border, the western edge of the Grand Erg Occidental (GEO) (623 m a.s.l.). In the Figures 7 and 8, the main climate characteristics of the oasis are represented.

Although almost 98% of urban wastewater is collected regularly, the main source of pollution is represented by a poor sustainable wastewater management. Currently, wastewater generated from 5 villages located around the oasis Taghit (Zaouia Fougania, Thaghit, Berrabi, Bhakti, Zaoui Tehtania /

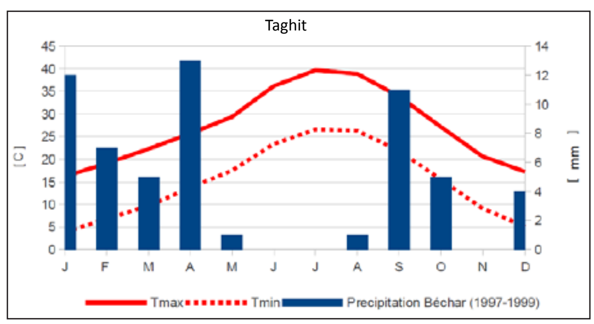

Figure 7 - Taghit (Algeria) – annual average, maximum and minimum temperatures, and annual rainfall distribution.

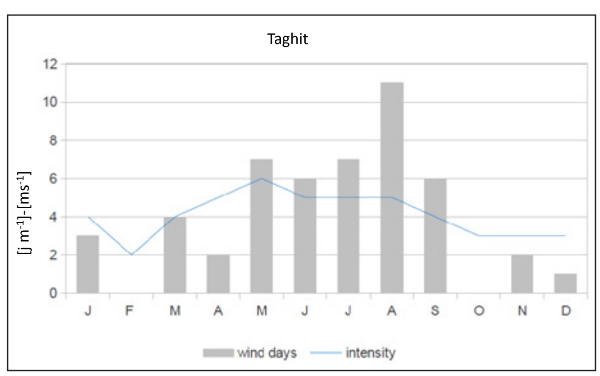

Figure 8 - Taghit (Algeria) – wind regime during the year.

Brika) are released downstream of urban areas and upstream of the palm stands. Final destination of the wastewater stream is the bed of the river Zousfana. Based on qualitative and quantitative characteristics of wastewater produced by each village, constructed wetlands were specifically designed (Fig. 9). After a careful analysis of the characteristics and problems of Taghit Oasis, different possible reuse of the treated wastewater for reforestation and revegetation were also designed, and summarized as follows.

1. Realization of multipurpose irrigated forestry and agroforestry systems

Given the fragility of the oasis ecosystems and climate extremes that characterize them, the fundamental priority is to promote the enhancement of local biodiversity and forest genetic resources (FGR). Indeed, the selection of suitable species for the realization of multifunctional production systems is strongly required. Collection and comparative test of species and provenances is an essential tool for the selection and improvement of forest trees and for starting a process of conservation and management of Forest Genetic Resources. In the specific case of the oasis of Taghit, the implementation of a pilot comparative plantation (species/provenances) was proposed, aiming to assess the variability of the main adaptive traits responsible of the individual adaptability, to sustain the growth and carbon sequestration and to reverse the ecological degradation of fragile ecosystems. Species of high ecological and economic interest (e.g., *Populus alba* L., *P. euphratica* Oliv., etc), will be tested in the experimental plantation (Fig.10).

2. Consolidation of embankment by woody species in order to stop the erosion and to protect the urban infrastructures

Part of the treated wastewater can be used for irrigation of naturalistic engineering works such as: consolidation of embankment, roadsides, riverbanks and landslide slopes. The use of woody species (e.g. *Nerium oleander* L., *Olea europaea var sylvestris* L., *Capparis spinosa* L., *Tamarix* spp.) in such applications allows to increase the effectiveness of anti-erosion and consolidation, reducing water and wind erosion as well as landslides occurrence. Thus, such applications increase the safety of peri-urban and urban infrastructures. In addition to the technical and functional effects mentioned above, works of this kind are also important for other purposes. These bioengineering works, by using native species of the different stages of the dynamic series of potential vegetation, can favour the reconstruction or trigger of the natural potential at the landscape scale. Bioengineering provides cost-effective structures as alternatives (e.g. slope fascines) in respect to traditional structures (e.g. retaining concrete head wall). These are usually more expensive and characterised by higher envi-

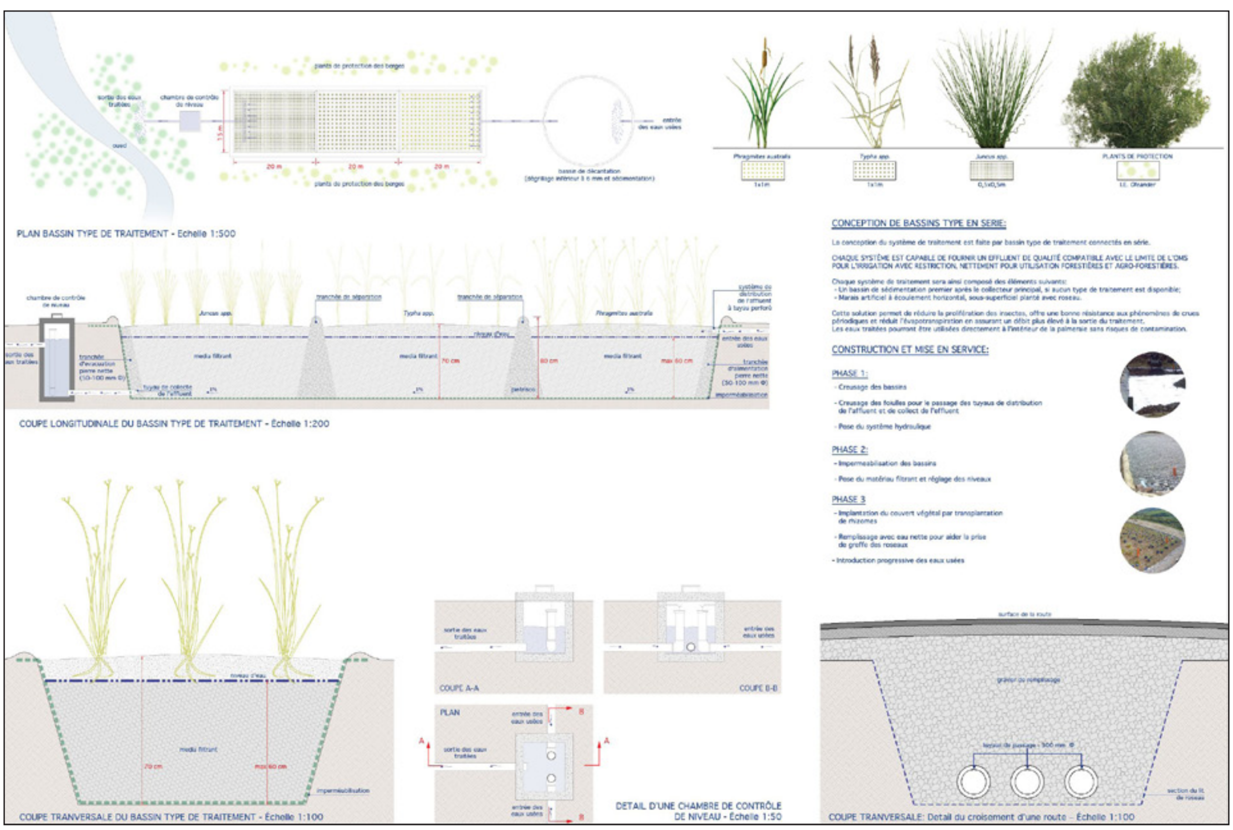

Figure 9 - Taghit (Algeria) – scheme of treated wastewater: plan and sections.

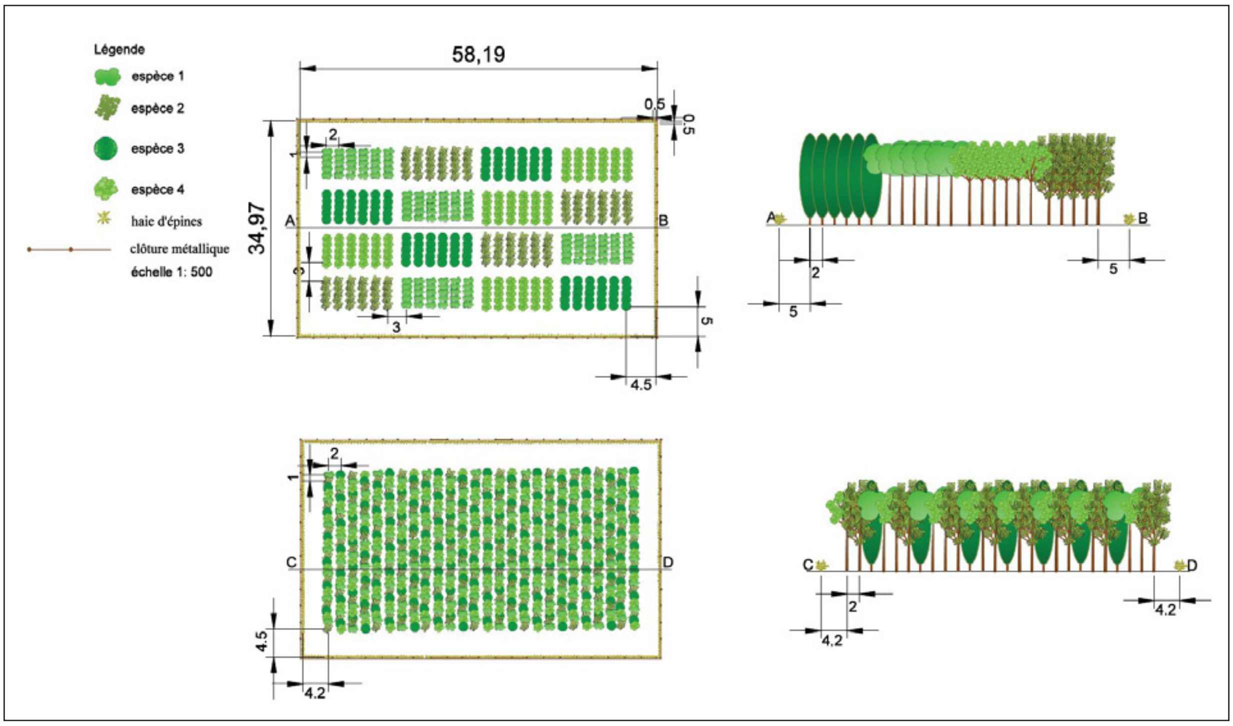

Figure 10 - Taghit (Algeria) – test plots for field trial of trees species irrigated with treated wastewater.

ronmental impacts. Moreover, the green structures provide social and economic incomes and benefits, as their construction and maintenance determine employment, improved environmental quality and environmentally sound management of natural and non-conventional resources (e.g. treated wastewater). Given the degradation and instability of most of road slopes in Taghit, stabilizing interventions were planned, based on the use of local herbaceous plants and shrubs and on rescue irrigations with treated water. In case of superficial instability of the slopes, realization of small steps with wattle fences and fascines was considered.

3. Reducing the environmental impact of the basins of primary treatment (lagoons, settling basins), through the use of vegetated strips of herbaceous species, aromatic shrubs and trees with use of treated waste water for irrigation

The project goal has been the creation of irrigated green belts surrounding the lagoon basin in construction at Taghit (Fig. 11), which are structured as:

A. Buffer zone, formed by herbaceous species (e.g. *Mesembryanthemum* spp.) to limit the damage from possible flooding of the pond caused by extraordinary climatic events and thus reduce the risk of contamination of surface and underground water resources.

B. After a service corridor for the ordinary maintenance of the lagoon basine, a belt of aromatic shrubs (e.g. *Artemisia herba-alba* Turra, *Lavandula antineae* Maire, *Rosmarinus officinalis* L., *Rosa* spp., *Astragalus armatus* Willd., *Helichrysum* spp., *Atriplex halimus* L., etc.) was envisaged with the purpose to reduce the smell air pollution of the primary treatment system.

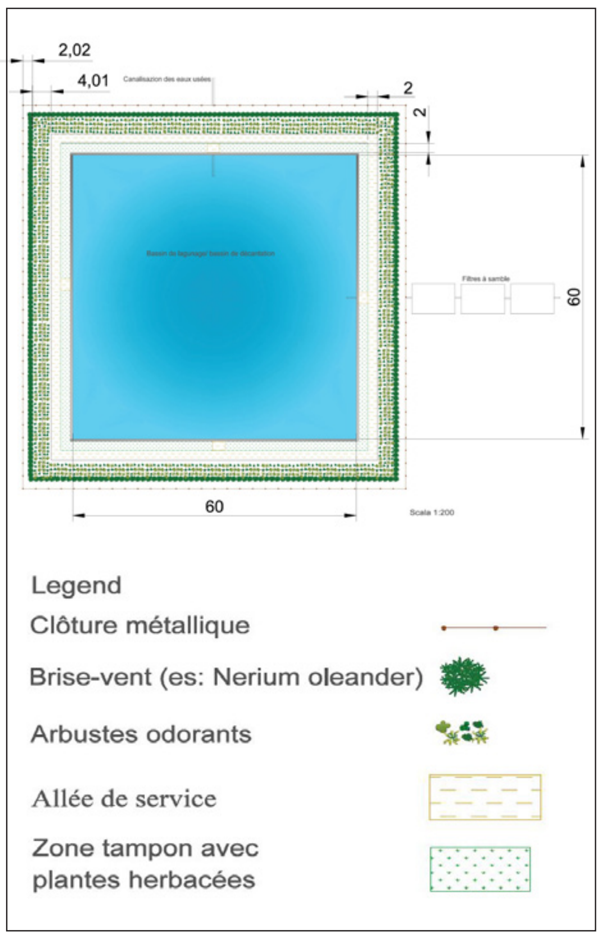

Figure 11 - Plantation of aromatic plants and shrubs to reduce the impacts of the treatment basin.

C. A trees or shrubs windbreak is finally expected (e.g. *Nerium oleander* L., *Tamarix africana* Poir., *Popolus* spp.) that, in addition to the protective function of the lagoon basin to the possible silting effects, will preclude the view from road. The use of species such as N. *oleander* characterized by intense colored blooms, also determines a pleasant visual effect contributing to the aesthetic landscaping, a basic element given the huge tourist interest of Taghit Oasis.

Conclusions

Wastewater harvesting and treatment are required to guarantee a sustainable development of dry lands. Treated urban wastewater is an unconventional but relevant resource, allowing to reserve fresh water uses for more essential needs.

The actual human and economic development produces widespread availability of wastewaters even in areas with scarce surface and ground water. Recycling wastewaters reduces the risk of pollutants seeping into natural habitats and of contaminations of drinking water wells. Such recycle has beneficial environmental effects on soils and water bodies. It can improve carbon storage and water retention in dry soil.

Treated wastewater can be safely used for irrigation of wood plantations, non-food and energy crops. Recycling makes available fresh water resources for the essential needs of people living in dry areas. Moreover, fertigation methodologies, such as those selected for the project, reduce the energy costs of up to 50% compared with traditional systems, allowing the recovery of nutrients to enrich soil fertility.

The use of non-conventional water resources promote reclamation of marginal land, reduction of wind erosion, amelioration of soil conditions, economic stimulation for timber and non-timber products as well as local manpower requirements for new management systems. A new and sustainable agro-forestry management of arid and degraded land is required to guarantee new economic benefits to the local people and to conserve and recover the arid and semiarid lands. The integrated approach proposed in the FAO project can be considered a "*win win*" solution for restoration and conservation of dry lands, mitigation of global climate change and for a sustainable development on the local scale.

In addition, the use of partially treated wastewaters, in forestry and agroforestry activities can provide valid water supply to support the production of timber and firewood, the creation of windbreaks and thus preserve and protect the productivity of agricultural lands. This unconventional resource can contribute to ensure food for local communities, and helps to combat desertification. All this concurs to the achievements of some of "The Millennium Development Goals" established by the United Nations, as the objective 1, 7 and 8 "eradicate poverty and hunger, ensure environmental sustainability, and develop a global partnership for development".

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Technical note

Analisi esplorativa della disponibilità idrica del suolo in un querceto Mediterraneo

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Riassunto - In questa nota si valutano alcune possibili cause della mancata rinnovazione naturale del querceto, analizzando l'ambiente pedo-climatico attraverso il bilancio idrologico in un'area di querceto mediterraneo (Roma, Italia centrale). Il rilievo dei parametri è stato effettuato in continuo per determinare il grado di aridità del suolo in funzione delle condizioni ambientali. Per evitare l'utilizzo di formule climatiche empiriche per la stima dell'evapotraspirazione e quindi della variazione della riserva idrica del suolo, è stato testato il sensore Theta Probe Soil Moisture sensor Delta-T-Devices, mod. ML2x, con strumento di lettura diretta che fornisce il contenuto idrico del suolo come percento in volume. La correlazione lineare tra valori sperimentali ottenuti con metodo gravimetrico e valori misurati tramite sensore, è risultata significativa. Lo studio dell'umidità alla profondità di 100 cm, ha evidenziato uno stato idrico di acqua utile anche nel periodo estivo e addirittura la presenza di acqua libera nel periodo invernale. Per il querceto adulto non esistono problemi di carenza idrica, al contrario si possono verificare, in anni particolarmente piovosi, problemi di asfissia radicale. Si evidenzia invece, dal bilancio idrologico, che soltanto in annate umide è possibile avere un esito positivo della rinnovazione naturale perché la carenza idrica estiva non consente la sopravvivenza dei semenzali oltre la stagione. Questi risultati sono stati verificati in aree recintate e protette dall'azione della fauna che, attualmente, appare essere il fattore limitante più significativo per la rinnovazione del querceto nel contesto di studio.

Parole chiave - rinnovazione naturale, querceto, bilancio idrologico, umidità del terreno, Mediterraneo

Abstract - ***Exploring soil water budget of a pristine oak wood in peri-urban Rome, central Italy.*** The water budget in bounded and fenced areas was assessed by analyzing pedo-climatic conditions and the soil moisture content. Water content in the soil was measured using a Theta Probe Soil Moisture sensor (ML2x by Delta-T-Devices) with a direct read-out device that provides soil moisture estimates as percent volume. The correlation between the experimental values obtained by the gravimetric method and the values directly measured by Theta Probe was found signifi cant. Soil moisture at 100 cm depth indicates soil water as permanently available for plants through the year except during exceptionally dry summer periods. Therefore, oaks experienced no water defi ciency with normal rainfall rates, possibly suffering root asphyxia during rainy years. Results are col-lected in fenced areas, sheltered by the action of the local fauna.

Keywords - oak natural regeneration, water budget, soil moisture, Mediterranean

Introduzione

La foresta mediterranea, ed il querceto in particolare, sono elementi importanti per il mantenimento di condizioni eco-compatibili con la crescente pressione antropica (Campos et al. 2007, Bobiek et al. 2011). Sostenibilità ambientale e funzionalità ecosistemica necessitano tuttavia del monitoraggio permanente delle possibili modifiche delle condizioni edafiche e dello stato di flora e fauna, soprattutto in relazione ai recenti cambiamenti climatici (Drunasky et al. 2005). L'analisi agro-climatica può dare contributi importanti allo studio del funzionamento degli ecosistemi mediterranei influenzati da una progressiva pressione antropica (Hanique 1991), attraverso le numerose grandezze rilevate; tra queste, si segnala l'analisi di aspetti peculiari nel processo di rinnovazione del querceto (Gonzalez Hernandez et al. 1998).

Questo studio considera il progressivo invecchiamento di un querceto mesofilo presso la città di Roma e verifica, attraverso rilevazioni in campo di tipo idrologico e agro-climatico, se la mancata rinnovazione può essere imputata a condizioni climatiche, pedologiche e idrologiche (Tombolini and Salvati 2014), oppure a cause di natura esogena, quali il sovrapascolamento (Montserrat-Martì et al. 2009). A questo scopo, si sono determinate le condizioni climatiche sotto chioma e sopra chioma dal 2005 al 2009 con installazione di una centralina agroclimatica dedicata. Per lo studio della disponibilità idrica sono stati acquisiti, su base temporale oraria e giornaliera, dati di precipitazione, bagnatura fogliare e umidità del suolo a 10, 50 e 100 cm di profondità.

L'approccio metodologico utilizzato è stato di tipo sperimentale. Sono state utilizzate aree protette e non protette (recintate/non recintate) per discri-

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minare l'azione esercitata dalla fauna (cinghiali e caprioli soprattutto) che svolge una riconosciuta azione distruttiva delle plantule di quercia. Per evitare la stima indiretta dell'evapotraspirazione, fattore particolarmente importante nel determinare la variazione della riserva idrica del suolo, è stata utilizzata una sensoristica di nuovo tipo in grado di determinare in continuo il grado di umidità del terreno e quindi la quantità di acqua a disposizione delle piante nell'arco dell'anno.

Materiali e Metodi

Il sensore Theta Probe Soil Moisture sensor prodotto da Delta-T-Devices, modello ML2x, con strumento di lettura diretta capace di fornire il contenuto idrico del terreno come percento in volume, è stato installato sulla stazione agro-climatica posizionata sotto chioma in località Campo di Rota, a circa 20 km dal centro di Roma, in un querceto misto di *Quercus cerris* e *Q. frainetto* (Moretti et al. 2006). La conoscenza in continuo della situazione idrica consente di determinare eventuali periodi di siccità di durata tale da compromettere l'accrescimento delle giovani piantine da seme (Manes et al. 1997). Per verificare la rispondenza del sensore utilizzato, i dati ottenuti dal posizionamento alla profondità di 50 cm in due punti diversi della stessa area, sono stati confrontati con quelli ottenuti in laboratorio dalla misura dell'umidità di campioni di suolo con metodo gravimetrico. Il controllo è stato condotto per circa 18 mesi (maggio 2003-novembre 2004). I risultati sono evidenziati in Fig. 1. Gli andamenti sono comparabili e il grado di correlazione è risultato elevato e significativo ($R^2 = 0.95$, $p < 0.001$).

Verificata la funzionalità del sensore ed effettuata la calibrazione in loco, è stato effettuato il collegamento alla centralina operante in continuo presso l'area sperimentale recintata. La centralina agro-climatica ha rilevato sotto chioma la temperatura

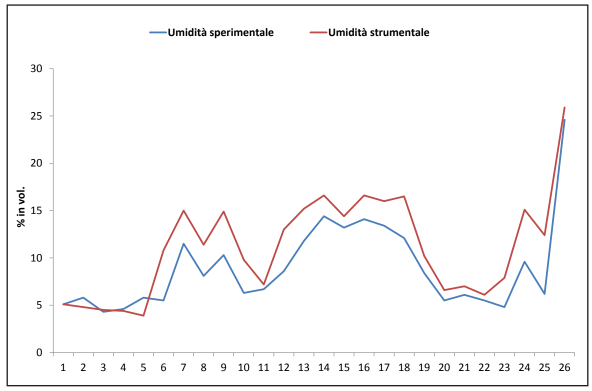

Figura 1 - Andamento dell'umidità del suolo per decadi. Anni 2003-2004.

e l'umidità relativa dell'aria, la radiazione solare, la bagnatura fogliare e l'umidità del terreno a 10, 50 e 100 cm di profondità. Sono state inoltre misurate le precipitazioni sotto chioma e sopra chioma (Brunt 2011, Holton and Hakim 2012). Obiettivo di quest'ultima misura è di verificare l'intercettazione della pioggia da parte della vegetazione e mettere in relazione la stessa con la bagnatura fogliare espressa come valore globale (pioggia+condensazione) e valore netto (solo condensazione).

Risultati

Dal 1 gennaio 2005 la stazione agro-climatica ha iniziato a fornire dati validi (Tab. 1). Si riportano di seguito gli andamenti rilevati sotto chioma e all'aperto relativi agli anni 2005 e 2006. Il confronto sotto - sopra chioma evidenzia l'azione di intercettazione in funzione dello stato vegetativo del querceto per energia radiativa e precipitazioni, mentre i parametri termici non presentano variazioni elevate per la limitata circolazione di aria sotto la copertura arborea. I dati rilevati nel 2006, confermano quelli del 2005 e in particolare l'abbattimento dell'energia radiativa pari all'80% e l'intercettazione delle precipitazioni per il 64%. Mentre la temperatura dell'aria non mostra differenze significative sopra e sotto chioma, l'umi-

Tabella 1 - Dati climatici sotto chioma (media 2005-2009).

MESI	TEMPERATURA ARIA °C			UMIDITA' RELATIVA ARIA %					UMIDITA' TERRENO % in volume		
	Max	Min	Media	Max	Min	Media	RADIAZIONE SOLARE Cal cm^{-2} giorno	PRECIPITAZIONI mm	10 cm	50 cm	100 cm
Gennaio	13,3	2,6	7,3	98,9	65,1	89,1	41,8	56,0	16,7	25,4	26,8
Febbraio	14,2	1,7	7,4	99,0	54,1	83,9	65,4	47,2	18,0	24,8	32,5
Marzo	16,8	3,5	9,9	98,8	53,6	83,5	89,8	30,4	17,1	23,7	36,2
Aprile	20,0	6,9	13,3	99,6	50,6	82,5	75,7	31,2	14,0	18,0	31,0
Maggio	23,3	10,6	16,9	99,6	51,0	82,3	48,1	21,8	11,0	13,1	21,9
Giugno	26,3	13,4	20,0	99,2	49,5	80,5	41,4	8,8	8,5	9,7	13,3
Luglio	29,9	16,6	23,5	99,1	46,9	77,8	42,8	3,5	7,5	8,6	10,4
Agosto	29,9	16,2	22,9	98,8	44,7	77,3	37,7	2,6	7,1	8,4	9,8
Settembre	26,8	14,2	20,0	98,1	50,4	80,9	35,7	47,1	7,8	10,6	11,0
Ottobre	22,5	10,8	15,7	99,0	59,3	86,8	31,1	49,9	8,3	11,3	11,5
Novembre	17,7	7,1	11,6	99,5	65,9	91,1	25,0	82,4	9,9	15,4	13,5
Dicembre	13,3	3,2	7,7	99,1	64,0	88,8	27,7	94,7	14,7	22,2	21,7
ANNO	**21,2**	**8,9**	**14,7**	**99,1**	**54,6**	**83,6**	**47,0**	**475,5**	**11,7**	**15,9**	**20,0**

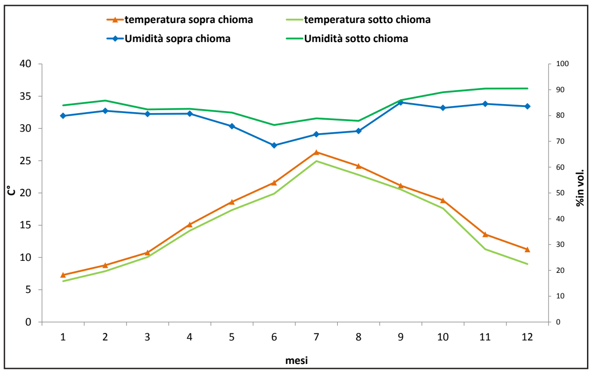

Figura 2 - Un esempio di andamento della temperatura e dell'umidità dell'aria sopra e sotto chioma (2006).

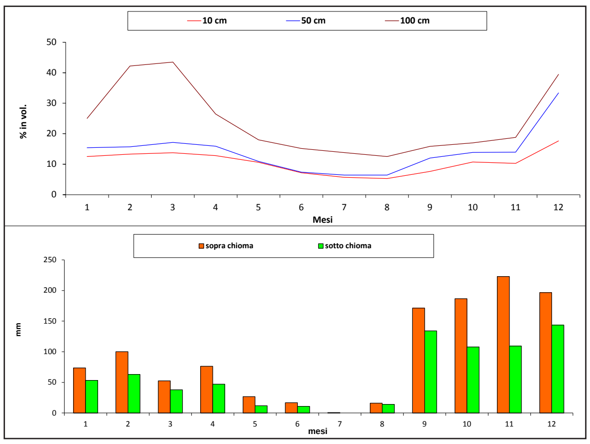

Figura 3 - Andamento dell'umidità del suolo e delle precipitazioni (2005).

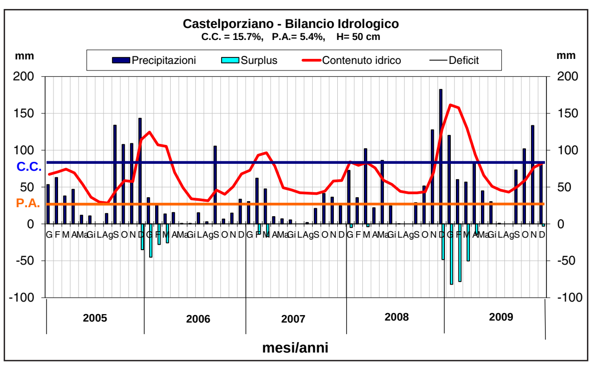

Figura 4 - Andamento della riserva idrica del suolo e rappresentazione delle precipitazioni e del surplus nell'area di studio (2005-2009).

dità relativa dell'aria registra valori sotto chioma mediamente superiori del 10% nei confronti dei valori misurati sopra la vegetazione (Fig. 2).

Per quanto riguarda l'acqua nel suolo, la natura del primo strato (5-10 cm), ricco di sostanza organica con tessitura franco-sabbiosa è in grado di captare una buona quantità di acqua e di opporre una certa resistenza al suo attraversamento. Diverso è il comportamento dello strato successivo fino a 50-60 cm, completamente sabbioso e poco compattato, che non oppone alcuna resistenza al passaggio dell'acqua. Questa rapidamente raggiunge gli strati più profondi dove generalmente crea un deposito a causa della compattazione della sabbia. Si riporta di seguito l'andamento dei valori giornalieri di umidità del suolo misurata in continuo (Fig. 3). Il bilancio idrologico è stato elaborato a partire dall'umidità relativa allo strato di 50 cm interessato all'assorbimento radicale dei semenzali di quercia germinati a Marzo 2005. La riserva idrica (RI) del terreno è stata determinata con la seguente espressione (Moretti et al. 2006)

$$RI = (Au*h)/10$$

dove RI = Riserva idrica espressa in mm; Au = Acqua utile in % vol. ottenuta dalla differenza tra l'umidità in % vol. misurata e quella relativa al Punto di appassimento determinata in laboratorio a pF 4,2; h = Altezza dello strato di terreno espressa in cm.

Il 16% delle precipitazioni totali, pari a 2.810 mm in 5 anni, che raggiungono il suolo, supera lo strato di 50 cm e percola negli orizzonti sottostanti come surplus (449 mm), mentre l'84%, pari a 2.361 mm resta nello strato di suolo a disposizione dei semenzali (Fig. 4). Se si calcola che il contenuto idrico ad inizio anno 2005, pari a 65 mm, viene incrementato a fine 2009 di 20 mm, la quantità di acqua utilizzata per l'evapotraspirazione del sottobosco pari a: Pioggia - Variazione contenuto idrico - Surplus è

$$ET = 2810 - 20 - 449 = 1341 / 5 = 268,2 \text{ mm/anno}$$

Dal bilancio idrologico risulta quindi che l'evapotraspirazione è pari in media a circa 270 mm/anno, il 35% di quella ottenuta, ad esempio, con la formula di Thornthwaite pari a 770 mm/anno calcolata con valori medi decennali (Tab. 2). Questo dato appare logico se si tiene conto che: a) la radiazione solare misurata sotto chioma risulta essere pari a circa il 30% di quella rilevata sopra chioma; b) il tasso di umidità relativa dell'aria sotto la vegetazione è più alto; c) l'azione di intercettazione delle precipitazioni da parte dell'apparato fogliare tende a concentrare l'acqua al suolo in punti determinati.

L'analisi del bilancio idrologico, consente di affermare che, dal 2005 al 2009, lo stato idrico del suolo non ha assolutamente limitato lo sviluppo dei semenzali germinati nella primavera del 2005. Le plantule di quercia sono germinate i primi di marzo e, nell'area recintata, hanno avuto uno sviluppo notevole. La sequenza fotografica mostra la germinazione nonchè i diversi stadi di sviluppo all'interno dell'area monitorata (Fig. 5). Si notano, anche all'esterno, numerosi semenzali, successivamente morti. Questo evidenzia l'azione distruttiva della fauna per la rinnovazione naturale. Come già sottolineato in precedenza, l'assenza di deficit idrico risultante dal bilancio idrico dello strato 0-10 cm, probabilmente determinato anche dalla pur esigua risalita capillare,

Tabella 2 - Bilancio idrologico del suolo sotto chioma di querceto per lo strato 0-50 cm, elaborato sulla base dell'umidità del suolo misurata nell'area di studio (2005-2009).

Anno	Mese	Umidità % in vol.	Pioggia terreno mm	Contenuto idrico iniziale mm	Variazione mm	Contenuto idrico finale mm	Surplus mm	Deficit mm
2005	G	13,5	53,4	65,0	2,3	67,3	0,0	0,0
2005	F	14,1	63,0	67,3	3,3	70,6	0,0	0,0
2005	M	14,9	38,0	70,6	3,8	74,4	0,0	0,0
2005	A	13,8	47,0	74,4	-5,2	69,2	0,0	0,0
2005	Ma	10,7	11,8	89,2	-15,5	53,7	0,0	0,0
2005	Gi	7,2	11,0	53,7	-17,4	36,2	0,0	0,0
2005	L	5,9	0,0	36,2	-6,5	29,7	0,0	0,0
2005	Ag	5,7	14,2	29,7	-1,4	28,3	0,0	0,0
2005	S	9,1	134,0	28,3	17,2	45,5	0,0	0,0
2005	O	11,8	107,8	45,5	13,3	58,6	0,0	0,0
2005	N	11,5	109,2	58,8	-1,3	57,5	0,0	0,0
2005	D	22,9	143,4	57,5	57,0	114,4	-34,9	0,0
2006	G	24,9	35,6	114,4	10,2	124,6	-45,1	0,0
2006	F	21,5	26,0	124,6	-17,3	107,3	-27,8	0,0
2006	M	21,0	13,6	107,3	-2,1	105,2	-25,7	0,0
2006	A	14,0	15,5	105,2	-35,3	69,9	0,0	0,0
2006	Ma	9,9	0,8	69,9	-20,6	49,3	0,0	0,0
2006	Gi	6,8	0,8	49,3	-15,2	34,0	0,0	0,0
2006	L	6,6	15,2	34,0	-1,1	32,9	0,0	0,0
2006	Ag	6,3	3,0	32,9	-1,4	31,5	0,0	0,0
2006	S	9,2	105,6	31,5	14,5	46,0	0,0	0,0
2006	O	8,1	6,6	46,0	-5,8	40,3	0,0	0,0
2006	N	10,1	14,8	40,3	10,2	50,5	0,0	0,0
2006	D	13,6	33,6	50,5	17,4	67,9	0,0	0,0
2007	G	14,6	30,3	67,9	4,9	72,8	0,0	0,0
2007	M	18,6	62,0	72,8	20,4	93,2	-13,7	0,0
2007	A	19,3	47,5	93,2	3,4	96,6	-17,1	0,0
2007	Ma	15,7	9,8	96,6	-18,1	78,5	0,0	0,0
2007	F	9,8	6,9	78,5	-29,3	49,2	0,0	0,0
2007	Gi	9,2	5,4	49,2	-3,0	46,2	0,0	0,0
2007	L	8,5	0,0	46,2	-3,9	42,3	0,0	0,0
2007	Ag	8,3	2,0	42,3	-0,6	41,7	0,0	0,0
2007	S	8,2	21,1	41,7	-0,6	41,1	0,0	0,0
2007	O	8,9	41,4	41,1	3,4	44,5	0,0	0,0
2007	N	11,6	36,4	44,5	13,7	58,2	0,0	0,0
2007	D	11,8	24,7	58,2	0,8	59,0	0,0	0,0
2008	G	16,9	72,6	59,0	25,3	84,3	-4,8	0,0
2008	F	15,9	35,6	84,3	-4,8	79,5	0,0	0,0
2008	M	16,7	102,1	79,5	3,8	83,3	-3,8	0,0
2008	A	15,2	22,0	83,3	-7,4	75,9	0,0	0,0
2008	Ma	11,8	86,1	75,9	-16,8	59,2	0,0	0,0
2008	Gi	10,7	24,6	59,2	-5,6	53,6	0,0	0,0
2008	L	8,8	0,1	53,6	-9,5	44,2	0,0	0,0
2008	Ag	8,4	0,0	44,2	-2,0	42,2	0,0	0,0
2008	S	8,4	28,9	42,2	-0,1	42,1	0,0	0,0
2008	O	8,7	51,5	42,1	1,5	43,7	0,0	0,0
2008	N	14,0	127,7	43,7	26,2	69,9	0,0	0,0
2008	D	25,6	182,5	69,9	58,0	127,8	-48,3	0,0
2009	G	32,3	120,2	127,8	33,7	161,5	-82,0	0,0
2009	F	31,5	60,1	161,5	-3,9	157,8	-78,1	0,0
2009	M	26,0	56,7	157,8	-27,9	129,6	-50,3	0,0
2009	A	18,7	82,5	129,8	-36,2	93,6	-14,1	0,0
2009	Ma	13,2	45,0	93,6	-27,6	66,0	0,0	0,0
2009	Gi	10,2	30,1	66,0	-15,0	51,1	0,0	0,0
2009	L	9,2	1,0	51,1	-5,2	45,8	0,0	0,0
2009	Ag	8,7	0,0	45,8	-2,6	43,3	0,0	0,0
2009	S	10,1	73,3	43,3	7,2	50,4	0,0	0,0
2009	O	12,0	101,9	50,4	9,5	60,0	0,0	0,0
2009	N	15,3	133,5	60,0	16,7	76,7	0,0	0,0
2009	D	16,5	80,2	76,7	5,8	82,5	-3,0	0,0
2005-2009		13,4	2810,2	65,0	20,5	82,5	-448,7	0,0

data la natura sabbiosa del suolo, ha permesso ai semenzali di superare il periodo estivo e procedere quindi al ricaccio primaverile nel marzo 2006 come si evidenzia nella foto (Fig. 6).

Le plantule hanno successivamente raggiunto la completa affermazione e, a parte la mortalità naturale per competizione, lo sviluppo ulteriore non è condizionato da stress idrici, a conferma dei risultati evidenziati dal bilancio idrologico (Fig. 6).

Conclusioni

L'osservazione quinquennale consente di affermare che, in annate normali (con umidità del suolo

Figura 5 - Germinazione e sviluppo dei semenzali di quercia (2005).

Figura 6 - Confronto delle radici di semenzali del primo e secondo anno (2006) e rinnovazione in pieno sviluppo nel 2009.

non inferiore, nel periodo estivo, al punto di appassimento permanente), la rinnovazione del querceto è possibile e si realizza (Bobiek et al. 2011). Ciò è valido in aree protette dall'azione della fauna, che diventa altrimenti il fattore ostativo dominante. Lo studio dell'umidità del suolo alla profondità di 100 cm, ha evidenziato uno stato idrico di acqua utile sempre presente nel periodo estivo e addirittura una presenza di acqua libera nel periodo invernale. Non esistono quindi problemi di carenza idrica per il querceto adulto, mentre la falda superficiale temporanea consente ai semenzali di superare particolari momenti di scarsa piovosità. Lo studio delle dinamiche dell'acqua nel terreno esteso a livello territoriale per realizzare una cartografia delle condizioni idrologiche a scala di forte dettaglio spaziale (Salvati et al. 2012), appare uno dei temi di rilevante interesse in relazione all'analisi della rinnovazione naturale del querceto in aree soggette a variazioni climatiche persistenti.

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