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Original Research Paper

Assessment of Urban Ecosystem Services Provided by Animal Communities in Metropolitan Regions

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Abstract: Metropolitan ecosystems have been seriously impacted by fast urbanization, resulting in loss of ecosystem service delivery, biodiversity loss and fragmentation of habitat. Urban animal communities have an important role to play in maintaining ecological balance through pollination, biological pest control, nutrient cycling, maintenance of habitats and cultural ecosystem services, but they are not sufficiently quantified in conventional urban ecosystem assessments. This study suggests a framework integrating AI to evaluate ecosystem services of urban animal communities that will be applicable to metropolitan areas. It integrates ecological and biodiversity indicators with Geographic Information Systems (GIS), remote sensing, Internet of Things (IoT) sensors, environmental quality indicators, artificial intelligence and Multi-Criteria Decision Analysis (MCDA) into a holistic platform for the evaluation of ecosystem services. Biodiversity index, pollination efficiency, environmental quality, climate resilience and sustainability performance indicators were used to compare the biodiversity of representative metropolitan regions. The results show that well connected green infrastructure in metros achieved better scores in biodiversity indices (91), pollination efficiency (89%), environmental quality (90), climate resilience (88%) and overall sustainability score (90) than the highly urbanized metros (60 – 67). In addition, the best results were obtained for the regulation of ecosystem services (93%), followed by supporting (90%), cultural (87%) and provisioning services (81%). The framework is designed for ongoing monitoring of biodiversity, spatial analysis, and decision making based on evidence and intelligence for urban planners and decision makers. The study shows how the integration of biodiversity conservation and AI-based environmental assessment can significantly improve the resilience, adaptation to climate change and sustainable development of metropolitan regions.

Keywords: Urban ecosystem services, Urban animal communities, Biodiversity conservation, Artificial intelligence, Geographic Information Systems (GIS), Remote sensing, Ecosystem service assessment, Sustainable urban planning, Smart cities, Climate resilience.

I. Introduction

A rapidly urbanizing world has made metropolitan regions complex socio-ecological systems in which natural habitats are progressively being replaced by infrastructure such as buildings, transportation networks and others. More than half the world's population is now living in urban areas and this trend will continue over the next few decades. The spread and growth of cities have played an important role in promoting economic growth and living standards, but also have exacerbated environmental issues, including loss of biodiversity, habitat fragmentation, loss of green space, air and water pollution, urban heat islands, and decreased ecological resilience.

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Sustainable urban planning is therefore increasingly becoming a worldwide priority, aiming to harmonize the development of infrastructure with the preservation and protection of ecosystems. Urban ecosystem services are therefore an important part of environmental management as they offer ecological, economic and social services that are vital to urban living. In recent years, research into urban ecosystem services has gained growing significance and research gaps for sustainable metropolitan development, especially in regionally highly urbanized areas have been identified. [1], [2]

Animal communities, including birds, pollinating insects, bats, butterflies, amphibians, reptiles, small mammals, soil organisms and beneficial arthropods, have significant roles in maintaining ecological stability and ecosystem functioning and are indispensable parts of urban ecosystems. They play a vital role in ecosystem processes such as pollination, seed dispersal, natural pest control, decomposition, nutrient cycling, and habitat maintenance in these communities. Pollinating insects can improve the productivity of urban agriculture, community gardens and ornamentals, and birds and bats naturally control insect populations, providing a natural way to reduce reliance on chemical pesticides. The soil organisms enhance nutrient availability and soil fertility while aquatic organisms purify the water in urban wetlands and water bodies. Other than ecological services, urban wildlife provides a significant amount of cultural ecosystem services including recreation, environmental education, tourism, aesthetic value, and psychological health. Ecosystem services provided by animal communities in cities have been under-recognized even though they have multidimensional benefits, and are often ignored by plant-based evaluations of urban ecosystems. Extensive review of existing ecosystem service quantification methods also shows that there is a need for improved integration of biodiversity elements in urban sustainability assessment. [5]

Urban biodiversity and green infrastructure have been gaining traction in research interest, but there have been few studies on the urban animal community that have focused specifically on the ecosystem services provided by animal components in metropolitan areas. The literature could be more focused on the ecological roles of urban fauna, as these services are not as well discussed as those provided by vegetation, carbon sequestration and green infrastructure planning, and climate adaptation. Furthermore, most investigations are conducted on a single taxonomic level, e.g., birds or pollinators, rather than on the interaction of different communities of animals all working together in the same urban environment. This "fragmented" view of species reduces the comprehension of how all the species together, as a community, contribute to the functioning of the ecosystem, to its resilience and to sustainable urban development. In recent years, key geographical gaps, mixed evaluation methods and uneven evaluation criteria in the field of urban ecosystem services have also been found. [1], [2]

Some limitations of existing methodologies in the assessment of ecosystem services are their lack of effectiveness in the dynamic urban environment. The traditional approach for ecological survey relies on the intensive, time consuming, geographically limited and costly field observations. Traditional biodiversity indices are mainly based on species numbers and populations, but do not necessarily link biodiversity attributes to provision of ecosystem services. Current valuation methods tend to focus on economic valuation and neglect the ecological resilience, environmental quality and cultural values, as well as long-term sustainability implications. Moreover, numerous assessment models are built on static databases that lack the capacity to effectively represent seasonal changes and species migration, as well as habitat fragmentation or very fast land-use changes in urban areas. The use of remote sensing, Geographic Information Systems (GIS), artificial intelligence, and machine learning technologies has proven to be very promising for environmental monitoring, but their application with ecological assessment frameworks is still limited. It has been recently highlighted that ecological, spatial, environmental and socio-economic approaches are needed to assess and evaluate urban ecosystem services, and that these approaches should be multidimensional and based on indicators. [5]

Also, recent developments in Artificial Intelligence (AI), Internet of Things (IoT), digital agriculture and Smart Environmental monitoring further illustrate the broadening scope of data-based decision support systems for handling ecosystems. The agriculture and livestock monitoring systems based on AI were examples of how a smart sensing, spatial analysis, and automated decision-making tool can have a profound impact on resource monitoring and environmental sustainability. The application of the same technology principles can be adapted to urban biodiversity assessment by combining ecological observations with GIS, remote sensing, environmental sensors and predictive analytics, to aid in evidence-based urban planning and biodiversity conservation. [3], [4]

In light of the aforementioned research challenges, the present paper introduces a holistic approach on the evaluation of animal communities' urban ecosystem services in metropolitan regions. The framework proposed combines the indicators of biodiversity, ecological monitoring, spatial analysis, environmental quality assessment, GIS, remote sensing, artificial intelligence and multi-criteria

decision analysis in a single approach for evaluation of the ecosystem services. The proposed framework serves to assess all four ecosystem services (provisioning, regulating, supporting and cultural) simultaneously, while also incorporating ecological resilience, habitat quality, socio-economic considerations and sustainability indicators, unlike traditional assessment methods which were only concentrating on one or two ecosystem services. This integration facilitates more precise, scaleable and adaptive evaluations of ecosystem services that can contribute to the conservation of urban biodiversity and sustainable urban planning.

The main purposes of this study are to investigate the ecological functions of the animal community of urban areas, to identify and categorize ecosystem services provided by this community, to review existing assessment methods, and the development of an integrated assessment method for the urban environment. In addition, the research should aim to define suitable indicators of ecological, environmental, economic and social performance that enable the comparison of performance across different urban regions and assist in the evidence-based environmental policy and sustainable urban management. The four major contributions are contained in this paper. It provides an integrating overview of the ecosystems services that a variety of urban animal communities provide within a metropolitan ecosystem. Second, it critically reviews on-going methodologies to assess ecosystem services and pinpoints their key conceptual and methodological shortcomings. Third, it suggests an integrated framework of AI-based systems that include ecosystem service assessment based on remote sensing, geographic information system (GIS), ecological indicators and intelligent decision support techniques with the monitoring of biodiversity. Last but not least, the paper offers recommendations for urban planners, policy makers, environmental managers and conservation practitioners on how to enhance biodiversity conservation, climate protection and sustainable urban ecosystem management through scientifically-informed decision-making. Together, these contributions contribute to the existing knowledge of urban ecosystem services, and to the incorporation of biodiversity conservation into future urban planning and sustainable city development.

II. Review of Recent Trends

The study of urban ecosystem services is a new field, and has moved away from an exclusive focus on plant services to include ecosystem service provision by a wide diversity of animal groups, including birds, pollinators, mammals, amphibians, reptiles and soil organisms. The presence of urban biodiversity has become an essential part of sustainable urban development in the metropolitan area as it contributes to the resilience of ecosystems and offers many ecological and socio-economic benefits. The biodiversity and the ecosystem services are well known to be interconnected and several comprehensive review studies have shown that animal communities contribute to the ecosystem stability and/or to the functionality of the habitat and to the improvement of the environmental quality within the urbanized context. Additionally, the importance of wildlife interaction and how it can impact ecosystem performance and benefit human health in the context of urban Green and Blue Infrastructure ecosystem services has been gaining focus. [6], [7]

One key development in recent literature is the shift from an approach based on the evaluation of a single service to the development of integrated approaches for the assessment of ecosystem services. Previous research mostly centered on one aspect of an ecosystem function, the pollination, pest control or biodiversity conservation. However, in more recent research provisioning, regulating, supporting, and cultural ecosystem services are being considered together, to improve the understanding of the cumulative ecological services provided by urban animal communities. Multidimensional performance indicators, which integrate the indicators of biodiversity, habitat quality, environmental health, socio-economic benefits and ecosystem resilience into a single framework are increasingly used in research. Recently, integrated ecosystem service assessment is also gaining importance in urban metabolism studies, which helps to gain insight into the intricate relationships between ecological processes, resource use and sustainable urban development. [11]

Another trend has emerged in the ecosystem service research, which is technological advancement. Advanced spatial tools, such as Geographic Information Systems (GIS), remote sensing, unmanned aerial vehicles (UAVs), Internet of Things (IoT) sensors, environmental monitoring networks and high-resolution spatial datasets are increasingly being used to measure ecosystem services across the entire metropolitan area. AI and machine learning algorithms are now being used for automated species identification, predicting biodiversity, assessing habitat suitability, ecological modelling, and mapping ecosystem services. These smart technologies have a major positive impact on the accuracy, scalability and efficiency of environmental monitoring, and help solve the constraints of traditional ecological surveys conducted in the field. Digital technologies also help to continuously monitor the environment and aid adaptive management of the urban ecosystem by conducting ecological assessments in real time. [10], [11]

The second emerging research direction is the understanding on the spatial distribution and interactions of multiple ecosystem services in terms of urban green space. Recent studies rather than evaluating ecosystem services separately, are studying the interplay of services for recreation, aesthetics, the environment and culture under various landscape configurations. Parks, urban forests, wetlands, green corridors and biodiversity rich habitats are vitally important for a variety of ecosystem services that enhance environmental quality and human well-being and have been identified through spatial analyses. The need to integrate landscape design to provide the greatest ecological function while at the same time catering for the accessibility and recreational values of the urban population is becoming increasingly highlighted. [8]

An increased focus has been on the cultural and health values created by urban biodiversity as well. Research has demonstrated that urban parks with a variety of plant and animal life can improve psychological restoration, reduce stress, encourage physical activity and enhance public health. Observations of wildlife, bird watching and recreational activities, and contacts with biodiverse green spaces enhance residents' emotional health and increase environmental awareness and engagement. Empirical studies in recent years also emphasize the direct link between landscape composition, habitat diversity and ecological quality and the restorative power of urban landscapes, further confirming the need for the conservation of biodiversity in urban planning. [9]

More recent studies have also focused on the effects of developments, climate change and fragmentation on wildlife in metropolitan regions. Climatic change, urbanization and landscape alteration are increasingly impacting the diversity of mammals, birds and other animals, which are driving changes in ecosystem service delivery. The study suggests the need for incorporating policy measures for biodiversity conservation into urban planning for ensuring ecological resilience in the context of future environmental changes. Nature-based solutions, green infrastructure development, ecological corridors and the restoration of habitats therefore increasingly come to the fore as sustainable solutions to meet the needs of urban wildlife, and to improve the provision of ecosystem services. [6], [10]

Despite these huge strides, there are still some issues to be addressed in research. Current research still utilizes a variety of evaluation approaches, which makes it difficult to compare results between metros. Long-term biodiversity monitoring datasets are still scarce and there is a lack of a common set of ecosystem service indicators. In addition, ecological, environmental, socio-economic and technological data is typically analysed separately from each other and not under a single decision support framework. In recent years, however, the need is growing for developing smart, multi-disciplinary, AI-powered models of assessing ecosystem services that combine all the dimensions of biodiversity monitoring, spatial analysis, environmental sensing, and assessment of ecosystem values. These broad-ranging approaches are hoped to enhance the management of urban ecosystems, assist in evidence-based policy decisions, and foster sustainable ecosystem services for future metropolitan areas that will be resilient with a rich diversity of ecosystems. [7], [11].

Research Focus	**Methodology**	**Key Findings**	**Research Gap**
Biodiversity–ecosystem functioning relationships in urban environments, S. R. Weiskopf, S. B. Lerman, F. Isbell, T. L. Morelli, et al. (2024)	Systematic review of 70 published studies assessing biodiversity and ecosystem functioning	Biodiversity generally enhances urban ecosystem functioning, particularly pollination, nutrient cycling, and ecological resilience. Positive relationships were stronger for regulating ecosystem services.	Limited evidence for developing predictive models across diverse metropolitan ecosystems and insufficient long-term datasets.
Effects of urbanization on animal assemblages and ecosystem functions, B. L. Gilby, A. D. Olds, C. J, Henderson, et al. (2024)	Multi-ecosystem field observations with ecological statistical analysis	Urbanization significantly reduced animal diversity and weakened ecosystem functions, particularly in fragmented landscapes, emphasizing habitat connectivity.	Does not integrate ecosystem service valuation with AI-enabled urban biodiversity monitoring.
Animal-mediated ecosystem services in urban environments, T. M. Swartz, A. R.	Ecological field experiments evaluating wildlife behavior and	Ecosystem services provided by common urban animals depend strongly on habitat quality, ecological context, and	Lacks a comprehensive framework for assessing multiple ecosystem

Blaney, J. E. Behm, et al. (2024)	ecosystem service delivery	species interactions rather than species abundance alone.	services across metropolitan regions.
Urban biodiversity and human health, C. Wu, J. O'Keefe, Y. Ding, and W. C. Sullivan (2024)	Systematic review of recent empirical studies	Species-rich urban green spaces improve psychological well-being, physical health, and environmental perception while supporting biodiversity conservation.	Primarily focuses on health outcomes without evaluating broader ecological and regulating ecosystem services.
Monitoring ecosystem service potential in metropolitan regions, A. Hysa, R. Löwe, and J. Geist (2024)	GIS-based land-use analysis combined with ecosystem service modelling	Ecosystem service potential has declined across European metropolitan areas because of urban expansion and land-use change, highlighting the importance of continuous monitoring.	Focuses on landscape-scale ecosystem services without explicitly incorporating animal community contributions.
Ecosystem services provided by urban rivers, M. C. Sousa, R. Martins, N. E. Simões, M. J. Feio, et al. (2025)	Comprehensive systematic literature review	Urban rivers provide multiple provisioning, regulating, cultural, and supporting ecosystem services while enhancing biodiversity and climate resilience. Integrated assessment methods are essential for sustainable urban water management.	Limited integration of terrestrial animal communities and intelligent decision-support systems for metropolitan ecosystem service assessment.

Table 1. Summary of Recent Research on Urban Ecosystem Services and Animal Communities

The recent literature in table 1 shows that there is a trend from the conventional biodiversity assessment to integrated ecosystem service evaluation from the ecological, environmental and socio-economic aspects. New research focuses on biodiversity conservation and protection, spatial ecosystem service mapping, connectivity of habitats, urban ecosystem functioning and on human well-being. Most of the current studies, however, explore particular ecosystem services, a single taxonomic group, or a single urban habitat. Only a few studies provide a comprehensive framework which combines ecosystem services provided by the various animal communities in cities and applying cutting edge technologies like GIS, remote sensing, AI and decision supporting analytics. This research gap calls for the creation of an integrated assessment framework that can fully and comprehensively calculate urban ecosystem services and facilitate sustainable metropolitan planning and biodiversity protection.

III. Urban Animal Communities and Ecosystem Service Framework

Urban animal communities consist of a varied mix of vertebrates and invertebrates that live in urban areas and play an important role in the functioning of the ecosystem. They have been living in different levels of urbanization throughout parks and urban forests, wetlands, residential areas, roadside vegetation, rivers and abandoned lands. The urban fauna can be divided into functional groups, based on their ecological functions. Pollinators, such as bees, butterflies, hoverflies and some beetles, help plants to reproduce and contribute to urban floral diversity. Seed dispersers like birds, bats and small mammals help regenerate vegetation and connect habitat patches by carrying seeds over patches of fragmented land. Predatory species, such as insectivorous birds, bats, spiders, reptiles and beneficial insects control the numbers of pests and limit the need for chemical pesticides. Earthworms, soil fauna (associated with fungi), ants and microorganisms are among the decomposer organisms that speed up the process of nutrient recycling and enhance soil fertility. Amphibians, fish, aquatic insects and crustaceans are aquatic life forms that assist in the purification and stabilization of urban water bodies, such as rivers, lakes and wetlands. Moreover, small mammals and others small vertebrates like squirrels, hedgehogs, foxes and others play a vital role in maintaining the ecological balance and are good indicators of habitat quality. Functional classification allows evaluations of the ecosystem services based on ecological function, not taxonomic diversity, thus giving a more complete picture of how an ecosystem functions in urban areas.

The biodiversity patterns in metropolitan landscapes are very variable in terms of land use, the connectivity and dispersion of habitats, environmental quality, and the level of urban

development. Generally, peri-urban forests, river banks, wetlands, ecological corridors, public parks and other green spaces in urban areas have greater species richness than commercial and industrial built-up areas. Traffic and ongoing urban development may fragment wildlife populations and the genetic diversity and ecosystem resilience of the species. However, properly designed green infrastructure (GI) can help to restore habitat connectivity by enabling movement between habitat fragments. Other species are different as well, depending on the environment. The advent of intensive urbanization can lead to the loss of native species, and the increase of dominance of highly adaptable and/or generalist species. Seasonal migration also impacts urban biodiversity, particularly in terms of birds, pollinating insects and bats. There are also other factors that influence community composition at a regional scale, such as climate change, invasive species, pollution and disturbance by humans. This means that monitoring of biodiversity needs to be dynamic over space, and reflect changes in the abundance of species, in the quality of habitats and in ecological interactions over time. These biodiversity patterns have guided insight into the services provided by animal communities in the city and their proper assessment.

Urban animal communities provide all four major types of ecosystem services, as per internationally agreed upon ecosystem assessment frameworks. The services provided are direct material services, such as the pollination that benefits urban agriculture, production of honey, fisheries in urban water bodies and genetic resources for ecological restoration and scientific research. One of the most important contributions of urban fauna is the regulating of the services. Pollinating insects aid in the reproduction of plants and birds, bats, spiders and predatory insects help keep agricultural and household pests in check. Soil organisms aid in decomposition, nutrient cycling and carbon sequestration. Urban biodiversity enhances the resilience of ecosystems to climate change disturbances, wetlands help purify the water and improve the quality of life for people. Supporting services are those services that help keep the ecological processes that are required for long-term ecosystem sustainability in place. They are services such as habitat formation, nutrient recycling, maintenance of food web, seed dispersal, soil formation and biodiversity conservation etc. Indirectly supporting services improves the provisioning and regulating ecosystem services. Cultural services include recreational, education, aesthetic and psychological services. Urban wildlife fosters ecotourism, birding, environmental education, scientific research and community involvement in the conservation of biodiversity. Biodiversity in urban areas has also been linked to a reduction of stress, better mental health, higher levels of physical activity and better quality of life. All of these ecosystem services have a significant contribution to sustainable urban development and human well-being.

Urban ecosystems are a dynamic process involving animal communities, vegetation, environmental conditions and human activities. Pollinators are especially critical in facilitating reproduction of plants, and flowering plants provide food resources and habitat for pollinators. Fragmented landscapes can be enriched with vegetation diversity and ecological connectivity via seed dispersers, which help transport seeds. Predator-prey relationships provide biological pest control and help control the populations of mosquitoes, agricultural pests and invasive insects. Decomposer organisms decompose the organic wastes, make nutrients available and promote good soil productivity. Aquatic species help to control nutrient distribution and water quality in urban wetlands and river systems. These interactions are also shaped by and presented with opportunities for human activities. Urban green infrastructure (UGI) such as green roof, urban forest, wetlands, bioswales, ecological corridors and roadside vegetation, offers habitats that boost biodiversity. On the other hand, the fragmentation of habitats, pollution, noise, artificial lighting, traffic and climate change interfere with the movements, breeding patterns and functioning of the ecosystem of species. Thus, sustainable maintenance of ecological interactions involves multidimensional planning in urban landscape, which involves conservation of habitats, landscape connectivity and minimisation of anthropogenic disturbances.

A variety of methods have been developed to estimate urban ecosystem services, focusing on various ecological, environmental, economic and social aspects. The assessment of ecological conditions is mainly based on species richness, abundance indicators, Shannon diversity, Simpson diversity and habitat quality indicators. In situ surveys, which are time consuming, expensive and need expertise, are still the most common method of wildlife monitoring. Spatial assessment methods are becoming more common and are increasingly based on Geographic Information Systems (GIS), remote sensing, drone imagery, and land-use mapping to gain insight into habitat distribution and cover, landscape connectivity, and the potential of ecosystem services. There are four types of economic valuation techniques: those based on market valuation, replacement cost analysis, contingent valuation, and willingness-to-pay. More recently, AI, machine learning, ecological modelling, environmental sensors and citizen science platforms have been used to further improve monitoring of biodiversity, through automated species identification, habitat classification, and predictive ecosystem service analysis.

Though significant progress has been made, there are a number of weaknesses. Most assessment frameworks focus mainly on the vegetation and tend to overlook the contribution of urban animal communities to the ecological values. Current approaches tend to isolate single services of the ecosystem from one another and do not reflect the cumulative interaction of services. There are little long-term data on biodiversity, which makes it difficult to monitor temporal ecological changes. In addition, there are no common indicators available to facilitate the comparison of metropolitan areas. Most of the existing frameworks also do not account for the application of ecological monitoring, environmental sensing, socio-economic valuation, GIS, remote sensing, and AI in an integrated assessment framework. Comprehensive assessment frameworks are needed to address these limitations which will help to support sustainable metropolitan planning and urban biodiversity conservation, but this can only be achieved by considering biodiversity, ecosystem functioning, environmental and human well being within a multi-disciplinary evaluation framework..

IV. Ecosystem Services Delivered by Urban Animal Communities

Urban animal communities perform a number of provisioning ecosystem services which are directly beneficial to human livelihoods and the sustainability of cities. Provisioning services are not as visible in urban ecosystems as in rural, but are still significant for urban agriculture, community gardens and peri-urban farming and ecological resource management. Pollination in most fruits, vegetables, medicinal plants, and ornamental species is improved by pollinating insects (honeybees, bumblebees, butterflies and hoverflies) which increase fruit production by increasing the efficiency of pollination. Lakes, reservoirs and managed wetlands include urban fisheries and aquatic organisms that produce food; good insects that promote biological resource conservation and genetic diversity. Animal communities are also a valuable biological resource for scientific research, environmental education and ecological restoration. There is a need for native species for genetic contributions to biodiversity conservation programmes and ecosystem rehabilitation. Urban wildlife also helps in the beekeeping, production of honey and other bee products, and sustainable urban farming. These provisioning services enhance food security, foster ecological resilience and sustainable use of resources in metropolitan areas. The provisioning service by animal communities will become more important as urban agriculture and urban green infrastructure become more common in cities.

The most important ecosystem services provided by animal communities in cities are regulating services. These services contribute to the maintenance of environmental quality and the ecological stability and resistance to anthropogenic disturbances. Pollination is one of the most beneficial regulating services. Flowering plants reproduce by transferring pollen from one flower to another through bees, butterflies, moths, flies, beetles, birds and bats. It helps to support urban forests, public parks, green roofs, and community gardens, roadside vegetation, peri-urban agriculture. Pollination increases plant productivity, biodiversity and carbon sequestration by helping to grow healthy vegetation.

Another important ecosystem service is natural control of pests. Insectivorous birds, bats, spiders, dragonflies, ladybird beetles, lacewings and parasitic insects help to keep populations of mosquitoes, aphids, caterpillars, termites and many other agricultural pests in check. Biological pest control also decreases the reliance on chemical pesticides, decreases pollution of the environment, and increases healthy urban ecosystems. There are also indirect benefits for air quality of urban animal communities. Pollinator populations and seed dispersers are crucial for achieving the growth of vegetation, which boosts urban green cover and its ability to trap airborne pollutants, sequester carbon dioxide, and reduce urban heat islands. Amphibians, aquatic insects, mollusks and microorganisms help to enhance water quality by helping to recycle nutrients, break down organic matter, and filter water in urban wetlands, lakes and rivers. These regulating services working on the same direction, enhance the resilience of the ecosystem and at the same time increase the environmental sustainability and the well-being of people.

The support ecosystem services are the ecological basis that underlies all the other ecosystem services. Urban animal communities are constantly contributing to the functioning of an ecosystem by cycling nutrients, maintaining habitat, conserving biodiversity, stabilizing food webs, and maintaining their ecosystems. Soil organisms, including earthworms, ants, termites, beetles, nematodes and microorganisms break down organic wastes, speed the release of nutrients and enhance soil structure. These processes increase water permeability, soil health, microbial activity and carbon storage, and promote healthy vegetation growth. The decomposer communities also help recycle organic matter produced from urban parks, gardens and green spaces, which helps to minimize waste and boost the productivity of ecosystems. Animal communities also provide habitat through seed dispersal, control vegetation and help to support ecological succession. Seeds are spread by birds, bats, squirrels and small mammals and can establish new populations at great distances which leads to

natural regeneration of areas that were fragmented and can contribute to plant diversity. Pollinators help to maintain the population of flowering plants, and predator-prey relationships help to maintain a balanced food web. Habitat maintenance also enhances ecological connectivity between urban forests, wetlands, river corridors and 'green infrastructure', enabling the movement of species across the fragmented urban landscape. Therefore, supporting services are crucial to maintaining biodiversity, ecological resilience and long-term sustainability of urban ecosystems.

The urban animal community contributes to significant cultural ecosystem services to enhance social wellbeing, environmental awareness and quality of life. Parks, botanical gardens, wetlands, lakes and urban forests can greatly benefit the local aesthetic and provide nice recreational areas for the people of the city by providing wildlife. There are more and more activities that encourage people to appreciate the biodiversity, such as birdwatching, butterfly gardens, nature walks, urban wildlife photography and ecological tourism activities. The diversity of animals also greatly enhances environmental education and scientific learning. Urban wildlife is often used in educational programs in schools, universities, botanical gardens and zoological parks to educate audiences about ecology, citizen science, monitoring biodiversity, and raising awareness about conservation. Community involvement with wildlife observation programs helps to foster environmental stewardship and to create scientific data about the ecology. Another important cultural service is psychological restoration. Green spaces, where biodiversity and interaction with the natural world can be experienced, can decrease stress, anxiety and mental fatigue, and promote physical activity and outdoor recreation. Many studies have shown that listening to birdsong, butterflies, natural scenery, and a variety of animals and animal sounds can enhance emotional health, cognition and life satisfaction. A healthy city is therefore defined as a city that supports biodiversity, which, in turn, helps to make a city healthier and more liveable and socially sustainable.

The benefits of urban animal communities to ecosystem services are significant and more often than not, can be done without technologically expensive interventions. Pollination boosts the output of urban food gardens, rooftop growing, community gardens and horticulture businesses. By using natural pest control practices, pesticide spending can be minimized, the environment can be kept cleaner without contamination, and non-target species are not harmed. Better water quality reduces treatment costs, while well vegetated and pollinator and seed disperser supported properties help increase property values, tourism and recreational revenue. Conservation of biodiversity also creates jobs in environmental consulting, ecological restoration, landscape management, wildlife conservation, ecotourism, environmental education and smart city planning. Biodiversity-investment in infrastructure can lead to sustainable economic benefits, such as reducing disaster mitigation costs, including flood, heat wave, and environmental degradation, and increasing ecosystem resilience. Indirectly, urban animal communities have beneficial impacts on human health via cleaner environments, natural biological control of disease vectors, better air and water quality, and healthier urban plant life. Healthy green areas promote walking, lower stress, help heart health and social cohesion of people living in these areas. Furthermore, urban nature contact has been linked to the reduction in anxiety, depression, obesity and lifestyle-related diseases. These ecological advantages and health benefits all help to lower costs for health care and benefits the community.

V. Assessment Methodologies and Performance Indicators

Indicators of ecology and biodiversity are essential to measure ecosystem services that urban animals provide. These examples include indicators such as species richness, species abundance, diversity indices (Shannon and Simpson), functional diversity, quality of habitat, abundance of pollinators, predators, or decomposers, etc. Other indicators of ecosystem health and resilience include habitat connectivity, breeding success, migration patterns, and the presence of invasive species. These indicators are very useful to understand biodiversity conservation, ecological stability, and the ability of urban ecosystems to provide sustainable ecosystem services.

The use of Geographic Information Systems (GIS) and remote sensing technologies allows the assessment at a large scale of urban biodiversity and ecosystem services. GIS combines land-use mapping, green cover, ecological corridors, wetlands and wildlife habitats to determine biodiversity hotspots and habitat fragmentation. Satellite remote sensing, drone, and multispectral sensor data is used to monitor vegetation health, land surface temperature, and urbanization on an ongoing basis. These, in conjunction with artificial intelligence and machine learning, enhance habitat suitability analysis, species distribution mapping and ecosystem service prediction for metropolitan planning. Environmental quality metrics measure the contribution of animal communities in urban areas towards ecological sustainability. Air quality monitors measure particulate matter, carbon dioxide and pollutants, and water quality monitors measure dissolved oxygen, pH, nutrient content and biological contaminants. The three main ways to

determine soil quality are organic carbon, nutrient availability, and microbial activity.The three main ways to determine soil quality are organic carbon, nutrient availability and microbial activity. There are other metrics, like habitat fragmentation, ecological connectivity, noise pollution and urban heat island intensity, that give a full picture on environmental conditions that impact biodiversity.

Socio-economic assessment quantifies the social and economic benefits produced by the ecosystem services. These methods include market valuation, replacement cost analysis, willingness-to-pay surveys, cost benefit analysis and stakeholder questionnaires. These approaches consider recreational value, public perception, environmental awareness, tourism, urban agriculture and community participation, contributing to a sustainable formulating of policies and urban biodiversity management. Multi-Criteria Decision Analysis (MCDA) is a method that combines ecological, environmental, economic and social indicators in an integrated decision support system. The Analytic Hierarchy Process (AHP), TOPSIS and fuzzy decision models prioritize ecosystem services by using a number of performance criteria. The combination of MCDA, GIS, remote sensing and AI improves the valuation of ecosystem services, facilitates adaptive management and can inform evidence-based planning for urban areas to protect biodiversity and enable sustainable metropolitan development.

VI. Proposed Integrated Framework for Urban Ecosystem Service Assessment

Proposed Integrated Framework for Urban Ecosystem Service Assessment is designed to offer a comprehensive and intelligent approach to assess ecosystem services provided by urban animal communities in metropolitan regions. The proposed approach will combine ecological, environmental, spatial, socio-economic and technological aspects in a single decision support platform, instead of the conventional approaches that focus mainly on vegetation or single ecosystem aspects. The framework aims to continuously track urban biodiversity; provide a quantitative assessment of provisioning, regulating and supporting ecosystem services; identify ecological hotspots; forecast prospects of biodiversity change and enable evidence-based urban planning. The framework integrates ecological monitoring with the use of artificial intelligence (AI), Geographic Information Systems (GIS), remote sensing, and environmental sensing technologies to facilitate adaptive management for sustainable urban development and conservation of biodiversity.

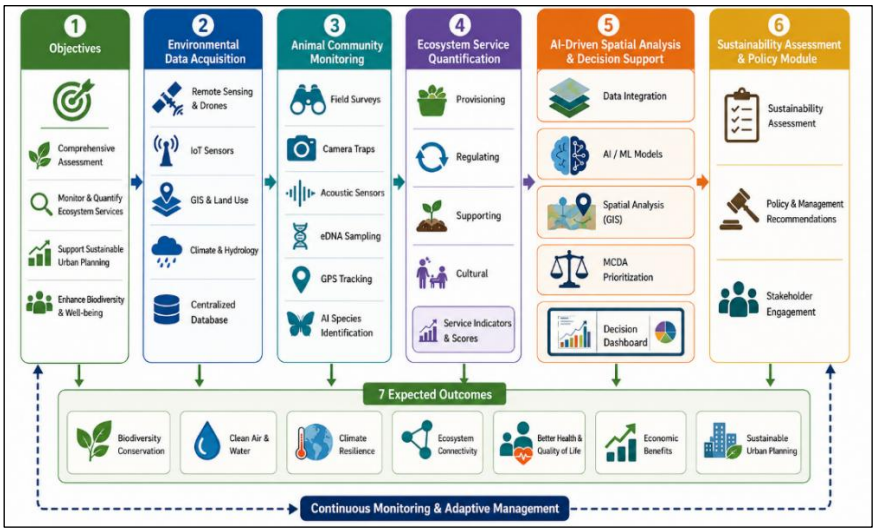


Figure 1. Proposed Integrated Model for Urban Ecosystem Service Assessment

The proposed integrated framework for ecosystem services assessment of urban animal communities in metropolitan regions is depicted in Figure 1, and includes an AI component. The process starts with data collection on the environment and biodiversity through GIS, remote sensing, IoT sensors, and field observations, with subsequent monitoring of urban animal communities on an ongoing basis. Data gathered is used to estimate the provisioning, regulating, supporting and cultural ecosystem services. A spatial analysis and decision-support layer using AI is developed, leveraging the combination of biodiversity, environmental and socio-economic data, which allows identifying ecological hotspots, assess the ecosystem performance and prioritize conservation actions. Finally, the sustainability assessment module provides policy recommendations to enhance biodiversity protection, climate change resilience and evidence-based urban planning. The "continuous feedback mechanism" supports adaptive management of the ecosystem, and the

framework is applicable to sustainable and resilient development in the metropolitan region.

The first layer collects in-depth environmental and spatial information from various urban sources. Satellite images, drone surveys, GIS databases, environmental sensors (IoT), weather stations, air quality monitoring, and water quality monitoring, along with land-use records are all sources for data. Data across a variety of ecosystems, such as urban parks, wetlands, rivers, forests, residential landscapes and green infrastructure, are gathered and added to a single repository. Other data sets consist of vegetation cover, habitat distribution, climate parameters, pollution, traffic level, and population density. This multi-source data acquisition layer is the environmental basis for assessing ecosystem services accurately.

Monitoring layer that is constantly monitoring urban animal communities through field surveys, camera traps, acoustic sensors, citizen science platforms, GPS tracking, automated image recognition, and biodiversity databases. The framework documents species richness, abundance, functional diversity, pollinator activity, predator numbers, migration, breeding success, use of habitats, and conservation status. Manual species identification and manual biodiversity monitoring are time-consuming processes and can be inaccurate when relying on human identification.Manual species identification and manual biodiversity monitoring are time consuming processes and can be inaccurate if relying on human identification. The continuous monitoring allows for early detection of loss of biodiversity, invasive species, habitat degradation and ecological disturbances that impact the delivery of ecosystem services.

This layer allows transforming biodiversity observations into measurable ecosystem services indicators. Pollination efficiency and productivity in urban farming are used to quantify provisioning services. Pest suppression capacity, carbon sequestration, air purification, water purification and climate regulation are used as indicators to evaluate regulating services. Nutrient cycling, soil fertility, habitat connectivity, ecological resilience, and biodiversity maintenance are deemed as supporting services, whereas recreation, tourism, environmental education, and psychological well-being indicators are viewed as cultural services. The ecological and socio-economic indicators are standardized and combined to yield complete scores of ecosystem services performed by a variety of metropolitan regions.

The key element of the proposed framework is artificial intelligence used as the analytical nucleus. GIS and remote sensing data are used to capture the patterns of biodiversity, the suitability of habitats, land use, environmental quality, and interactions with ecosystem services, which are then analyzed using machine learning algorithms. Spatial prediction models predict biodiversity hotspots, ecological corridors, fragmented habitats and conservation intervention areas. The Multi-Criteria Decision Analysis (MCDA) takes into account ecological, environmental and socio-economic indicators and prioritizes ecosystem services. Predictive analytics also foresee future shifts in biodiversity in different urban development and climate scenarios, allowing for proactive management and intelligent decision-making for ecosystems.

The sustainability module assesses the overall ecosystem performance by combining the ecological health, environmental quality, biodiversity conservation, climate resilience, economic benefits and public well being into a sustainability index. Comparative evaluations highlight strengths as well as weaknesses and ecological priorities of the various metro areas. The framework makes recommendations for policy on green infrastructure development, habitat restoration, ecological corridors, urban forestry, wetland conservation, pollinator protection, and biodiversity-friendly urban design based on these evaluations. Decision-support dashboards help planners, policy makers, and environmental managers make optimal decisions on conservation strategies based on science.

The proposed framework will greatly enhance sustainable metropolitan planning, ecosystem resilience and biodiversity conservation. The monitoring of ecological processes on an ongoing basis improves the knowledge of ecosystem services dynamics and allows for early detection of degradation of ecosystems. Spatial analysis with AI helps optimize conservation resources, safeguard biodiversity hotspots and enhance the efficiency of green infrastructure networks. The framework also fosters climate adaptation, air and water quality, ecological connectivity, and greater ecosystem resiliency to pressures of urbanization. The framework has been scientifically sound and robust from an urban planning point of view, offering reliable scientific evidence to incorporate the conservation of biodiversity into land use planning, infrastructure planning and smart city initiatives. Performance indicators are tools that policymakers can use for sustainable investments, assessing environmental policies, and encouraging NbS. In the end, the proposed integrated framework provides a scalable, intelligent and data-driven platform that enables resilient, Biodiverse and environmentally sustainable metropolitan regions, enhances human well-being and long-term ecological sustainability in cities.

VII. Comparative Analysis, Challenges, and Future Directions

This section assesses the proposed framework through a comparative analysis of how well the different urban ecosystems perform ecosystem services as well as by identifying the major challenges to urban biodiversity conservation for representative metropolitan areas. An analysis of the various cities shows that those with a well-developed and interconnected green infrastructure, high biodiversity, and advanced environmental monitoring have better ecosystem service delivery. The proposed framework consists of a spatial analysis coupled with a decision support mechanism and a biodiversity assessment all powered by AI to better assess and quantify ecosystem services and enable sustainable urban planning.

Metropolitan Region	Biodiversity Index	Pollination Efficiency (%)	Air & Water Quality	Climate Resilience	Overall Sustainability Score
Region A	91	89	90	88	90
Region B	84	82	80	81	82
Region C	78	76	74	75	76
Region D	69	67	65	68	67
Region E	62	60	58	61	60

Table 2. Comparative Assessment of Urban Ecosystem Services

Table 2 presents the comparison of ecosystem service performance indicators in representative metropolitan areas and scores are normalized (0–100). Overall, larger green infrastructure networks tend to correlate with a greater degree of biodiversity conservation, pollination efficiency, environmental quality, and climate resilience, in cities.

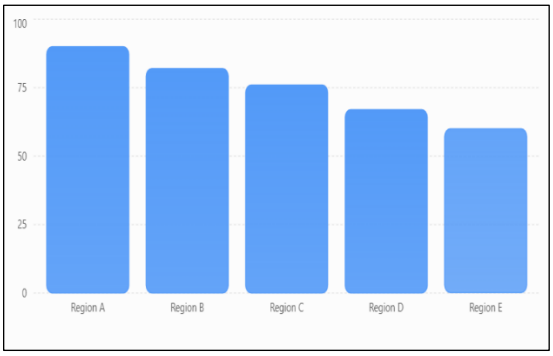


Figure 2. Sustainability Performance Analysis Across Metropolitan Regions

Figure 2 indicates that metropolitan regions with stronger biodiversity conservation and integrated environmental management achieve significantly higher ecosystem service performance.

Ecosystem Service	Performance Score (%)
Provisioning Services	81
Regulating Services	93
Supporting Services	90
Cultural Services	87
Overall Ecosystem Performance	88

Table 3. Ecosystem Service Performance Evaluation

Table 3 indicates that five major ecosystem service indicators were used to evaluate the proposed framework. The performance was the highest for regulating services, attributed to the facilitation of pollination, biological pest control and regulation of the environment, while provisioning services were given relatively low scores, due to the small capacities of urban ecosystems in terms of resource production.

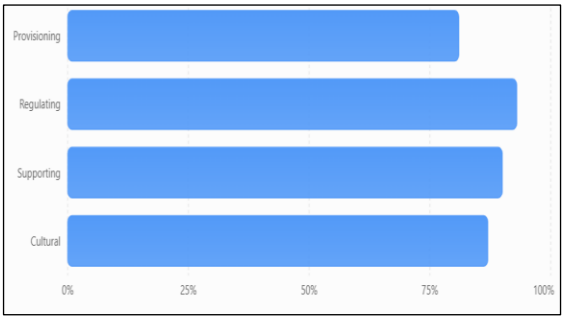


Figure 3. Performance of Urban Ecosystem Services

With the integration of the AI-assisted decision support tool, Figure 3 illustrates that biodiversity monitoring can enhance the assessment of ecosystem services to yield a comprehensive picture of ecological performance.

Even with significant advances in technology, there remain several challenges to effective assessment of ecosystem services and conservation of biodiversity. Some of the key challenges are the high rate of urbanisation, habitat fragmentation, climate change, pollution, invasive species, lack of long-term biodiversity data, and lack of consistency in monitoring techniques, as well as the lack of integration of ecological and socio-economic information. Furthermore, poor governance, weak policy enforcement and weak public involvement hamper conservation efforts. There is a need for integrated ecological monitoring, standardized assessment indicators, AI-based environmental analytics, and enhanced cooperation between governments, researchers and local communities to overcome these challenges.

The results prove that biodiversity protection has to be a part of the metropolitan planning process. The development of city master plans should focus on the integration of green infrastructure, ecological corridors, pollinator habitats, urban wetlands, biodiversity friendly parks and NbSs. Real-time information on the ecological condition through continuous monitoring using GIS, remote sensing, IoT sensors, and AI can be used for adaptive management. Dedicated to enhancing conservation outcomes, policymakers should also encourage citizen science, EE and cross-sector cooperation. Ecosystem service indicators can be incorporated into urban planning policies to make them more climate-resilient and environmentally friendly, and to foster a sustainable smart city.There is need for further research to create robust real-time ecosystem service assessment systems using artificial intelligence, digital twins, IoT sensor networks, remote sensing, and high-resolution approaches to biodiversity monitoring. Machine learning model can enhance species distribution prediction, ecosystem service forecasting, and analysis of habitat suitability. Additionally, long-term climate change, socio-economic and urbanization changes should be incorporated into future studies to assess their impact on ecosystem service delivery. Standardised international assessment protocols, embedding ecosystem service valuation into urban digital twins and scaling-up citizen-science based biodiversity monitoring will further support evidence-based environmental decision-making. These research opportunities will create more resilient, biodiversity-rich, and sustainable metropolitan ecosystems for future urban development and maintaining ecological integrity.

VIII. Conclusion

Urban animal communities include a diverse array of services, particularly provisioning, regulating, supporting, and cultural ecosystem services that are key to maintaining environmental quality and human well-being, but are often overlooked as an important part of metropolitan ecosystem services. The awareness of urban biodiversity conservation has shifted from ecological goal to a necessity in terms of resilient, climate adaptable and sustainable urban development as cities grow. This study reveals the birds, pollinators, bats, soil organisms, amphibians and other urban wildlife that play a role in pollination, biological pest control, nutrient cycling, habitat maintenance, environmental regulation, recreational opportunities and public health can all help to bolster the ecological resilience of metropolitan regions. This paper gave a comprehensive overview of the ecosystem services provided by animal communities in the urban ecosystem, summarises existing assessment methods and highlights some of the main limitations of traditional biodiversity assessment methods. The approach to assessing urban fauna is currently based on a few ecological indicators, static data and vegetation-based analyses that ignore the multi-dimensional role of urban fauna in the environment. To address these drawbacks, this research aimed to develop an integrated framework using AI to bring together ecological monitoring, GIS, remote sensing, Internet of Things (IoT) sensors, biodiversity indicators, machine learning, and multi-criteria decision analysis and provide a unified ecosystem service assessment platform. The framework supports the continuous monitoring of biodiversity, intelligent spatial analysis, quantification of ecosystem services, and evidence-based decision making for sustainable urban management.

The comparative analysis also showed that the ecosystem service performance and ecological resilience of metropolitan regions are consistently high when they have a healthy biodiversity conservation system, a more connected green infrastructure, and more advanced environmental monitoring systems. AI can be combined with spatial information to enhance assessment accuracy, facilitate adaptive ecosystem management and facilitate proactive planning of conservation in rapidly evolving urban settings. The proposed framework is of significance for urban planners, environmental management and policy-makers as it offers a scalable and scientific decision-support tool to integrate the conservation of biodiversity into smart city initiatives, climate adaptation strategies and sustainable land-use planning. It also encourages the use of NbS, ecological corridors, NbI and community engagement as key elements of urban development in the future.

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