ANALYSING THE LATEST TRENDS IN FOREST ECOSYSTEM MODELLING: APPLYING NDVI INDEX VALUES FOR URBAN FOREST RESEARCH IN GEOGRAPHIC AXIS SYSTEM

ALEXANDRU MARIUS TĂTAR
PhD student Babeş-Bolayi University Cluj-Napoca, Romania

ABSTRACT: *Forest models are becoming essential tools in forest research, management, and policymaking but are currently under deep transformation. In this review of the most recent literature (2018–2023), I analysed an updated general view of the main topics currently attracting the efforts of forest modellers, the trends already in place, and some of the current and future challenges the field will face.*

Four major topics attracting the most of current modelling efforts: data acquisition, productivity estimation, ecological pattern predictions, and forest management related to ecosystem services Although the topics may seem different, they all converge towards integrated modelling approaches by the pressure of climate change as the major coalescent force, pushing current research efforts into integrated mechanistic, cross-scale simulations of forest functioning and structure.

I analysed that forest modelling is experiencing an exciting but challenging time, due to the combination of new methods to easily acquire massive amounts of data, new techniques to statistically process such data, and refinements in mechanistic modelling that incorporate higher levels of ecological complexity and breaking traditional barriers in spatial and temporal scales.

However, new available data and techniques are also creating new challenges. In any case, forest modelling is increasingly acknowledged as a community and interdisciplinary effort.

As such, ways to deliver simplified versions or easy entry points to models should be encouraged to integrate non-modeller stakeholders into the modelling process since its inception. This should be considered particularly as academic forest modellers may increase urban forest models' ecological and mathematical complexity. The Geographical axis system includes cities in Mures and Bistriţa-Năsăud counties. Cities in Mures: Târgul Mureş-Reghin-Luduş, in Bistriţa-Năsăud: Bistriţa-Beclean-Năsăud-Sângeorz-Băi.

Keywords: *Forest modelling; strategy; Urban forestry Methods; Geographical axis; NDVI;*

1. Introduction

Forests are one of the most complex ecosystems on Earth's biosphere, as they host a large proportion of terrestrial biodiversity and exist at the interface between the atmosphere and the pedosphere. in addition, forests are defined as such because the dominant organisms are long-lived trees. After all, the dominant organisms are long-lived trees immobile individuals that are usually large (.Mendoza, G.A.,1999).

These features allow forests to develop specific spatial and temporal structures that directly influence how the ecosystem functions (i.e., nutrient, water, and energy cycles, gene flows, population, and successional changes). All this natural complexity poses a true challenge for representing forest structure and functioning in scientific and technical studies and science-based management. (Kimmins JP et all,2008) Traditionally, forest models have focused on the dominant organisms (trees) and how they grow, survive, and are distributed (Berzaghi F et, all, 2018).

This approach has been dominant since the beginning of early quantitative forestry in the eighteenth century. However, for the last few decades, it has been well-known that understanding how trees function is not enough to understand how forests function, as other forest components (understory, wildlife, soil, and microbial communities) also influence trees. Hence, forest models have constantly evolved to incorporate some of the forests' complexity into their algorithms to produce the estimations that model developers consider necessary to meet their objectives.

The development of the first forest growth simulator marked the beginning of a new approach to estimating tree growth. Since then, modelling has evolved from the data-based approach of using statistical tools to transform observed data ("empirical models") into an approach in which an understanding of causal relationships between variables was added to statistical relationships to predict variables of interest ("process-based models") (Daniel B. Botkin et all, 1972).

Soon after, the advantages and disadvantages of both approaches were identified (Battaglia M, Sands PJ,1998) (Bugmann HKM et all,1996), and to solve them, an intermediary approach was proposed (Kimmins JP, et al.,2020). Since then, forest models have evolved considerably, and in the last few years, important technical developments have revolutionized the forest modelling field (Blanco JA, Améztegui A, Rodríguez, 2020). An 'urban' system is a spatially heterogeneous system, definitions, such as those provided by (Jorgensen,1986), the Society of American Foresters (Helms, 1988), (Konijnendijk et al.,2006) and all focus on the comprehensive nature of urban forestry, involving scientific, management and planning activities planning, and planning elements. In this article, I look at urban forestry in a general way. In the literal sense, "urban forestry" consists of two parts "urban" and "forestry".

Creating and managing urban forests to achieve sustainability is the long-term goal of urban foresters as well as elected officials, business leaders, and citizens. (Clark et al.,1997)

The following the continuous increment of computing power (Waldrop MM.,2016); the development of new statistical methods (Tredennick AT et al.,2021); the great expansion in techniques for data acquisition such as LiDAR, spectral, hyperspectral, thermal, or radar sensors that can be applied at broad scales (Belward AS, Skøien JO.,2015); or the development of autonomous continuous measurement devices for soil, vegetation, and atmospheric variables (Sethi SS, et all., 2022).

Therefore, this review aims to identify the current points of interest in forest modelling that capture most of the research efforts and to produce a catalogue in which the urban forest areas of the 7 cities analysed are listed as a geographical axis.

2. Materials and methods

To give a cursive to the research carried out the methods section is structured as follows:

2.1. Current Main Topics in Forest Modelling. To identify the current trends in forest modelling, first I searched the Web of Science database (https:// www. web of science. com/ wos/ woscc/ advanced- search) for the years 2018 to 2023 using the terms "forest modelling," "forest function," "forest distribution," "forest adaptation," and "modelling forest function" (with their alternative spellings) in the title and keywords of documents. They identified a total of 4933 documents.

Among those, 154 papers were reviews of different modelling topics. After papers that were reviews of different modelling topics. After screening for relevance, the selected review papers used for our narrative review were reduced to 79. In the second phase, to objectively identify the most popular topics in the most recent literature, we used the visualisation tool VOS Viewer (Van Eck NJ, Waltman L,2011) with a database of 4933 documents to map the relationships between their keywords.

However, the statistical term "random forests" distorts documents with this term. As a result, we retained the database (data not shown), I removed the 2040 documents for keyword mapping with VOS viewer v1.6.18 (Centre for Science and Technology Studies, Leiden University, the Netherlands, http:// www. vosvi ewer. com). I limited the minimum number of occurrences for each keyword displayed in the map to 30 (Fig. 1).

As a result, 20 different keywords were selected. This search was not intended to be a formal or in-depth quantitative review but merely a way to gain unbiased and up-to-date insight into current popular modelling trends.

As the main result of the keyword mapping, I found the term "climate change" as the most cited. Climate change also stood out in a central position among all other terms. In addition, four different clusters of terms were identified, with climate change being the main connector among them. The first cluster (in red in Fig. 1) could be considered as built around quantitative assessments of vegetation biomass (or carbon) using remote-sensing techniques (either aerial or terrestrial).

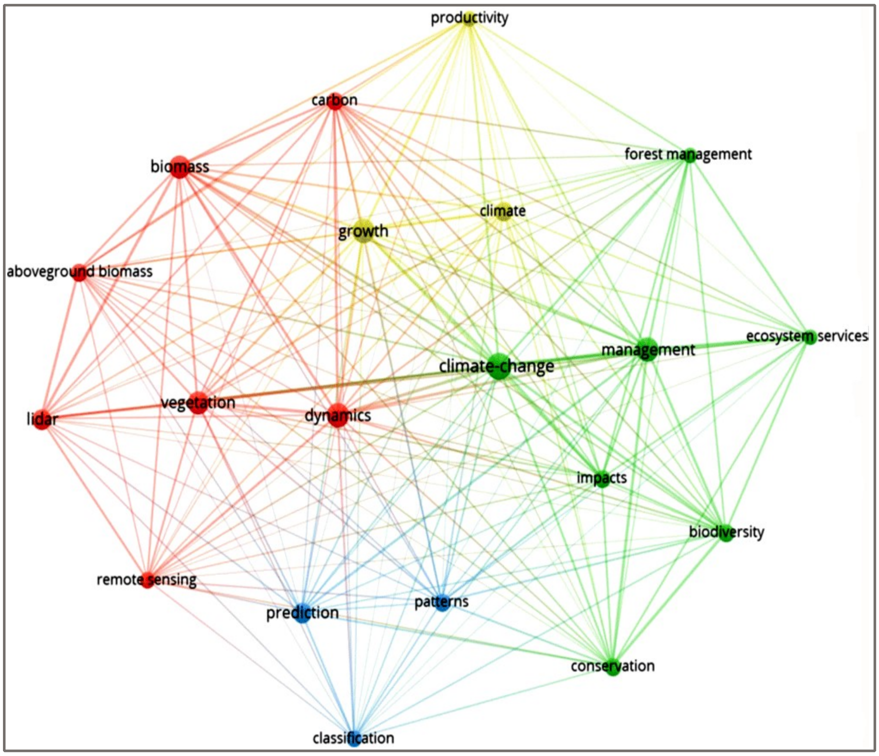

Fig. 1 Keyword map showing relationships between the 20 most common keywords in documents related to forest modelling published on the Web of Science in 2018–2023
Different lines and dot colours indicate different clusters of terms. The dot size is proportional to the frequency of each keyword and the line thickness is proportional to the frequency of the co-occurrence of connected keywords. Source: Realised by the author

The second cluster (in yellow in Fig. 1) was composed of the relationships between growth, productivity, and climate. The third cluster (in blue in Fig. 1) was limited to more technical terms related to model building.

Finally, the fourth cluster (in green in Fig. 1) was related to ecosystem services and management, in combination with climate change. Below, I discuss the main trends in each cluster in the following sections, based on the 79 review papers identified as relevant.

2.2 Contribution of urban forests to sustainable development goals and forestry strategy. It is used a methodological review is a type of systematic secondary research (i.e., research synthesis) which focuses on summarising the state-of-the-art methodological practices of research in a substantive field or topic" (Chong et al, 2021).

This chapter reviews information on strategies that set out a vision and concrete actions to improve the quantity and quality of forests in the EU and to strengthen their protection, restoration, and resilience. It also looks at how urban forests contribute to sustainable development goals

2.3. Use of Normalized difference vegetation index (NDVI) techniques in urban forest analysis. In the simplest terms possible, the Normalized Difference Vegetation Index (NDVI) measures the greenness and the density of the vegetation captured in a satellite image. Healthy vegetation has a very characteristic spectral reflectance curve which we can benefit from by calculating the difference between two bands – visible red and near-infrared. NDVI is that difference expressed as a number – ranging from -1 to 1.

NDVI of a crop or a plant calculated regularly over periods can reveal a lot about the changes in their conditions. In other words, we can use NDVI to estimate plant health remotely.

The value drop can also correspond to normal changes, such as the time of harvesting, which is why NDVI should be counter-checked against other available data. Correct NDVI values interpretation can help agronomists raise healthier yields, save money on fertilizers, and take better care of the environment.

NDVI is derived from satellite imagery and calculated per the formula:

$$NDVI = \frac{NID - RED}{NID + RED}$$

where:

NIR – light reflected in the near-infrared spectrum;

RED – light reflected in the red range of the spectrum;

According to this formula, the density of vegetation (NDVI) at a certain point of the image is equal to the difference in the intensities of reflected light in the red and infrared range divided by the sum of these intensities. NDVI defines values from -1.0 to 1.0, where negative values are mainly formed from clouds, water and snow, and values close to zero are primarily formed from rocks and bare soil. Very small values (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand, or snow.

Moderate values (from 0.2 to 0.3) represent shrubs and meadows, while large values (from 0.6 to 0.8) indicate temperate and tropical forests.

Put simply, normalized difference vegetation index is a measure of the state of plant health based on how the plant reflects light at certain frequencies (some waves are absorbed, and others are reflected).(Figure2)

In the NDVI analysis of urban forests in the geographical axis formed by 7 cities with administrative extension on two bordering counties Mureş and Bistriţa-Năsăud, the following EOSDA Crop Monitoring from EOS DATA ANALYTICS is a perfect tool for remote crop health monitoring using NDVI. EOSDA Crop Monitoring tracks changes in the NDVI for individual fields throughout the season. Monitor both the crop rotation patterns and the current vegetation rates. With the help of user-friendly graphs, the platform visualizes different types of data, including vegetation indices, temperature, precipitation rate, growth stages, historical weather, and much more.

Analysed period 2022-2023, Index values are based on Sentinel-2 imagery with 50% or less cloudiness.

3. Results

To give a flow to the research carried out, the results section is structured as follows:

3.1. Climate Change: the Main Driver for Forest Modelling. It is not surprising that climate change is at the centre of current forest modelling efforts, a pattern already noticed in other recent reviews (Gon alves AFA et. al,2021). This result could just reflect the generalized wish of forest researchers to link their work to the current widespread scientific policies focused on addressing climate change, but it could also genuinely indicate the need for understanding how complex systems such as forests will behave under unknown climate conditions.

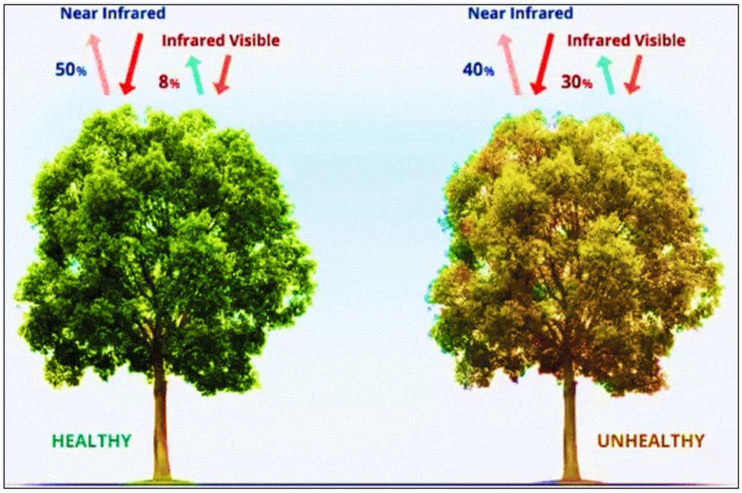

Fig. 2. Exposure vegetation condition analysis

Climate change is being observed as a major force behind many changes in current and future forest environmental changes (Machado Nunes Romeiro et al, 2022)(Prichard SJ et. al,2021).

Such changes will affect in different ways the key factors driving tree physiology, and therefore, new modelling approaches need to disaggregate climate influences on those drivers. Hence, understanding the detailed effects of climate change, alone or in combination with other major drivers for change such as land-use change, or biodiversity loss is the ultimate goal of much of the current modelling effort.

The realisation of the first signs of climate change and the need for early action in forest management well in advance of other economic sectors (due to the long-lived nature of trees) has meant that for at least two decades, the need to provide forest models with capabilities to simulate climate change has been recognised. (Mäkelä A et al,2000)(Mahnken M et al, 2022)

Such need has meant that the use of simple correlational models using traditional data from permanent plots or inventories has long been seen as inadequate among the scientific community for climate change-related studies. However, such an approach can be very suitable for other research and management applications (Kimmins JP et. al,2021). In addition, other models that had implicit representations of climate, influences have moved into explicit representations to keep up with the knowledge demands on climate change effects on forest systems from different stakeholders (Crookston NL et. al,2010) (Liu Y et. al,2020)

Nevertheless, for the successful implementation of climate change simulation capabilities into forest models, modellers need to move beyond direct effects on temperature and precipitation.

For example, the scarce availability of models able to link climate change with ecological disturbances has been identified (Romeiro, JMN et al,2022). Similarly, most regeneration algorithms used in forest models do not capture the effect of climate change (Hanbury-Brown AR et al,2020). In any case, climate change must be directly linked to modelling physiological responses (e.g., phenology, photosynthesis, respiration) and to the frequency and severity of disturbances (fire, drought, insect outbreaks, etc.).

In turn, changes in these processes will also affect other ecosystem processes (allocation, allometry, growth at tree ecosystem processes (allocation, allometry, growth at tree level, biodiversity, and competition at the ecosystem level), and therefore, simulating climate change effects will indirectly be needed to improve how such processes are modelled.

3.2. Remote Sensing and Biomass Accounting. Biomass (in the form of timber, firewood, cork, fruit, resin, charcoal, etc.) has traditionally been the most important charcoal, etc.) has traditionally been the most important commodity obtained from forests. Therefore, it is not surprising that the different ways to estimate forest biomass and other closely related variables (i.e., timber volume, carbon) are still among the most important topics in current forest modelling efforts (Fig. 1). Among them, modelling strategies to sequester C stands out as one of the most important topics. (Nunes LJR et al, 2019)

The large size and immobile nature of trees allow individual features such as diameter and height to be measured at different times over extended periods. Such an inventory-based approach can provide a wealth of data, but it quickly becomes a cumbersome task when large and diverse forest areas need to be assessed.

However, the explosive development of remote-sensing techniques, the lowering prices of unmanned aerial vehicles, and the continuous growth in computing capabilities are generating the ability to finally obtain a detailed assessment of not only the basic population features but also the structure and spatial distribution of individual trees over large areas (Coops NC, et al, 2021).

A model convergence towards the tree scale for meaningful C-cycle modelling, both from upscaling more physiologically oriented models and downscaling stand-level C accounting models, has been noted (Babst F et al,2021). However, not until very recently have researchers looked for ways to incorporate structural diversity into process-based models.

A detailed structural diversity into process-based models. A detailed review of the potential and limitations of using terrestrial laser scanning to calibrate functional-structural plant models is available (O'Sullivan et al,2021).

3.3. Process analysis and modelling. A second main topic in current forest modelling research is the development of new and refined methodological is the development of new and refined methodological approaches, mostly through the use of advanced mathematical approaches, mostly through the use of advanced mathematical or statistical tools or borrowing them from other fields.

New progress is made almost daily in deep learning methods that are revolutionizing modern ecology(Borowiec ML et al,2022).

These methods have great potential to improve computationally costly tasks such as the classification of information from remote sensing or the simulation of interactions between individuals in large forest areas. The use of these advanced statistical techniques is greatly expanding modelling capabilities to link research done at multiple scales, simulate larger regions, and incorporate dynamic changes at shorter temporal scales (crucial for accurate C flux modelling).

There is a dire need for tools that can provide usable predictions for managers, as the forestry sector needs to adapt to climate change even earlier than other sectors, given the long-term consequences of current management decisions (Jandl R, Spathelf P, Bolte A,2019). Hence, using techniques to simplify model use will undoubtedly facilitate the generation of tools easy to interpret and share with non-modellers, and that can be easily compared with expert knowledge (Robinet C et .al, 2020).

This idea of simplification while retaining the behaviour of complex process-based models is behind the development of "model emulators" (Lim TC,2021). Model emulators are built to mimic the same outputs from complex (usually process-based) models, with the main objective of reducing computing requirements. This simplification allows for the integration of the emulator into other modelling platforms (and therefore connectivity with other models or submodules different from the original process-based model), to expand temporal and spatial scales not reachable with the original process-based models or to simplify interaction with model users.

Hence, emulators could be valuable tools in the future to understand ecological patterns at large scales, particularly under novel ecological conditions created by the combination of climate, biodiversity, and land-use changes.

3.4. Modelling Forests Beyond Trees. While tree growth and productivity are still important topics, the largest cluster of research topics identified was related to modelling forest components other than trees.

Most of this research is based on a clear understanding that for models to be able to handle climate change effects, it is essential to include more ecosystem components that historically have received less attention. (Kimmins JP et al, 2021) Further developments that mechanistically link hydraulic conductance with physiology, growth and mortality are taking place.(Venturas MD et al, 2021) (Brodribb TJ et al,2019)

How biodiversity is integrated into forest models is another of the issues in this keyword cluster traditionally there is a biodiversity bias towards trees in forest models (Lõhmus A. et al, 2020). This is not surprising, as biodiversity interactions (both animal and vegetal) in forests are a complex and broad field that has not been incorporated into models until relatively recently, and that remains largely ignored in operational models used in forest management. In this regard, a lack of integration of modelling approaches at different spatiotemporal scales has been identified as a barrier to implementing biodiversity into forest modelling (Morán-Ordóñez A.et al, 2018)

Similarly, calls for more attention to the role of the understory in key ecological processes have been raised (Landuyt D . et al,2018), even if early examples of the importance of tree-understory interactions when simulating commercial forestry are available e.g., (Bi J et. al,2007). It is currently advocated that the most efficient approach is to use plant functional traits that can accommodate the inherent complexity of understory communities.

To do so models the complexity of understory communities. Models must have detailed time and spatial scale to allow for the different Eco physiological behaviours (many times resource opportunistic) that understory species usually display, particularly following disturbances (Taylor BN et al, 2017).

Other approaches to account for biodiversity include the use of habitat and species distribution models. They link the smallest (habitat) to the largest (distribution) spatial scales and provide a better understanding of the potential impacts of novel ecological conditions over the mid to long term.

The dramatic increase in available data on climate, soils, and species distributions allows for finely gridded modelling at both temporal and spatial scales. This advance allows statistically based species distribution models to be linked to process-based models (Maréchaux I. et al,2021) although a better understanding of absence data and improved inclusion of abiotic interactions become crucial to estimating the effects of climate change (Booth TH., 2018) (Pecchi M et al,2019).

Important conceptual advances in disaggregating disturbances into their constituent components and embedding disturbances into system dynamics have been recently completed (Sturtevant BR, Fortin M-J., 2021).

Important steps in making forest models more meaningful for stakeholders include modifying the way models are created.

The focus is on participatory processes in which model users and forest stakeholders interact with forest modellers during the inception of the modelling studies is being increasingly recognized as fundamental for the model to make an actual impact in the forest sector (Lim TC., 2021).

This approach aims to bring non-academic forest stakeholders into the process at the beginning, so they develop a sense of ownership of the research outcome and therefore are much more likely to implement the model outcomes. Three models for science-policy interaction have been identified (Polidori L et al, 2022): the "linear phase" when science-informed policymaking is in a unidirectional manner, the "interactive phase" when both sides find themselves in continuous interaction, and the "embedded phase."

The linear phase is still dominant in many regions, with scientists developing models and scenarios of their interest and then approaching non-academic stakeholders with their results. Only in some scarce cases the interaction has progressed and moved into the second stage of science-policy interaction (i.e., (Lim TC.,2021). It is the time to push towards a multi-actor approach (the second "interactive" phase of bringing science into practice). However, to achieve this goal, models need to be accessible, relevant, and user-friendly for non-modellers and address current forest management concerns to bring change into forestry practices (Benson DL. Et al, 2022).

A comparison of how different European decision support systems face these challenges has identified the need to incorporate forest owner behaviour and accurate spatial analysis to better estimate landscape-level provisioning of ecosystem services. (Nordström EM.et L, 019)

3.5. Forest Policy Strategy and Contribution of Urban Forests to Sustainable Development Goals

3.5.1 Forest Policy Strategy. Forests are essential for our health, well-being, and the planet's health. They are rich in biodiversity and are hugely important in the fight against climate change.

The new EU forest strategy for 2030 is one of the flagship initiatives of the European Green Deal and builds on the EU biodiversity strategy for 2030. The strategy will contribute to achieving the EU's biodiversity objectives as well as a greenhouse gas emission reduction target of at least 55% by 2030 and climate neutrality by 2050. It recognises the central and multifunctional role of forests and the contribution of foresters and the entire forest-based value chain for achieving a sustainable and climate-neutral economy by 2050 and preserving lively and prosperous rural areas. (https://environment.ec. europa.eu/ strategy/forest-strategy_en)

On 22 November 2023, The Commission is proposing a Forest Monitoring Law that will plug existing gaps in the information on European forests and create a comprehensive forest knowledge base, to allow Member States, forest owners and forest managers to improve their response to growing pressures on forests and strengthen forest resilience (https://ec.europa.eu/ commission/ presscorner/detail/en/ip_23_5909).

Forests are an essential ally in the fight against climate change and biodiversity loss and are crucial for flourishing rural areas and the economy. Unfortunately, Europe's forests suffer from many pressures, including climate change and unsustainable human activity. (https:// ec.europa.eu/commission/ presscorner/)

Better monitoring will enable action to make forests more resistant to the cross-border threats of pests, droughts and wildfires that are exacerbated by climate change, enable new business models such as carbon farming, and support compliance with agreed EU legislation.

Ultimately, it helps strengthen the capacity of forests to fulfil their multiple environmental and socio-economic functions, including their role as natural carbon sinks (https://ec.europa.eu/ commission/presscorner/detail/en/ ip_23_5909)

3.5.2 Contribution of Urban Forests to Sustainable Development Goals. Forests in and around cities face many threats, such as those posed by unregulated urban development and a lack of investment and management. Investment in the establishment, protection and restoration of urban forests can help create a healthy environment, such forests are often appreciated more for their aesthetic value than for their ecosystem functions.

Mayors, planners, and other urban decision-makers are often unaware of the crucial economic, social, and environmental benefits that urban forests can provide (Tab.1).

3.6. Model for Urban Forest Research in Geographical Axis System using NDVI. Illustration of index value between -1 and +1. of urban vegetation analysed (Figure 3). A higher or more positive value indicates a higher vigour of the plants and a better overall health status

Following the analysis for Bistrita the average NDVI value is established between 0.05-02. Isolated values of 0.85 (Fig. 4).

Table No.1 Contribution of Urban Forests to Sustainable Development Goals

Sustainable Development Goal	The role of urban forests
POVERTY	Urban forests create employment, provide a resource for entrepreneurs, reduce the cost of urban infrastructure, provide ecosystem services for all citizens, improve the living environment and increase property values, ultimately boosting local green economies
ZERO HUNGER	Urban forests are direct sources of food (e.g. fruits, seeds, leaves, mushrooms, berries, bark extracts, saps and roots, herbs, wild meat, and edible insects). Indirectly, they support healthy eating by providing affordable wood fuel, high-quality water and improved soil for sustainable agricultural production
GOOD HEALTH AND WELL-BEING	Forests and other green spaces in and around cities provide ideal settings for many outdoor recreation and relaxation activities, thereby contributing to the prevention and treatment of non-communicable diseases and the maintenance of mental health. Urban forests filter and efficiently remove pollutants and particulates, which also helps reduce the incidence of non-communicable disease
CLEAN WATER AND SANITATION	Urban forests are efficient regulators of urban hydrological cycles. They filter drinking water by reducing biological and chemical pollutants, reduce the risk of floods and erosion, and reduce water losses by minimizing microclimatic extremes through evapotranspiration processes
AFFORDABLE AND CLEAN ENERGY	The sustainable management of urban forests can produce renewable energy for use by urban communities. This is a vital function for billions of urban and peri-urban dwellers worldwide, particularly in lower-income countries, where wood fuel is often the most affordable and sometimes only available source of energy
DECENT WORK AND ECONOMIC GROWTH	Investments in urban forests and other green infrastructure adds significantly to green economic growth by providing an attractive environment for tourism and business, improving home values and rental rates, creating job opportunities, and providing materials for housing, and generating savings in the costs associated with energy and the maintenance of human health
SUSTAINABLE CITIES AND COMMUNITIES	Well-designed and managed urban forests make significant contributions to the environmental sustainability, economic viability, and liveability of cities. They help mitigate climate change and natural disasters, reduce energy costs, poverty and malnutrition, and provide ecosystem services and public benefits
CLIMATE ACTION	Trees and forests in and around cities contribute to Climate change mitigation directly by sequestering carbon and reducing greenhouse gas emissions and indirectly by saving energy, reducing the urban heat island effect, and mitigating flooding
LIFE ON LAND	Urban forests help create and enhance habitats, constitute a pool of biodiversity, significantly improve soil quality, and contribute to land restoration

Source: Realised by the author

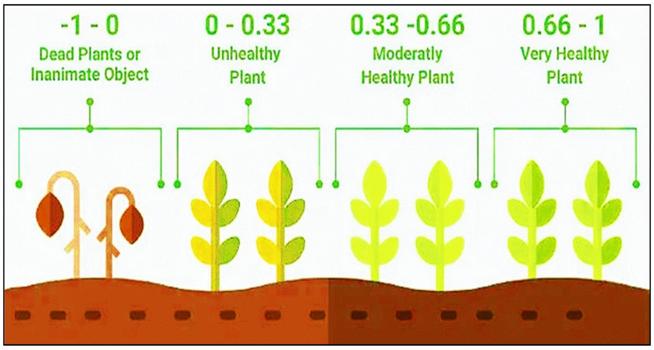

Fig. 3. Illustration of NDVI Index applied
Source: Realised by the author

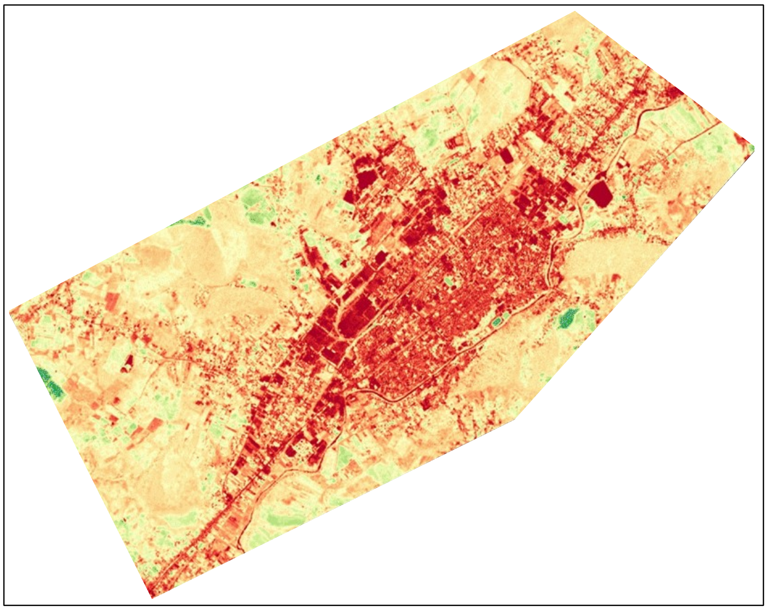

Fig. 4. NDVI values for Bistri a

Following the analysis for Beclean the average NDVI value is established between 0.05-03/0,43-0,75. (Fig. 5).

Based on the analysis for Năsăud, the average NDVI value is set between 0.20-0.10. Isolated values of 0.30 are recorded (Fig. 6).

According to the analysis for Sângeorz-Băi, the average NDVI value is set between 0.30-0.15. Isolated values of 0.05 are recorded (Fig. 7).

The NDVI values are analysed in the form of Geographical Axis 1 Bistriţa-Beclean -Năsăud-Sângeorz -Băi (Fig. 8).

From the analysis for Târgul Mureş, the average NDVI is set between 0.45 and 0.35. Isolated values of 0.50 are recorded (Fig. 9).

Based on the analysis for Luduş, the average NDVI is set between 0.20-0.15. Isolated values of 0.05 are recorded (Fig.10).

From the analysis for Reghin, the average NDVI is set between 0.45 and 0.30. Isolated values of 0.15 are recorded (Figure 11).

The NDVI values are analysed in the form of Geographical Axis 2 Târgul Mureş-Luduş -Reghin (Figure 12)

4. Discussion

4.1. Following challenges for the forest model Convergence. Understanding how complex ecosystems such as forests are structured and function as a system has still been and will be challenging. The challenge lies in understanding how climate change affects forests, while our understanding of how to model forests under “normal” conditions is still far from complete.

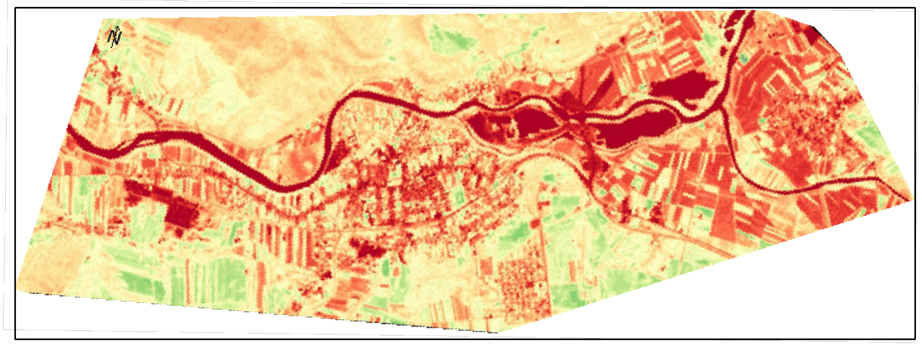

Fig. 5. NDVI values for Beclean
Source: https://crop-monitoring.eos.com/analytics/field/9876179?period_from=2022-02-04&period_to=2023-02-04&sceneID=S2B_tile_20230123_34TGT_0

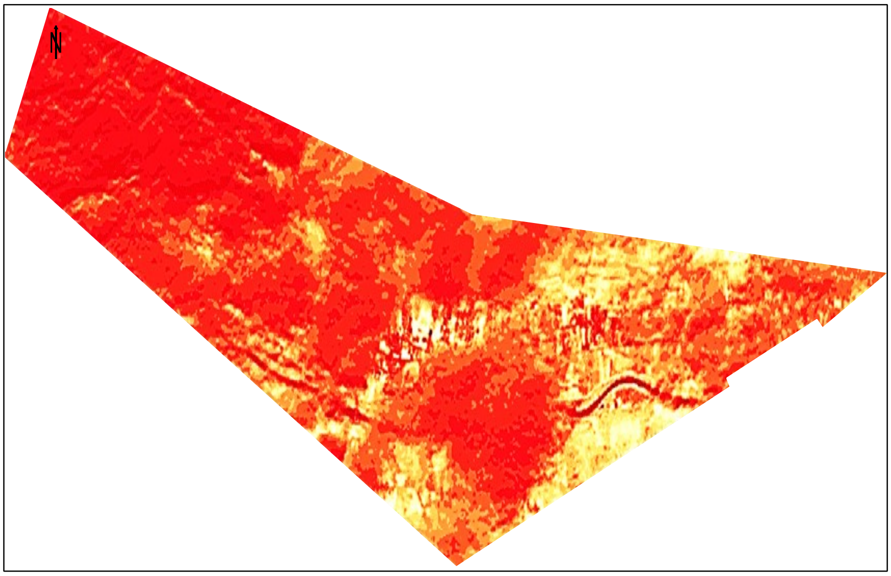

Fig. 6. NDVI values for Năsăud
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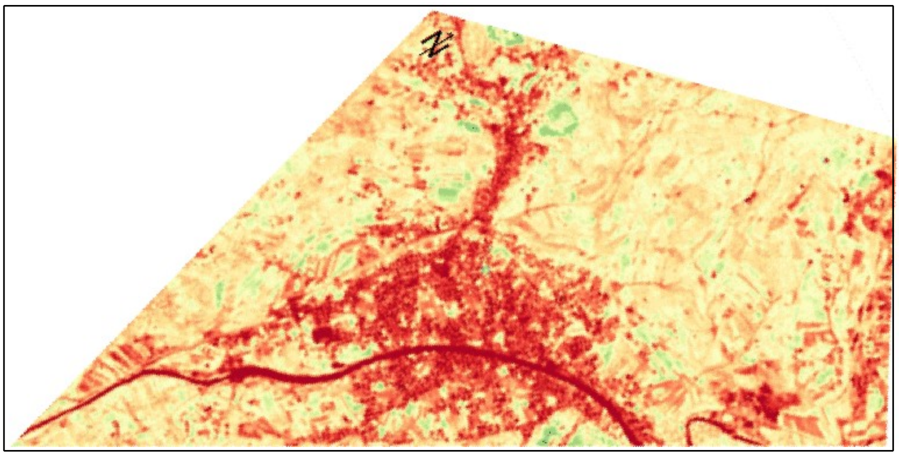

Fig.7 NDVI values for Sângeorz-Băi
Source: https://crop-monitoring.eos.com/analytics/field/9876197?period_from =2022-02-04&period_to=2023-02-04&sceneID=S2B_tile_20230123_35TLN_0

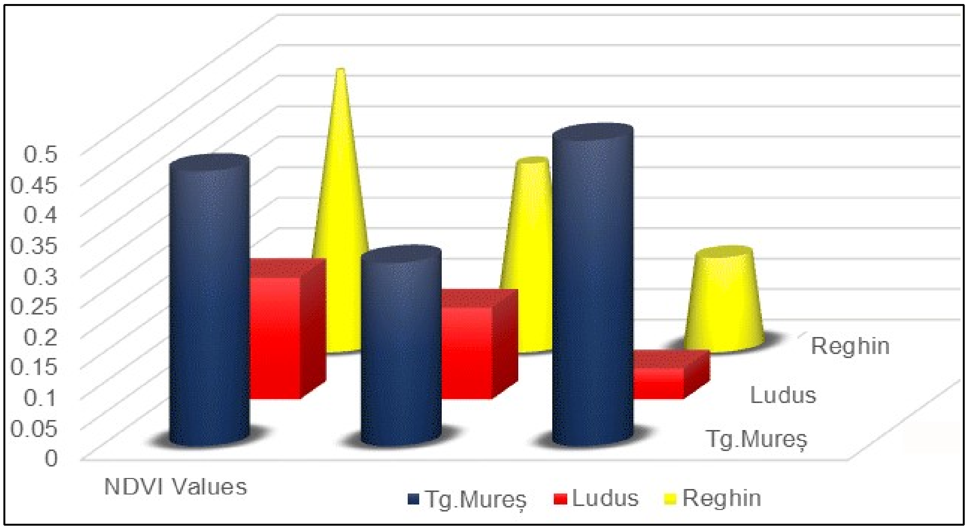

Fig. 8. NDVI values in the Geographical Axis 1
Source: Realised by the author

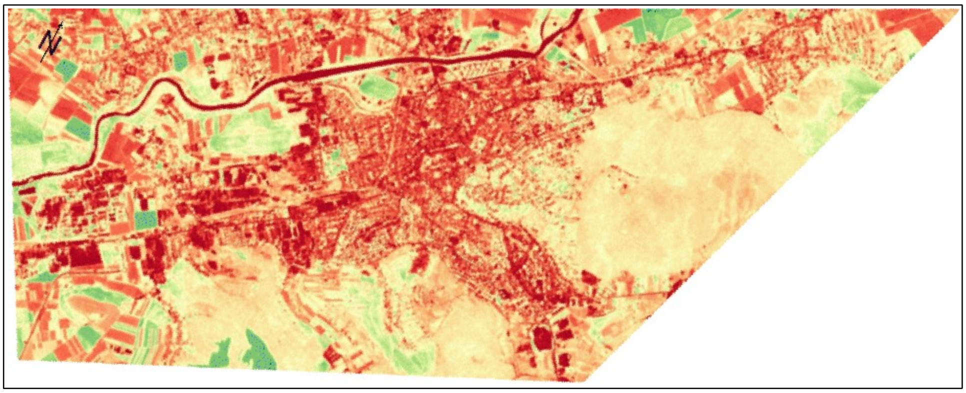

Fig. 9. NDVI values for Târgul Mure
Source: https://crop-monitoring.eos.com/analytics/field/9876296?period_from=2022-02-04&period_to=2023-02-04&sceneID=S2B_tile_20230123_35TLM_0

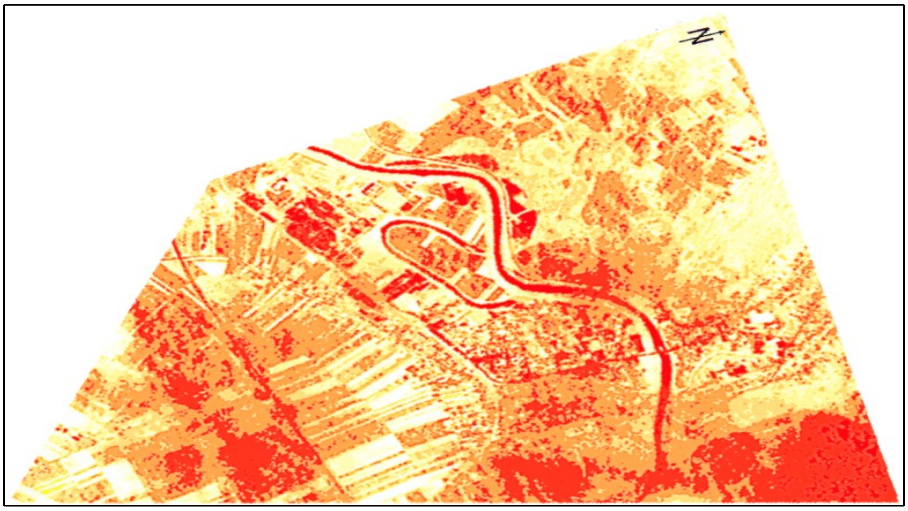

Fig. 10. NDVI values for Luduş

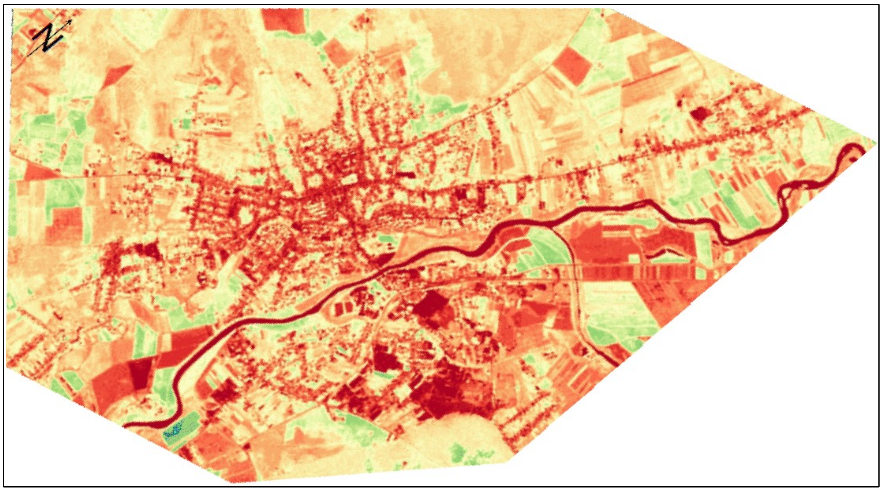

Fig.11 NDVI values for Reghin
Source: https://crop-monitoring.eos.com/analytics/field/9876308?sceneID=S2B_tile_20230123_34TGS_0&period_from=2022-02-05&period_to=2023-02-05

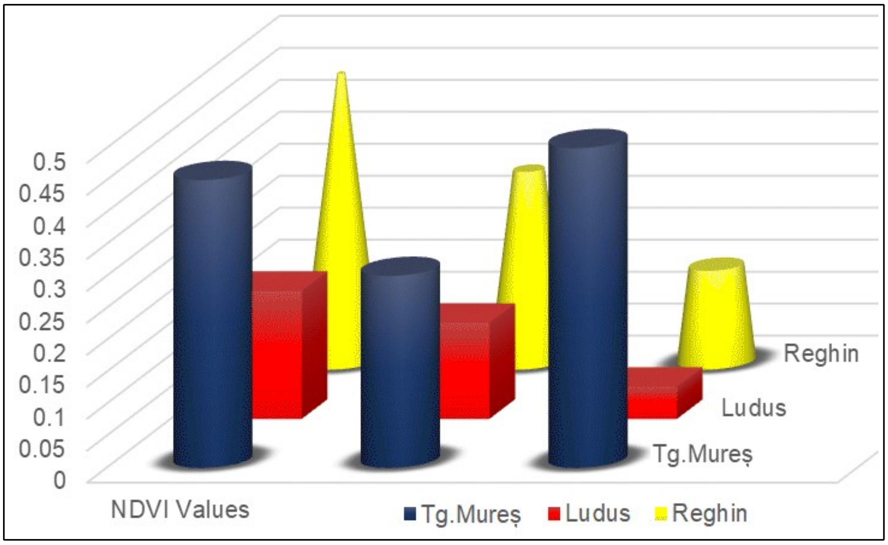

Fig. 12. NDVI values in the Geographical Axis 2
Source: Realised by the author

In addition to the most popular topics currently being explored in forest modelling discussed earlier, we have identified through our review several topics that deserve mention due to their relevance, even if they did not explicitly appear in the keyword map in Fig. 1. Such topics include the following:

• Small forests: Landscapes around the globe are becoming increasingly fractioned, making small forests of increasingly fractioned, making small forests of a few hectares or smaller increasingly common. Managers of such forests usually have limited resources to access and use models, and models usually lack representations of external factors (such as the vicinity of agricultural lands) that can be relevant to the functioning and structure of small forests;(Benson DL et al, 2022)

• Urban forests: As urban landscapes expand; urban forests are becoming very important in delivering a multitude of ecosystem services. However, urban forest models have been developed only for a few regions around the world (i.e., USA, Europe, and China) and are mostly correlational. To better assess the effects of climate change on ecosystem services, better linkages with Eco physiological mechanisms must be incorporated into urban forest models (Lin J et al,2019).

Among the potential ecosystem services that could be modelled in urban forests are not only carbon sequestration (Zheng J et al,2018) but also aesthetic values (Mundher R et al,2022);

• Overlooked physio-ecological processes: Important mechanisms have attracted little attention in the forest models until now. One is regeneration (including masting), which is now recognized as a process that can significantly affect biomass allocation and hence carbon and energy flows.

Even if detailed conceptual models on forest regeneration have been available for on forest regeneration have been available for some time (i.e., Blanco JA,2009), regeneration has usually been oversimplified in forest models (Hanbury-Brown AR et al,20229.

4.2 Analysis Comparison of NDVI values between Geographical Axis 1 and Geographical Axis 2. The NDVI values are analysed in the form of Geographical Axis 1 Bistriţa-Beclean -Năsăud -Sângeorz -Băi and Geographical Axis 2 Târgul Mureş-Luduş- Reghin (Figure 13).

new approaches and methods to model forest ecosystems and forest managers to use such models. It has also shown that we are at an exciting moment, in which the development of new statistical and measurement techniques is finally creating opportunities for developing true inter-scale models, from individuals to regions and beyond. In addition, the present need to incorporate users into the modelling process is stronger than ever, and options exist to simplify science-based models into operational models without losing an accurate representation of ecological patterns.

However, a need to better understand the ecological process is also more important than ever as climate, the process is also more important than ever as climate, biodiversity, and land-use change move forest ecology of the Earth to novel conditions. Hence, improving the mechanistic representation of ecological processes in an integrative manner that moves beyond trees will be crucial for meaningful predictions of the forest ecosystem development under novel conditions. In conclusion, I have shown that the traditional division between process-based and statistical models lacks actual meaning, as the major trend is

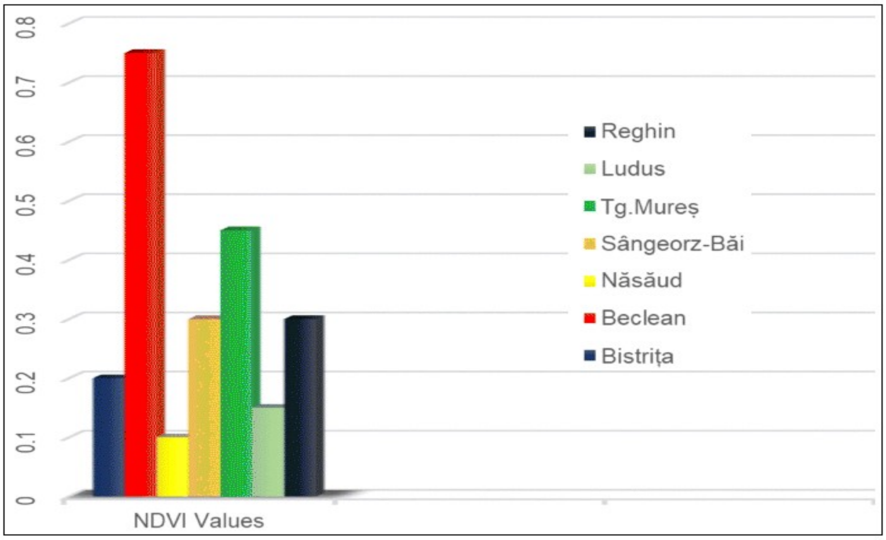

Fig.13 NDVI values for Urban Geographical Axis 1 and Urban Geographical Axis 2
Source: Realised by the author

5. Conclusion

A review of current trends in forest modelling has shown that climate change is the main driving force that is stimulating researchers to develop

towards cross-scale integration of different modelling approaches.

Application of Comparative NDVI analysis between Geographic Urban Axis 1 and Geographic Urban Axis 2.

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