Thesis title:

Modeling Phytoremediation and Climate-Induced Mortality in Urban Trees: Enhancing the DynaTree Model for La Goccia Forest, Milan.

Project Context and Motivation:

Urban trees are a key nature-based solution, providing critical ecosystem services (ES) such as carbon sequestration, local climate regulation, air purification, or water flow regulation. However, urban trees face chronic and acute stressors, including soil and air pollution, heat islands, drought, and constrained rooting volumes. Planning effective urban forestry actions, such as restoration, replanting or management activities in large parks, public squares or streets, requires quantifying future changes in the supply of ES as a consequence of specific decisions (e.g., species selection, management decisions) and expected future socio-environmental drivers (e.g. climate change). For this, we need predictive tools that can simulate how urban tress will grow, survive, and provide ES along decades into the future under varying environmental and management scenarios.

To address this need, the Ecology Group of Politecnico di Milano has developed **DynaTree**, an mechanistic and individual-based model. Unlike common statistical or pure allometric approaches that rely on historical correlations, DynaTree simulates the fundamental biophysical processes governing tree growth in a dynamic, spatially explicit manner, but simple mechanistic ways. This process-based foundation allows us to project tree development and ES provision under novel future conditions, such as specific climate change scenarios, serving as a decision-support tool for evidence-based planning.

Next Stage: A dual master thesis proposal

The next stage of DynaTree's model development will focus on integrating:

- A new ES module (mediation of soil pollution – i.e., phytoremediation module).
- A stochastic mortality and morbidity module to simulate tree decline and death from cumulative stress and acute shocks.

Thesis Topic 1: Modeling Phytoremediation as an Ecosystem Service:

Many urban greening projects, like those on former industrial lands, must address soil contamination. Trees can contribute to long-term stabilization and remediation through processes like phytoextraction and phytostabilization.

This thesis will develop a new phytoremediation module for DynaTree. The student will create a mechanistic representation of how different tree species interact with specific contaminants (e.g., heavy metals, hydrocarbons), quantifying their capacity to absorb or immobilize pollutants over time. The goal is to model soil decontamination as a dynamic ES dependent on biotic and abiotic interactions.

Thesis Topic 2: Simulating Tree Mortality and Morbidity as stochastic processes: Tree death in cities is rarely a simple function of age. It is often the culmination of long-term stress (e.g., from soil toxicity or chronic drought) or triggered by an acute event (e.g., a severe heatwave).

This thesis will integrate tree morbidity and mortality into DynaTree as stochastic processes. Building on integration of stochastic modeling in past mechanistic models (e.g., NBenefit$), the student will develop a model where the probability of decline or death for an individual tree is a function of species-specific tolerances, exposure to long-term stressors, and random disruptive shocks. This will enable DynaTree to generate more realistic forest dynamics and uncertainty estimation for ES supply.

Case Study: La Goccia Urban Forest, Milan

Both theses will be grounded in the real-world context of La Goccia, an urban forest being developed on a former brownfield north of the Politecnico di Milano Bovisa campus. This site is a perfect living laboratory, featuring co-existing soil contamination (heavy metals, hydrocarbons) and urban climate

pressures. It is also adjacent to the future expansion site of the Politecnico campus, making it a strategic green space.
Applying the enhanced DynaTree model to La Goccia will allow for simulations of different future scenarios, such as:
• Comparing long-term performance and ES provision of different tree species.
• Evaluating interactions between climate stress and contamination stress on forest health.
• Projecting the trajectory of soil remediation services over a 50-year horizon.

Proposed Thesis Work for Students:
We are looking for two highly motivated MSc students to for this dual-thesis proposal. The work can be structured as two single thesis or two interconnected but distinct theses, result of a collaborative project from a pair of students. The latter being the preferred case to ensure coherency in the development of DynaTree.

Thesis Track 1: Development of the Phytoremediation Module.
The student will be responsible for:
- Contributing to a literature review to identify how phytoremediation by trees was modelled in the past, particularly phytoextraction and pythostabilization.
- Parameterizing these processes for specific tree species and a few contaminant types relevant to La Goccia.
- Designing and implementing the module within the DynaTree framework (coding in R), ensuring it interacts correctly with the existing structure of DynaTree.
- Calibrating and validating the module's outputs against established empirical data from phytoremediation studies provided by supervisors.

Thesis Track 2: Development of the Stochastic Mortality/Morbidity Module.
The student will be responsible for:
- Researching drivers of urban tree mortality to define key stress indices (e.g., integrated soil toxicity load, cumulative water deficit) from DynaTree's outputs.
- Designing a stochastic framework where mortality probability is a function of these cumulative stresses and related random shock events.
- Implementing this framework in the R code, including species-specific vulnerability parameters.
- Analyzing model sensitivity and producing realistic mortality patterns in test simulations.

Both theses involve computational modeling, scientific programming in R, data analysis, and a strong interest in urban ecology and ecosystem services. Students will gain expertise in process-based modeling and contribute directly to a tool with immediate applied relevance for informing the future of La Goccia and consequently the new Politecnico campus development.

For further information:
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Thesis topic:

Correlating urban tree morphology and seasonal LAI phenology with the supply of two regulating ecosystem services: microclimate regulation and noise mitigation.

Project Context and Motivation:

Trees are a key component of urban green infrastructure in cities across the world, delivering critical ecosystem services (ES) such as local cooling, carbon sequestration, and stormwater management. However, their capacity to provide these benefits is under increasing threat from chronic urban stressors—heat islands, drought, soil sealing—and the novel challenges posed by climate change. Effective, forward-looking urban forestry planning therefore requires a shift from reactive management to predictive simulation. We must be able to answer: *How will our urban forest grow, survive, and function decades from now under different climate and management scenarios?*

To bridge this gap, the Ecology Group at Politecnico di Milano has developed DynaTree, a mechanistic, individual-based model designed to simulate the fundamental biophysical processes of tree growth and ES provision. Its process-based foundation allows it to project tree development under future conditions where historical data may fail. However, its predictive power and calibration depend on high-quality, temporally resolved empirical data that captures the dynamic relationships between tree structure, seasonal phenology, and ES delivery, relationships that for some regulating services such as microclimate regulation are highly variable even at short time scales.

As part of current research activities within the Ecology Group, we are increasing our efforts in the collection of data and empirical observation of relationships among tree morphology variables, and those with specific regulating services and processes underpinning their delivery.

In relation to these activities , we propose a master's thesis at the critical interface of empirical observation, statistical analysis, and predictive model validation. It aims to generate foundational data and correlations to enhance DynaTree's ability to simulate key regulating services.

Case Study: Giardino Sorelle Miraball and broader Ortica and Lambrate Neighhbourhoods

The thesis will be grounded in the real-world context of Giardino Sorelle Miraball, as a pilot case study of urban green space. The empirical observation, and collection of data, as well as integration with existing datasets, such as the tree inventory of Milan, will be also expanded to the Ortica and Lambrate Neighborhoods. The site and neighborhood will act as an open living laboratory.

Proposed Thesis Work for the Student

We are looking for a highly motivated MSc student to carry out this thesis. The student will contribute to an ongoing research effort by conducting empirical fieldwork and statistical analysis to build a foundational dataset. This work will directly support the parameterization and validation of process-based relationships for the DynaTree model.

The core of the thesis work will involve:

- **Field Data Collection:** The student will be responsible for executing afield campaign across the case study sites (Giardino Sorelle Miraball, and selected locations in Ortica and Lambrate). This includes collecting data on key tree morphology variables (DBH, height, crown dimensions, Leaf area) and abiotic variables (air temperature, land surface temperature, sound levels), which for some variables will require a seasonal campaign during the entire thesis. The specific campaign protocols will be co-designed with the supervisors.
- **Data Integration:** The student will integrate the collected field data with existing municipal datasets (e.g., the Milan Tree Inventory).
- **Data analysis and statistical correlation among the different tree morphology variables, and those with abiotic variables and ecological mediating processes of interest: The student will**

Establish species-specific allometric relationships between tree variables, to understand key traits (e.g., DbH and LAI ranges.). It will also quantify dynamic correlations between the seasonal trajectory of LAI and the measured provision of cooling and noise attenuation services. It identify the main drivers (e.g., crown volume, LAI, distance from source) for each service.

- **Contribution to Modeling:** A key outcome of the thesis will be to synthesize the empirical findings into clear, parameterized coefficients, and if possible, propose process-based equations that describe how tree structure and phenology influence the supply of local climate regulation and noise mitigation. If feasible, changes will be integrated within the DynaTree model, but this is not necessarily an expected output of this thesis.

The core of the thesis work will involve:

- **Field Data Collection:** The student will be responsible for executing a seasonal field campaign across the case study sites (Giardino Sorelle Miraball and selected locations in the Ortica and Lambrate neighborhoods). This includes collecting data on key tree morphology variables (DBH, height, crown dimensions, Leaf Area Index - LAI) and relevant abiotic variables (air temperature, land surface temperature, sound levels). The specific measurement protocols and the monitoring campaign itself will be co-designed with the supervisors.
- **Data Integration:** The student will integrate the collected field data with existing municipal datasets, such as the Milan Tree Inventory, to contextualize and enrich the analysis.
- **Data Analysis and Statistical Correlation:** The student will perform comprehensive statistical analysis to: i) establish species-specific allometric relationships between tree morphology variables (e.g., DBH and maximum LAI); ii) quantify the dynamic correlations between the seasonal trajectory of LAI and the measured proxies for ecosystem service provision (cooling and noise attenuation); iii) identify the main drivers (e.g., crown volume, LAI, distance from source) influencing each service.
- **Contribution to Modeling:** A key outcome will be to synthesize the empirical findings into clear, parameterized coefficients and, if possible, propose process-based equations that describe how tree structure and phenology influence the supply of local climate regulation and noise mitigation. However, the direct integration of changes into the DynaTree model is just a desirable, not mandatory output. This thesis work is designed to provide the essential empirical foundation for such future model development, not being the core of the thesis.

Student Profile: This thesis is ideal for a student with a strong interest in urban ecology and environmental data science, who enjoys a combination of fieldwork and quantitative analysis. The student will gain hands-on experience in urban forestry measurement protocols, time-series and spatial statistical analysis (using R preferably), and the translation of empirical data into forms usable for predictive modeling in urban sustainability science.

For further information:

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