Downscaling of ecophysiological information from natural communities to urban trees

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Abstract: *Knowledge about ecophysiological attitudes at tree level is basic for a correct knowledge of the performance of each species in different environments, and for the comprehension of the mitigation and compensation aspects that urban vegetation may exert. Data on photosynthesis and stomata conductance may be obtained from measurements at single leaf level, but their upscaling to plant level is very complex, due to the needs of considering light extinction patterns within complex canopies, and all the other regulatory physiological and physical factors. This paper starts from the opposite direction: scaling down information about single trees photosynthesis from data collected at stand level.*
Keywords: *CO_2 exchange flux, ecophysiology, urban vegetation, urban green planning.*

Riassunto: *Conoscere le risposte ecofisiologiche a livello di pianta è fondamentale per determinare le performances di ogni specie in ambienti diversi, e per comprendere gli aspetti di mitigazione e compensazione che la vegetazione esercita in aree urbane. Dati puntuali su fotosintesi e conduttanza stomatica possono essere ottenuti facilmente tramite misure dirette a livello di singola foglia, ma lo scaling a livello superiore, e quindi la trasposizione dei valori alla intera pianta è una operazione complessa. Occorre infatti tenere in conto l'estinzione della radiazione foto sintetica all'interno di chiome complesse, oltre che tutti i fattori di regolazione legati alle forzanti atmosferiche e alla componente fisiologica. Questo lavoro effettua quindi un livello di scaling che tiene in considerazione questi parametri e derivando le informazioni eco fisiologiche relative ad una singola pianta a partire dai dati raccolti a livello di ecosistema.*
Parole chiave: *Flussi di CO_2, ecofisiologia, vegetazione urbana, pianificazione verde urbano.*

INTRODUCTION

The photosynthesis process is a complex effect of interaction between the atmosphere and the vegetation surfaces. The sink of CO_2 at tree scale is more complex than the study of photosynthesis at leaf or ecosystem scales: the plant photosynthesis ability depends not only on genetic characteristics of a single specie, but also on total biomass and its volumetric and spatial distribution. The light energy that reaches the tree canopy and the single leaves is the source to activate the photosynthesis process, so the total daily CO_2 storage at plant scale is not the sum of single leaf stored terms, but it is function of the energy availability and the solar position of the geographical location where the plant is located (Ross, 1975).

Also the local meteorological and climatological conditions play a fundamental role in the determination of seasonal and annual photosynthesis (Carrara *et al.*, 2004): the air temperature is crucial in the variability of the plant respiration and the photosynthetic active radiation (PAR), as well as water wailability, modulate the changes in the photosynthesis fluxes. Therefore, the complete knowledge of all these regulating factors is necessary to estimate the net canopy exchanges.

The model developed in the present study aims to downscale information recorded at ecosystem level to single tree species, in order to have an estimate of the plant ability to absorb the atmospheric CO_2.

MATERIAL AND METHODS

The present study was carried out to obtain information about a sustainable green urban planning for an area in the Parma city (Lat. 44.80° N, Long. 10.33° E), considering the capacity of the different tree species to absorb CO_2.

Three-year-old potted plants belonging to 12 species (listed in Tab. 2) were taken as model-elements. Measurements of CO_2 leaf gas-exchanges were conducted under laboratory conditions by clamping a portion of fully expanded leaves of the tree canopy in the cuvette of the portable gas-exchange system Li-Cor 6400 (Li-Cor Inc., Lincoln, NE, USA). The leaf cuvette was equipped with a temperature and light control device that allowed to maintain the leaves at 30° C and at 1000 µmol m^{-2} s^{-1} of photosynthetic active radiation (PAR). Light-saturated photosynthesis was considered a maximum assimilation rate (A_{max}) (Baraldi *et al.*, 2010).

The monthly and annual CO_2 exchanges between each species and the atmosphere have been computed applying a model that was developed using real flux data measured since 2000 in a forest ecosystem (Nonantola deciduous forest) belonging to

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CarboEurope Network (http://www.carboeurope.org/; http://gaia.agraria.unitus.it/DATABASE/carboeuropeip/site.aspx (Yi *et al*., 2010). This forest is close to the city of Modena (Lat. 44.69° N, Long. 11.09° E), thus the climatic and meteorological conditions are representative of Parma, which is located nearby in the flat area of the Po plane in Italy.

Model Description

We considered three continuous years of ecosystem measurements (2001, 2002 and 2003) to avoid differences in biomass accumulation and meteorological conditions and only the vegetative months were taken into account (from April to October).

During the three years taken into consideration, the monthly typical day CO_2 exchange flux have been calculated from April to October and the A_{max} value of each single month was parameterized as function of the maximum PAR recorded in the month itself. The curve obtained from this parameterization (Fig. 1) has been successively modified to force the ecosystem A_{max} (at PAR=1000 μmolm^{-2} s^{-1}) to be equal to the A_{max} measured at leaf scale for each single species. In this way we defined the monthly variability of the A_{max} value. A single curve was obtained for each plant species under investigation Fig. 2 reports the case of *Carpinus Betulus*.

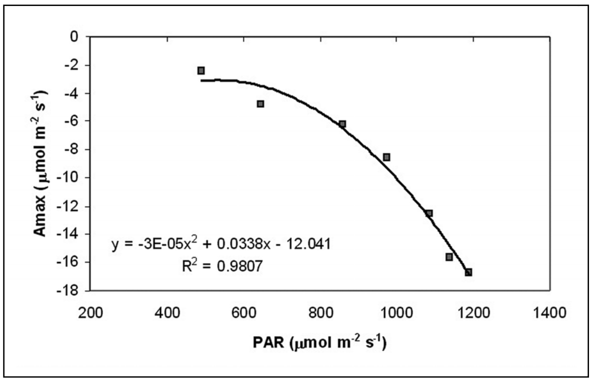

Fig 1 - A_{max} (maximum of photosynthesis) value of each single month (from April to October) as function of maximum PAR value. The best fit is a second order polynomial curve.
Fig. 1 - Valore di A_{max} (fotosintesi massima) per ogni mese (da aprile ad ottobre) in funzione del valore massimo di PAR. L'interpolazione ottimale è una curva polinomiale di secondo ordine.

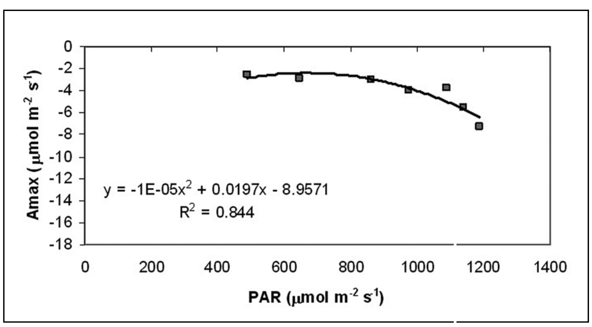

Fig. 2 - A_{max} (maximum of photosynthesis) value of each single month (from April to October) as function of maximum PAR value for the *Carpinus Betulus* species.
Fig. 2 - Valore di A_{max} (fotosintesi massima) per ogni mese (da aprile ad ottobre) in funzione del valore massimo di PAR per la specie Carpinus betulus.

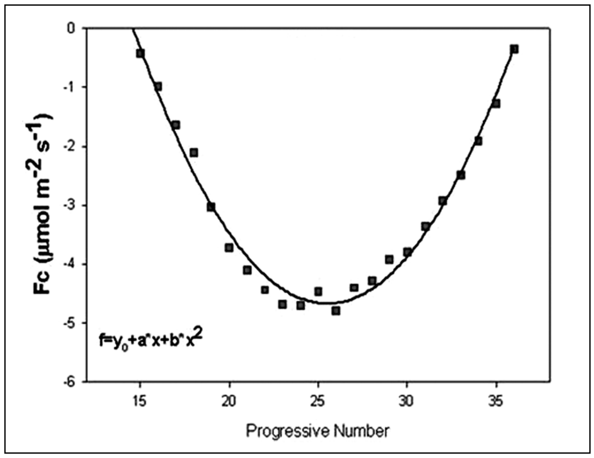

Fig. 3 - Parameterization of the typical day CO_2 flux for April month. The same curves has been obtained for each single month.
Fig. 3 -Parametrizzazione del flusso di CO_2 giornaliero tipico per il mese di aprile. Le medesime curve sono state ottenute per ogni singolo mese.

The CO_2 flux daily trend for each month (obtained from data recorded at ecosystem level) was parameterized by using a second-order polynomial regression curve: in Fig. 3 it is reported the case of the month of April. Tab. 1 reports the coefficients of the regression curve for each vegetative month together with the correlation coefficient of the best fit curve.

In order to impose the A_{max} value measured for each single plant species, the coefficients reported in Tab. 1 were re-computed for each month (a_{month}) as function of the A_{max} value obtained through the method above described (Fig. 2 results for *Carpinus Betulus*) applying the equation:

$$a_{month} = -\sqrt{(y_0 - A_{max\_month})4b} \qquad [1]$$

In Fig. 4 shows the results obtained of April for *Carpinus Betulus*. The same procedure was applied to compute the diurnal CO_2 fluxes for each month and for each species.

Tab. 1 - Coefficients and correlation coefficient (R^2) values of the quadratic best fit curve ($y= y0+ax+bx^2$) obtained for each single month.
Tab. 1 - Coefficienti dell'interpolazione ottimale mediante curva quadratica ($y=y0+ax+bx^2$) e relativo coefficiente di correlazione per ogni singolo mese.

Month	y_0	*a*	*b*	R^2
April	21.00	-2.01	0.04	0.98
May	46.32	-5.11	0.10	0.99
June	39.01	-4.33	0.09	0.98
July	27.87	-3.18	0.06	0.97
August	28.85	-3.00	0.06	0.97
September	27.77	-2.07	0.05	0.99
October	17.73	-1.58	0.03	0.94

The respiration flux was calculated by utilizing the empirical coefficients reported in Lloyd and Taylor (1994) taking into account that organic heterotrophic soil respiration is not present in an urban environment. The nocturnal contribution from the soil was taken equal to 40% of the total measured ecosystem respiration (Baldocchi *et al.*, 2001), while the respiration in the winter months was considered equal to zero (no litter and no leaves, so that the net CO_2 balance was equal to zero).

RESULTS AND DISCUSSION

The model developed in this work was applied to all species investigated, that are commonly present in the urban vegetation of North Italy cities (considered pot grown trees as model elements). Summing the values of diurnal CO_2 flux during the vegetative months, the Net Ecosystem Exchange (NEE) at tree scale was computed. The results are reported in Tab. 2, where for each species the A_{max} values measured in laboratory and the net ecosystem exchange per year and per surface units are reported. In order to scale-up the result at the whole tree level, it was a necessary step to multiply the obtained value for the plant average biomass area.

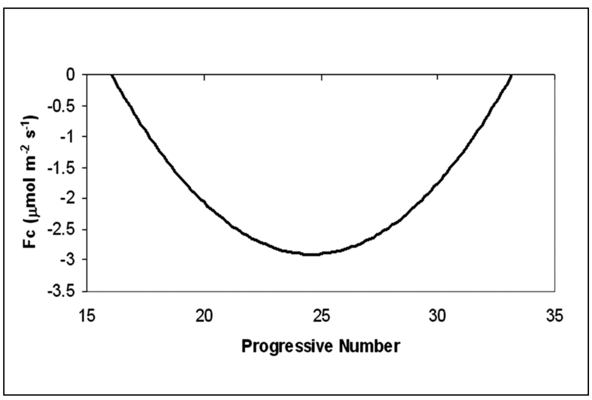

Fig. 4 - Typical day CO_2 flux for *Carpinus betulus* during April month. The same curves has been obtained for each month and for each species.
Fig. 4 - Flusso di CO_2 giornaliero tipico per Carpinus betulus *durante il mese di aprile. Le medesime curve sono state ottenute per ogni singolo mese e per ogni specie.*

Tab. 2 - Annual net CO_2 exchange (NEE) and maximum of photosynthesis (A_{max}) values for each single species under investigation in the present study.
Tab. 2 - Valori di scambio netto di CO_2 annuale (NEE) e di fotosintesi massima (A_{max}) per ciascuna specie esaminata nel presente studio.

SPECIES	**A_{max} (µmol $m^2 s^{-1}$)**	**NEE (Kg CO_2 m^{-2} year)**
Acer campestre	-10.72	-0.83
Acer platanoides	-12.47	-1.22
Carpinus betulus	-7.25	-0.55
Crataegus monogyna	-19.79	-3.82
Fraxinus excelsior	-9.01	-0.64
Fraxinus ornus	-22.63	-4.86
Liriodendron tulipifera	-8.53	-0.61
Liquidambar styraciflua	-9.36	-0.61
Malus everest	-11.72	-1.17
Prunus avium	-12.95	-1.50
Quercus cerris	-12.23	-1.32
Tilia cordata	-17.93	-3.19

The most efficient species, in terms of CO_2 absorption, is the *Fraxinus ornus* (NEE=-4.86 Kg $CO_2 m^{-2}$ year) while the *Carpinus betulus* (NEE=-0.55 Kg CO_2 m^{-2} year) is the lowest . NEE is the Net Ecosystem Exchange, that is the difference between the amount of C stored by photosynthesis and the amount lost by respiration.
These values can been there considered as an estimation of the different species ability to sink the CO_2 from the atmosphere, reporting an exercise to overcome the more-spatially significant

data available at single leaf level. When similar investigation are carried out in different geographical area, the local environmental conditions must of course be taken into account. In a strategy of urban planning, the present study can give a instrument to decide the right species to plant in order to limit both pollution and warming problems of anthropogenic origin.

CONCLUSIONS

The downscaling of ecophysiology information from ecosystem to single tree scale can be utilized to planning new urban green installation.

The urban green mitigation and compensation effects are strongly correlated with the plant species, the biomass area and the tree age. The present study gives a new tool to obtain single tree information from data collected at stand level. With the same scientific approach the annual evapotranspiration at plant level can also be computed, starting from laboratory measured stomatal conductance of the single species. Similarly to the photosynthesis process, the dependence of the evapotranspiration on environmental conditions variability can been studied considering the forest ecosystem measurements, thus providing important inputs to urban heat island mititgation practices and politics.

These results, together with the plant ability to absorb small particle and air pollutants, give a new instrument to detect the species that better adapt themselves to the urban environment, and that may furnish as well an important added value to sustainable urban ecosystem services.

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