Faculty of Forestry and Wood Sciences

Department of Forestry and Wood Economics

Dissertation Thesis

Assessment of the Impact of Climate Change on the Availability of Forest Ecosystem Services: Comparison Between the Czech Republic and Ghana

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A dissertation submitted in partial fulfilment of the requirements for the Doctor of Philosophy Degree in the Faculty of Forestry and Wood Sciences, Department of Forest and Wood Economics of the Czech University of Life Sciences, Prague

SUPERVISOR: Assoc. Prof. Miroslav Hájek, Ph.D.

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

Ph.D. THESIS ASSIGNMENT

Stephen Awuni

Global Change Forestry

Thesis title

Assessment of the impact of Climate Change on Forest Ecosystem Services:

Comparison between the Czech Republic and Ghana.

Objectives of the thesis

The aim is to assess the impact of climate change on forest ecosystem services in the Czech Republic and Ghana, with special emphasis on the socio-economic impact of selected ecosystem services. This will be achieved by comparing the nature of the impact and the similarities and differences in the impact in two different geographical regions. The study will further examine the impacts of land use change on selected ecosystem services, identify management practices, assess policy impacts and propose sustainable management practices in the use of forest ecosystem services.

Methodology

Relevant data from primary and secondary sources for analysis, including public and online data sources, will be collected. Additional data will be used from the government through studies of relevant ministries and agencies. Furthermore, a structured questionnaire will be used. Data from measurements of soil and water quality parameters will be used in order to determine the impact of anthropogenic activities and their possible impact on human well-being in the studied areas. The collected data will be analysed using SPSS, Microsoft Excel and other relevant statistical tools to assess the socio-economic impacts of climate change, compare the impacts of climate change and land use in the Czech Republic and Ghana. The most sustainable practices in the management of ecosystem services will be discussed, and recommendations will be made for the adoption of an appropriate strategy.

The proposed extent of the thesis

At least 100 standard pages

Keywords

Production service, non-market ecosystem services, socio-economic impacts, land use, sustainable management, forest management

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DECLARATION

I affirm that this dissertation is the result of my independent research and represents my original work. I confirm that neither this work nor any portion of it has been submitted for the award of a degree at any other institution. No part of this dissertation may be copied, stored in a retrieval system, or shared in any form, whether electronic, mechanical, photocopied, recorded, or otherwise, without the prior consent of either the author or the Czech University of Life Sciences, Prague. I hereby grant the Czech University of Life Sciences, Prague, the right to reproduce this dissertation in whole or in part, in any format or manner the university deems appropriate.

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ABSTRACT

Forests are critical ecosystems that provide numerous essential services, including medicinal plants and socioeconomic benefits. However, these services are increasingly threatened by climate and land use change, leading to environmental degradation and livelihood challenges. This study assesses perceptions of these changes and their impacts on forest ecosystem services, focusing on medicinal plant availability in two ecologically distinct regions, namely the temperate forests of the Czech Republic and the mangrove forests of Ghana. Using a mixed-methods, perception-based approach, the study applies the same methodological framework across both contexts to illustrate how climate-related and anthropogenic drivers manifest differently. The intention is not a direct empirical comparison of realities between the two countries but rather a methodological demonstration of how perceptions and impacts can be assessed across contrasting ecosystems. In the Czech Republic, respondents largely associated climate stressors and land use practices, such as excessive chemical use, with declines in medicinal plant populations. In Ghana, many perceived climate factors, such as rising temperatures and coastal flooding, as contributing to increased medicinal plant availability. However, land use drivers, including deforestation, illegal mining, excessive agrochemical use, and overexploitation of mangroves, were recognised as significant threats. While forest management and adaptation strategies exist in both study areas, perceptions of their adoption differ. In temperate forests, uptake of some management and adaptation strategies remains limited, reflecting gaps in policy engagement and support for forest owners. In mangrove areas, community-led conservation efforts are more visible but require stronger institutional backing. The findings highlight that climate and land use change impacts on medicinal plant availability are context-specific and shaped by local perceptions. Addressing these challenges will require participatory and knowledge-integrated governance approaches that align ecological science with stakeholder views and values to enhance forest resilience and sustain medicinal plant resources.

Keywords: temperate forests, mangrove forests, medicinal plants, land use change, ecosystem services, forest management, community-based conservation

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LIST OF ABBREVIATIONS AND ACRONYMS

CAWI –	Computer-Assisted Web Interviewing
CSIR –	Council for Scientific and Industrial Research
CZMOA –	Czech Ministry of Agriculture
CZMOE –	Czech Ministry of Environment
FGDs –	Focus Group Discussions
HSG –	High School Graduate
HSNG –	High School Non-Graduate
IBA –	Important Bird and Biodiversity Areas
IPCC –	Intergovernmental Panel on Climate Change
IUCN –	International Union of Conservation of Nature
KIIs –	Key Informant Interviews
MEA –	Millennium Ecosystem Assessment
NGOs –	Non-Governmental Organisation
NWFPs –	Nonwood Forest Products
ODK –	Open Data Kit
REDD+ –	Reducing Emissions from Deforestation and Forest Degradation

1. INTRODUCTION

1.1 Background of the study

Forest ecosystems provide vital ecosystem services, including biodiversity conservation, climate regulation, water cycle maintenance, carbon sequestration, and socioeconomic benefits such as timber, medicinal plants, and cultural heritage (MEA, 2005). However, climate change and land use changes increasingly disrupt these services, leading to environmental degradation and socioeconomic challenges (Lorencová et al., 2013; Bustamante et al., 2018). Understanding how different forest ecosystems respond to climate change is essential for developing sustainable management strategies that safeguard these services.

The effects of climate change on forest ecosystem services vary globally depending on geographic location, forest type, governance systems, and socioeconomic conditions (Lindner et al., 2010; Friess et al., 2022). Temperate and mangrove forests, for example, experience climate-driven impacts on ecosystem services, but the manifestations differ. In the Czech Republic, a developed country, climate-induced stressors such as drought, pest outbreaks, forest fires, and floods have degraded habitats and reduced the availability of non-wood forest products (NWFPs), including medicinal plants (Hlásny et al., 2021). In Ghana, a developing country, climate change drivers such as rising temperatures, floods, and sea level rise threaten mangrove ecosystem services, including medicinal plant provision (Awuni et al., 2023). Land use and land cover changes, including deforestation and agricultural expansion, further exacerbate these pressures and compound climate change effects (Findell et al., 2017).

This study employs a methodological comparison of two case studies in temperate forests in the Czech Republic and mangrove forests in Ghana to assess how climate and land use change influence forest ecosystem services. Medicinal plants were chosen as a focal ecosystem service because of their ecological, cultural, and socioeconomic importance in both regions. The study does not attempt a direct empirical comparison between the two countries. Instead, it applies a unified methodological framework to illustrate how similar drivers manifest differently across contrasting ecosystems. By focusing on public perceptions, the research provides insights into the dynamics of climate and land use change and contributes to the development of management strategies that enhance forest resilience.

1.2 Problem Statement

Although climate change affects all forests, its manifestations vary across different forest types. In the Czech temperate forests, impacts include droughts, pest infestations, and forest fires. Land use change activities, such as excessive chemical use in agriculture and logging, exacerbate these pressures and negatively affect key ecosystem services (Huertas Bernal et al., 2021). Among the most affected are provisioning services such as medicinal plants, which are a key component of NWFPs, and the broader ecological functions that sustain forest health. Although conservation programs exist, gaps remain in achieving sustainable management and enhancing climate resilience (Kjučukov et al., 2022).

In Ghana's mangrove forests, climate and land use change intensify vulnerabilities, leading to declines in ecosystem services (Awuni et al., 2023; Adarkwah et al., 2024). Climate drivers, including rising temperatures, droughts, sea-level rise, and flooding, combined with land use practices such as deforestation, reduce provisioning services such as medicinal plants and biodiversity, undermining livelihoods (Adarkwah et al., 2024).

Existing research tends to examine temperate and mangrove forests separately, with little methodological work that compares how similar drivers are perceived in different contexts.

This study addresses that gap by applying a unified framework, consistent with established mixed-methods design principles (Creswell and Clark, 2017), to assess the perceived effects of climate and land use change on medicinal plants in the Czech Republic and Ghana.

1.3 Justification of the Study

Assessing temperate forests in the Czech Republic and mangrove forests in Ghana provides valuable insights into how different forest ecosystems respond to environmental pressures. Although these forests exist in distinct climatic zones, they both play critical roles in biodiversity conservation and climate regulation (Ahmad et al., 2023), making their study relevant for understanding broader ecological and policy implications.

Temperate and mangrove forests provide a wide range of ecosystem services, some of which are similar, such as wood provision, medicinal resources, wildlife habitats, disaster prevention, carbon sequestration, soil erosion prevention, and recreation. Others are ecosystem-specific, such as salinity regulation and the role of mangroves as fish nursery habitats (MEA, 2005; Choudhary et al., 2024). Climate change and other environmental stressors in both ecosystems increasingly affect key services such as medicinal plants. Mangroves, which themselves have medicinal properties (Baba et al., 2013; Awuku-Sowah et al., 2023), are highly vulnerable to rising temperatures, sea-level rise, coastal erosion, and increased salinity, threatening their long-term viability (Ellison et al., 2015). Conversely, temperate forests are increasingly affected by droughts, pest outbreaks, and wildfires, leading to shifts in species composition and reduced ecosystem stability (Seidl et al., 2017). Land use changes further compound these challenges, altering the capacity of both forest types to provide essential ecosystem services. Studying the effects of these environmental stresses, many of which are driven by climate change, is crucial for understanding how forests sustain environmental and socioeconomic needs.

This research is justified as it enhances understanding of how climate and land use change affect ecosystem services across distinct forest biomes, with a specific focus on medicinal plants. It contributes to evidence-based policy recommendations to strengthen conservation and climate adaptation strategies, with broader implications for global environmental sustainability. By addressing the limited attention given to medicinal plant services in both temperate and mangrove contexts, the study provides a focused perspective on an under-researched but vital component of forest ecosystem services.

1.4 Significance and Contribution of the Study

This study enhances understanding of how climate change and land use change affect medicinal plant ecosystem services in the temperate forests of the Czech Republic and the mangrove forests of Ghana. Examining these distinct ecological and socioeconomic contexts provides insights into medicinal plant vulnerabilities, local adaptation strategies, and the effectiveness of conservation policies.

The research contributes knowledge on how climate stressors and human activities shape the resilience of medicinal plant ecosystem services. Unlike previous studies that consider forest ecosystem services broadly, this study focuses specifically on medicinal plants while integrating socioeconomic perspectives to provide a more holistic understanding. Practically, the findings support forest managers, policymakers, and conservationists in developing strategies to sustain medicinal plant resources across diverse environmental settings.

Beyond its case studies, the research contributes to ecosystem services research by highlighting the often-overlooked role of medicinal plants and their vulnerability to climate and land use change. The findings extend more broadly to understanding environmental drivers of forest ecosystem services and the conservation strategies adopted to sustain them. This study bridges insights from contrasting ecosystems and adds to global discussions on climate resilience and sustainable medicinal plant conservation, ensuring their long-term availability for ecological and socioeconomic benefits.

2. OBJECTIVES AND HYPOTHESES

2.1 Aim and Objectives

This study aims to assess the perceived effects of climate and land use change on forest ecosystem services, with a specific focus on medicinal plant availability, through case studies in temperate forests (Czech Republic) and mangrove forests (Ghana). Specifically, it seeks to:

1. Evaluate how climate change is perceived to affect the availability of medicinal plants in temperate and mangrove forests.
2. Assess how land use activities are perceived to influence medicinal plant availability in both ecosystems.
3. Identify and describe existing forest management strategies that function as adaptation and mitigation measures to address climate and land use pressures.
4. Examine the broader ecosystem services provided by temperate and mangrove forests to assess where medicinal plants rank in importance relative to other services.
5. Develop policy recommendations to enhance the resilience of forest ecosystem services, with tailored strategies for distinct ecological and socioeconomic settings.

2.2 Research Questions (RQ_1, RQ_2)

RQ_1: What management strategies are in place in temperate and mangrove forest ecosystems that serve as adaptation and mitigation measures to address climate and land use change?

RQ_2: What is the relative importance of medicinal plants among the broader ecosystem services provided by temperate and mangrove forests, and how is this perceived by local communities?

Research questions RQ_1 and RQ_2 are addressed through descriptive analyses and are therefore not formulated as testable hypotheses. In contrast, the impacts of climate change and land use change on medicinal plant availability were analysed using logistic regression, and thus hypotheses were formulated (see Section 2.3). This combined approach reflects the mixed-methods design of the study, integrating exploratory and inferential components.

2.3 Research Hypotheses

Null Hypotheses (H_0):

H_{01}: Climate change does not significantly affect the availability of medicinal plants in temperate (Czech Republic) and mangrove (Ghana) forest ecosystems, and the specific climate-related drivers do not differ between the two ecosystems.

H_{02}: Land use change does not significantly influence the availability of medicinal plants in temperate and mangrove forest ecosystems.

Alternative Hypotheses (H_1, H_2)

H_1: Climate change negatively affects the availability of medicinal plants in temperate and mangrove forest ecosystems, with differences in the specific climate-related drivers across the two ecosystems.

H_2: Land use change significantly reduces the availability of medicinal plants in temperate and mangrove forest ecosystems.

3. LITERATURE REVIEW

This literature review examines the effects of climate and land use change on forest ecosystem services in two ecologically distinct forest systems: temperate forests in the Czech Republic and mangrove forests in Ghana. It highlights how these drivers manifest differently across ecosystems, with important implications for medicinal plants as a key ecosystem service. The review considers ecological and socioeconomic impacts, including ecosystem degradation, biodiversity loss, and the availability of NWFPs. It also discusses public perceptions, adaptive management, and policy frameworks that shape forest conservation and the sustainable use of ecosystem services.

3.1 Global Change, Climate Change and Forest Ecosystems

Climate change and global environmental transformations profoundly affect ecosystems, biodiversity, and the services they provide to human societies. As temperatures rise and precipitation patterns shift, natural and human systems must adapt to maintain resilience (IPCC, 2021). Global change refers to large-scale alterations in Earth's systems, primarily driven by anthropogenic activities (Steffen et al., 2015). These transformations include climate change, shifts in land productivity, changes in water resources and atmospheric composition, and disruptions to ecological functions (MEA, 2005; Weiskopf et al., 2020).

Land use change interacts strongly with climate dynamics, influencing albedo, carbon sequestration, and hydrological cycles (Turner et al., 2007; Kleemann et al., 2017). Together, these processes alter the ability of forest ecosystems to deliver essential services such as biodiversity conservation, carbon storage, water regulation, and the provision of NWFPs, including medicinal plants. Understanding the combined effects of climate and land use change is therefore critical for assessing the vulnerability of forest ecosystem services and informing strategies to sustain them. This global perspective provides the basis for examining how climate and land use drivers manifest in specific forest ecosystems, including temperate and mangrove systems.

3.2 Climate Change and Forest Ecosystem Services

3.2.1 Climate Change and Forest Ecosystem Services in the Temperate Forest (Czech Republic)

In Central Europe, temperate forests such as those in the Czech Republic illustrate how climate-linked disturbances affect ecosystem services. Forests are increasingly vulnerable to climate change, with severe droughts, bark beetle infestations, and associated disease outbreaks causing an unprecedented decline in spruce-dominated stands (Cienciala, 2022; Hlásny et al., 2021). These stressors, often compounded by disturbances such as forest fires and floods, reduce ecosystem resilience and stability (Seidl et al., 2017). The consequences extend beyond timber yields, threatening NWFPs, including medicinal plants, which are highly sensitive to ecological stress and habitat degradation.

Climate projections indicate that Central European forests, including those in the Czech Republic, will face heightened risks as precipitation declines and temperatures rise, further accelerating forest degradation (Hlásny et al., 2014). The Report on the Environment of the Czech Republic (CENIA, 2022) noted that 2022 was the fifth warmest year since 1961, with above-average summer temperatures. Combined with erratic precipitation, these conditions triggered climatic, soil, and hydrological droughts across large areas, with river flows dropping below 90% of the long-term average in regions such as South Moravia and Bohemia. Such pressures undermine ecosystem services, including carbon storage, water retention, and soil protection (Seidl et al., 2017). They also compromise the availability of medicinal plants, which rely on stable ecological conditions and are among the most vulnerable NWFPs to climatic variability.

Without proactive adaptation measures, climate change will likely intensify declines in provisioning and regulating ecosystem services in Czech forests. The compounded stressors highlight the urgent need for management strategies that address timber and carbon storage and the conservation of medicinal plants as critical ecosystem services for cultural and health-related needs.

3.2.2 Climate Change and Forest Ecosystem Services in Mangrove Forests (Ghana)

In West Africa, mangrove forests in Ghana highlight the distinct ways climate change affects ecosystem services. Over the past four decades, average national temperatures have increased by about 1°C, with significant socioeconomic and environmental consequences (Klutse et al., 2020). These include reduced agricultural productivity, increased coastal inundation from sea-level rise, and more frequent extreme weather events (Awuni et al., 2023). Such climate-driven changes threaten agricultural systems and forest ecosystem services, underscoring the need for adaptive policies and proactive management strategies.

Forests in Ghana are critical for carbon sequestration, water regulation, and biodiversity conservation. However, their capacity to provide these services is increasingly undermined by rising temperatures, prolonged droughts, and shifting rainfall patterns that disrupt tree growth, regeneration, and species composition. These stressors affect not only timber resources but also NWFPs, particularly medicinal plants, which are integral to rural healthcare and cultural traditions.

Mangrove forests are especially vulnerable to sea-level rise, storm surges, and salinity stress. These pressures diminish their ability to store carbon, support fisheries, and protect coastal communities (Adarkwah et al., 2024). At the same time, they compromise the availability of medicinal plants, which are sensitive to habitat loss, flooding, and salinity. The fragility of mangrove-based medicinal resources places them among the most at-risk ecosystem services in Ghana's coastal regions, where they are indispensable for local livelihoods and health systems. These climate-induced vulnerabilities are further intensified by land use pressures, which are discussed in Section 3.3. The combined impacts highlight the urgency of developing management strategies that safeguard the regulating and provisioning services of mangroves and the medicinal plants that underpin community well-being.

3.3 Land Use Change and Its Impact on Forest Ecosystems

3.3.1 Land Use Change and Ecosystem Services in the Temperate Forests (Czech Republic)

Land use change in the Czech Republic has been driven primarily by industrialisation, timber harvesting, and agricultural expansion. These activities have fragmented forests, altered carbon sequestration and hydrological functions, and reduced biodiversity, thereby weakening ecosystem resilience and the capacity to sustain ecosystem services (Fanta and Petrik, 2018). Intensive forestry practices, such as the conversion of natural forests into monoculture plantations, have increased vulnerability to climate stressors such as drought and bark beetle outbreaks (Hlásny et al., 2021). The Ore Mountains, located along the Czech-German border, illustrate how mining, deforestation, and industrial activities degrade forest landscapes, diminishing the provision of services such as carbon storage, water regulation, and NWFPs, including medicinal plants (Bastian et al., 2017). Although natural regeneration projects and reforestation efforts are underway, their effectiveness remains constrained by the scale of ongoing land use pressures.

The Czech Republic's total forest area covers 2.61 million hectares, with ownership distributed across state (53.8%), municipal (17.2%), and private (19.1%) actors (CZMOA, 2021). Natural reforestation efforts expanded from 5,127 hectares in 2010 to 9,111 hectares in 2021, contributing to biodiversity recovery (CZMOA, 2021). Nevertheless, agricultural expansion and urbanisation continue to reduce forest connectivity, disrupt wildlife corridors, and undermine ecosystem services. Large-scale industrial farming and soil compaction have exacerbated land degradation, while historical land collectivisation has fragmented landscapes and slowed forest recovery (Zumr, 2022).

Beyond forests, land use change has affected broader ecosystems. For example, converting grasslands into agricultural land has reduced carbon sequestration capacity, increased vulnerability to erosion, and diminished pollination services (Hönigová et al., 2012). Urban expansion and infrastructure development, particularly near cities such as Prague and Brno, have also contributed to forest loss, placing additional pressure on ecosystem services (Zumr, 2022). While land use policies and conservation programs such as Natura 2000 and the Czech Forest Act aim to regulate deforestation, enforcement remains inconsistent due to economic trade-offs and competing land use priorities (CEEWeb for Biodiversity, 2019). Unsustainable logging practices further exacerbate soil erosion and reduce water retention capacity, intensifying environmental degradation (EC, 2023).

Land use change also affects NWFPs, including medicinal plants. Studies highlight the cultural, health, and socioeconomic importance of medicinal plants and other NWFPs in Czechia (Sisak et al., 2016; Pawera et al., 2017; Pokladnikova & Selke-Krulichova, 2018; Purwestri et al., 2023b). Fragmentation, habitat loss, and monoculture forestry will likely reduce the availability of such species, with potential consequences for cultural heritage, rural livelihoods, and the sustainable provision of forest ecosystem services. In summary, land use change in Czech forests threatens not only timber production and regulating services but also the availability of medicinal plants, making their conservation essential for ecological resilience and community well-being.

3.3.2 Land Use Change and Ecosystem Services in Mangrove Forests (Ghana)

Deforestation, illegal mining (galamsey), and oil exploration are major drivers of land use change in Ghana, resulting in extensive ecosystem degradation (Owusu et al., 2024; Adom et al., 2024). Urbanisation and agricultural expansion in the Amanzule Wetlands have accelerated mangrove loss, diminishing ecosystem services such as carbon storage, coastal protection, fisheries, and NWFPs like medicinal plants. Modelling projections indicate that this degradation will persist through 2054 if mitigation strategies are not implemented (Adarkwah et al., 2024). Migration into coastal areas has further intensified land use pressures, with the Volta Estuary losing 42.8% of its vegetation and the Ankobra Estuary experiencing a 12.6% decline, primarily due to settlement expansion, sand mining, and mangrove exploitation (Kutir et al., 2022).

Between 1980 and 2010, Ghana lost approximately 24% of its mangrove cover, with some regions experiencing up to 52% loss due to deforestation, settlement expansion, and overexploitation for fuelwood and timber (Ghana et al., 2024). The Volta Estuary and Amanzule Wetlands remain among the most affected areas, where unsustainable resource extraction has severely degraded habitats.

Weak governance, insecure land tenure, and limited enforcement of legal frameworks have facilitated uncontrolled deforestation and allowed economic demand to drive rapid land conversion for agriculture and infrastructure (Feka, 2015). Wetland ecosystems such as the Amanzule Wetlands and associated mangrove forests face increasing threats from pollution, agricultural runoff, and industrial activities, which endanger aquatic biodiversity and ecosystem stability (Adarkwah et al., 2024). Expanding human settlements and weak conservation policies further exacerbate these challenges, underscoring the urgency of effective management strategies (Adupong and Gormey, 2013).

These land use changes undermine the ability of mangrove ecosystems to provide critical services, including NWFPs such as medicinal plants. Overharvesting of mangroves and associated species for household and commercial use reduces the availability of medicinal resources that rural communities depend on for healthcare and livelihoods (Awuku-Sowah et al., 2023). Therefore, land use change in Ghana's mangrove ecosystems undermines biodiversity, fisheries, coastal protection, and the availability of medicinal plants, placing cultural traditions, rural healthcare, and livelihoods at risk.

3.4 Public Perception of Climate Change, Forest Management and Ecosystem Services

3.4.1 Public Perception of Climate Change, Forest Management and Ecosystem Services in Temperate Forests (Czech Republic)

Public awareness of climate change impacts on Czech temperate forests is increasing, with growing recognition of forest vulnerability and the need for sustainable management (Stachová, 2018). However, perceptions vary across demographic groups; urban populations tend to support climate policies, whereas rural forest owners often view regulatory measures as restrictive (Stachová, 2018). Surveys indicate that around 70% of Czechs visit forests regularly, underscoring their cultural and recreational importance (Krejčí et al., 2019). Public preferences, however, remain skewed toward provisioning services such as timber, mushrooms, berries, and medicinal plants, while regulating services like carbon sequestration and erosion control are comparatively undervalued (Purwestri et al., 2023b). This highlights a gap in awareness of the broader climate-regulating role of temperate forest ecosystems.

The rise in extreme weather events, including droughts and bark beetle outbreaks, has heightened public concern over forest health. Studies on forest ecosystem service demand show increasing support for conservation, though economic pressures still drive prioritisation of short-term timber production (Hochmalová et al., 2022). Adaptation policies such as nature-based solutions are gaining acceptance in urban contexts, particularly in Prague, where heat waves have made climate risks more visible (Badura et al., 2021).

Despite these changes, perceptions of policy effectiveness remain divided, with some stakeholders recognising the value of conservation measures while others perceive them as restrictive or poorly implemented. Enforcement of forest management policies is also viewed as inconsistent due to competing land use interests. While climate awareness is rising, public understanding of its impact on temperate forest ecosystems and associated services, including medicinal plants, remains limited. Strengthening engagement and improving policy communication are essential for bridging perception gaps, building trust with stakeholders, and promoting sustainable forest management in the face of climate change.

3.4.2 Public Perception of Climate Change, Forest Management and Ecosystem Services in Mangrove Forests (Ghana)

Local communities in Ghana perceive climate change as a direct threat to their livelihoods, particularly in coastal and wetland areas where mangrove ecosystems are vital for fisheries, shoreline protection, and medicinal resources (Ankrah, 2018; Awuku-Sowah et al., 2023). Awareness of climate variability is increasing, but many rural communities still lack accurate information on adaptation strategies. Traditional ecological knowledge strongly shapes perceptions, with some groups attributing forest loss and changing rainfall patterns to supernatural causes rather than human-induced activities. Economic dependence on land use practices such as logging, farming, and mining also limits willingness to engage in conservation initiatives (Adarkwah et al., 2024).

National-level surveys indicate that more than 70% of Ghanaians are aware of climate change, though only 43.9% understand its causes (Odonkor et al., 2020). In coastal towns such as Winneba, residents often associate climate change with rising temperatures and erosion, while supernatural explanations persist (Ankrah, 2020). Education and socioeconomic status significantly influence perceptions; individuals with higher education levels are more likely to recognise human-induced causes and express concern about climate risks to ecosystem services (Ofori et al., 2023a; Atanga et al., 2024). Mangrove degradation is widely recognised as a serious issue in coastal areas, particularly for its impacts on ecosystem services. People living within mangrove-dependent communities tend to value these ecosystems more highly than those residing farther away, illustrating how dependency shapes perception (Nyangoko et al., 2022).

While climate awareness is relatively high in Ghana, public understanding of its drivers and its effects on mangrove ecosystem services remains varied. However, culturally and economically significant medicinal plants are often overlooked in climate change discourses, despite being threatened by overharvesting and habitat loss. Strengthening communication, integrating traditional knowledge with scientific perspectives, and addressing the trade-offs between economic dependence and conservation priorities are essential for improving public engagement in mangrove management and safeguarding ecosystem services, including medicinal plants. However, effective responses also depend on robust policy and governance frameworks, which are examined in the following section.

3.5 Policy and Governance Frameworks for Forest Management

3.5.1 Forest Conservation and Climate Adaptation Policies in the Czech Republic

The Czech Republic participates in international and regional frameworks such as the Convention on Biological Diversity (CBD), the Aichi Targets, and the EU Biodiversity Strategy, which emphasise sustainable forest management and biodiversity conservation (CZMOE, 2014). Nationally, the Czech Biodiversity Strategy and Action Plan (NBSAP) reflects these priorities but faces challenges, including habitat fragmentation, invasive species, and limited financial resources (CZMOE, 2014). The EU Biodiversity Strategy for 2030, alongside the European Green Deal, prioritises restoring degraded ecosystems and expanding protected areas to enhance forest resilience. These frameworks shape conservation and adaptation responses in temperate forest ecosystems in the Czech Republic.

Forest governance in the Czech Republic is shifting from a predominantly timber-focused model to a more integrated approach that incorporates NWFPs and bioeconomy perspectives (Purwestri et al., 2023a). However, aligning economic objectives with conservation goals remains difficult (Sheppard et al., 2020). Adaptation measures such as reforestation, sustainable harvesting, and pest management have been introduced to mitigate climate-related pressures. Despite these policies, weak enforcement and limited regulation allow overexploitation of NWFPs, including mushrooms, berries, and medicinal plants, which are culturally and economically significant (Šiftová, 2020).

Legislative frameworks such as Natura 2000, the EU Biodiversity Strategy, and the Czech Forest Act are in place to regulate land use and promote conservation. However, landowners often perceive these measures as economically restrictive to land use, creating resistance to implementation (CEEWeb for Biodiversity, 2019). This reflects the broader challenge of ensuring that conservation policies are enforced and publicly supported.

3.5.2 Forest Conservation and Climate Adaptation Policies in Ghana

Ghana has developed several policies to address deforestation, biodiversity loss, and climate change impacts, including the Forest and Wildlife Policy (2012), REDD+, the National Mangrove Strategy, and the Land Use and Spatial Planning Act (2016) (Adarkwah et al., 2024). These frameworks promote sustainable forest management, safeguard biodiversity, and strengthen climate resilience. In Ghana, such policies are particularly relevant for mangrove ecosystems, which are highly vulnerable to climate and land use pressures. Wetland-specific measures, such as the Ramsar Convention and Wetlands Management Regulations (1999), protect ecosystems which are vital for carbon storage, fisheries, and medicinal plants (Agyare et al., 2024). However, persistent challenges such as weak enforcement, limited funding, and land tenure conflicts undermine their effectiveness (Danso et al., 2021). For example, unclear land rights have facilitated exploitation in the Keta Lagoon Complex, Songor Ramsar site, and Amanzule Wetland (Asante et al., 2017; Adarkwah et al., 2024).

Economic pressures from agriculture, logging, and urbanisation remain strong drivers of deforestation. Payment for Ecosystem Services schemes could help incentivise conservation, but integration into national frameworks has been limited (Ajonina, 2011). Studies report a 24% decline in mangrove cover between 1980 and 2010, mainly due to overexploitation and weak governance (Ghana et al., 2024). Community dependency on mangroves for fuelwood, construction material, and medicinal plants increases local vulnerability to ecosystem degradation. While local conservation initiatives exist, insufficient institutional support often constrains their success.

At the regional level, similar challenges are evident across West Africa, where weak enforcement and unregulated harvesting persist (Feka, 2015). Efforts to adopt integrated policies balancing conservation with economic development have gained traction (Feka and Morrison, 2017). However, Ghana's experience shows that policy ambitions will remain unmet without stronger land tenure governance, adequate financing, and effective decentralised enforcement. This threatens biodiversity and undermines the availability of ecosystem services, including medicinal plants, that are essential for livelihoods and climate adaptation.

The Czech Republic and Ghana have established comprehensive policy frameworks to guide forest conservation and climate adaptation. Yet enforcement gaps, financial constraints, and competing economic interests weaken their effectiveness. These shortcomings directly influence the sustainability of NWFPs, particularly medicinal plants, which are central to livelihoods and cultural practices. The following section, therefore, examines non-wood forest products and their vulnerability to environmental change.

3.6 Non-wood Forest Products and Their Vulnerability to Environmental Change

3.6.1 NWFPs in the Czech Republic: Medicinal Plants and Recreational Harvesting

Medicinal plants are a vital component of European non-wood forest products (NWFPs), valued for their health benefits, cultural importance, and contributions to rural livelihoods (Bilia et al., 2021; Hamilton, 2004). In the Czech Republic, species such as peppermint (*Mentha × piperita*), chamomile (*Matricaria chamomilla*), and fennel (*Foeniculum vulgare*)

are widely collected for personal health and traditional uses (Knotek et al., 2012). Other species, including *Melissa officinalis*, *Plantago lanceolata*, and *Tilia cordata*, reflect the country's rich ethnobotanical traditions (Amri et al., 2017; Neis et al., 2019).

Public demand for NWFPs remains high, and Czech forest legislation (Act No. 289/1995 Coll.) guarantees public access to mushrooms, berries, and medicinal plants while aiming to safeguard forest integrity (Sisak et al., 2016). Ecological databases such as PLADIAS, which catalogues nearly 5,000 vascular plant taxa and more than 13 million occurrence records, provide valuable taxonomic and spatial information (Wild et al., 2019; Chytrý et al., 2021). However, ecological studies that specifically examine regeneration, harvesting impacts, and the long-term sustainability of medicinal plants are still limited.

NWFPs also contribute significantly to the economy. In 2018, more than 17,000 tons of mushrooms and 7,800 tons of bilberries, many valued for their medicinal and nutritional properties, were collected in Bohemia and Moravia. These harvests were worth €113–138 million for mushrooms and €64–67 million for berries, providing alternative income during declining timber production (Purwestri et al., 2023a). Despite their economic and cultural value, medicinal plants and other NWFPs are mainly gathered for household use. Commercialisation is constrained by weak branding, fragmented markets, and limited value-chain development (Wolfslehner et al., 2019). These resources face increasing environmental pressures. Rising temperatures, prolonged droughts, pest outbreaks, and habitat degradation threaten NWFP availability and forest health (Fanta and Petřík, 2018). Medicinal species such as *Betonica officinalis* and *Althaea officinalis*, now listed on the IUCN Red List, illustrate the urgency of targeted conservation (IUCN, 2024). Public priorities often emphasise accessibility over sustainability, complicating efforts to align harvesting with ecological thresholds.

Traditional plant knowledge remains important in Czech ethnobotany, particularly in the Carpathians, where plant diversity and herbal traditions are preserved (Pawera et al., 2017). However, this knowledge is gradually declining, reducing its transmission across generations. Recent trends also show a shift from recreational harvesting toward the commercial use of NWFPs (Purwestri et al., 2023a), raising further concerns about sustainability. Addressing these challenges requires integrated strategies that combine public education on sustainable harvesting, stronger ecological monitoring, and effective policy enforcement. These measures are essential for conserving medicinal plants and related NWFPs under climate and land use pressures and advancing biodiversity and sustainability goals in the EU Biodiversity Strategy (EC, 2020).

3.6.2 NWFPs in Ghana: Medicinal Plants and Local Livelihoods

Mangrove ecosystems in Ghana provide a wide range of NWFPs, including medicinal plants and raw materials for local industries. These resources are essential for rural livelihoods. Medicinal plants from mangroves are widely used in traditional healing practices to treat different diseases (Awuku-Sowah et al., 2023; Ofori et al., 2023b). The decline of mangrove forests has reduced the availability of these plants, along with other key services such as fisheries, fuelwood, and culturally significant species (Adarkwah et al., 2024). Therefore, conservation strategies should promote the sustainable use of medicinal plants to protect community well-being and ecosystem resilience.

Mangrove-derived NWFPs also support local economies. They provide income and employment, particularly for rural communities that depend heavily on forest resources (Akomaning et al., 2023). However, Ghana's forest policies still classify NWFPs as "minor" products. This limits their integration into conservation and economic planning and restricts sustainable management and commercialisation opportunities. As a result, the potential of medicinal plants and other NWFPs to support livelihoods and biodiversity conservation remains underused. Stronger policies, better management, and integrating traditional knowledge with modern conservation approaches are needed.

Although research on climate change impacts on forests is increasing (Lindner et al., 2010; Friess et al., 2022), little attention has been given to how these impacts manifest in mangrove ecosystems. Studies on public perceptions of climate change exist (Nyangoko et al., 2022), but few focus on mangrove-dependent communities. This study addresses that gap by examining how climate and land use change affect medicinal plant services in Ghana's mangroves and assessing management strategies that influence their availability and resilience. Medicinal plants in mangroves are ecologically and culturally important, yet they remain under-researched, especially regarding how communities perceive and respond to environmental pressures. Ghana's mangrove cover has declined from 181 km^2 in the 1980s to 72.4 km^2 today, with severe losses in areas such as the Amanzule Wetland (Nunoo & Agyekumhene, 2022). This wetland supports more than 50,000 residents through fisheries, medicinal plants, and ecotourism. However, it faces intense pressures from oil exploration, illegal mining, logging, invasive species such as *Acrostichum spp.* and *Eichhornia crassipes*, and weak law enforcement (Danso et al., 2021; Adarkwah et al., 2024; Muthee et al., 2025). Although frameworks such as the Ramsar Convention and the National Wetland Strategy exist, the absence of a dedicated wetland policy and overlapping institutional responsibilities continues to weaken conservation (Nunoo & Agyekumhene, 2022; Kankam et al., 2021; Muthee et al., 2025).

NWFPs and broader ecosystem services have been widely studied in Ghanaian mangroves (Akomaning et al., 2023) and in the Czech temperate forests (Sisak et al., 2016; Janová et al., 2022). However, medicinal plants have received far less attention. In Ghana, research often generalises mangrove ecosystem service loss without focusing on medicinal plants, even though they are vital for rural healthcare and cultural identity. A similar research gap exists in the Czech Republic (see Section 3.6.1), though under different ecological and socioeconomic conditions. This lack of targeted research limits the development of effective, locally grounded conservation strategies.

To address these gaps, this study examines how climate and land use change affect the availability of medicinal plants in two contrasting forest systems, namely temperate forests in the Czech Republic and mangrove forests in Ghana. Using nationally representative survey data and community-based assessments, the research explores local perceptions, identifies key environmental drivers, and evaluates management responses. This approach positions medicinal plants as a critical but often overlooked component of ecosystem services, while providing evidence to inform conservation strategies that are both environmentally sustainable and culturally relevant.

4. METHODOLOGY

This chapter outlines the methods used to investigate how climate and land use change affect medicinal plants in temperate and mangrove forest ecosystems. It presents the study areas, data collection on local perceptions, adaptation strategies, and management practices for conservation, and the analytical approaches applied to link environmental drivers with medicinal plant availability.

4.1 Study Areas

4.1.1 Czech Republic (Temperate Forests)

The Czech Republic, located in Central Europe, consists of 14 administrative regions, including Prague, Central Bohemia, South Bohemia, and South Moravia (Fig. 1). Forests cover approximately one-third of the country's land area, with 54.63% owned by the state (CZMOA, 2022). Agricultural land accounts for 53% of the total area, while protected areas cover nearly 14% (Daněk et al., 2023). Water bodies, built-up areas, and other land types constitute approximately 11% of the country's surface. Czech forests are dominated by coniferous species (68.4%), primarily Norway spruce (*Picea abies L. Karst*) (46.8%), followed by pine (*Pinus spp.*, 16%), European larch (*Larix decidua Mill.*, 3.9%), and fir (*Abies spp.*, 1.3%). Broadleaved species represent 29.5%, including beech (*Fagus spp.*, 9.6%), oak (*Quercus spp.*, 7.8%), birch (*Betula spp.*, 2.9%), and other deciduous species (9.2%) (CZMOA, 2022).

Beyond timber, Czech forests are rich in NWFPs, which support local economies and traditional practices (Sisak et al., 2016; Purwestri et al., 2023a). Key NWFPs include medicinal plants, berries, mushrooms, and honey. Notably, pine and birch have pharmaceutical properties (Neis et al., 2019; IUCN, 2024). Common medicinal plants include *Agrimonia eupatoria* (Agrimony), *Leonurus cardiaca* (Motherwort), *Vaccinium myrtillus* (Bilberry), and *Tilia cordata* (Common Linden). Despite their widespread presence, these species face population declines due to environmental and anthropogenic pressures (IUCN, 2024). Beyond economic contributions, NWFPs also play a role in maintaining traditional forest-based livelihoods and practices. The harvesting and use of medicinal plants and other NWFPs are deeply embedded in local customs, reflecting the cultural and historical significance of forest resources.

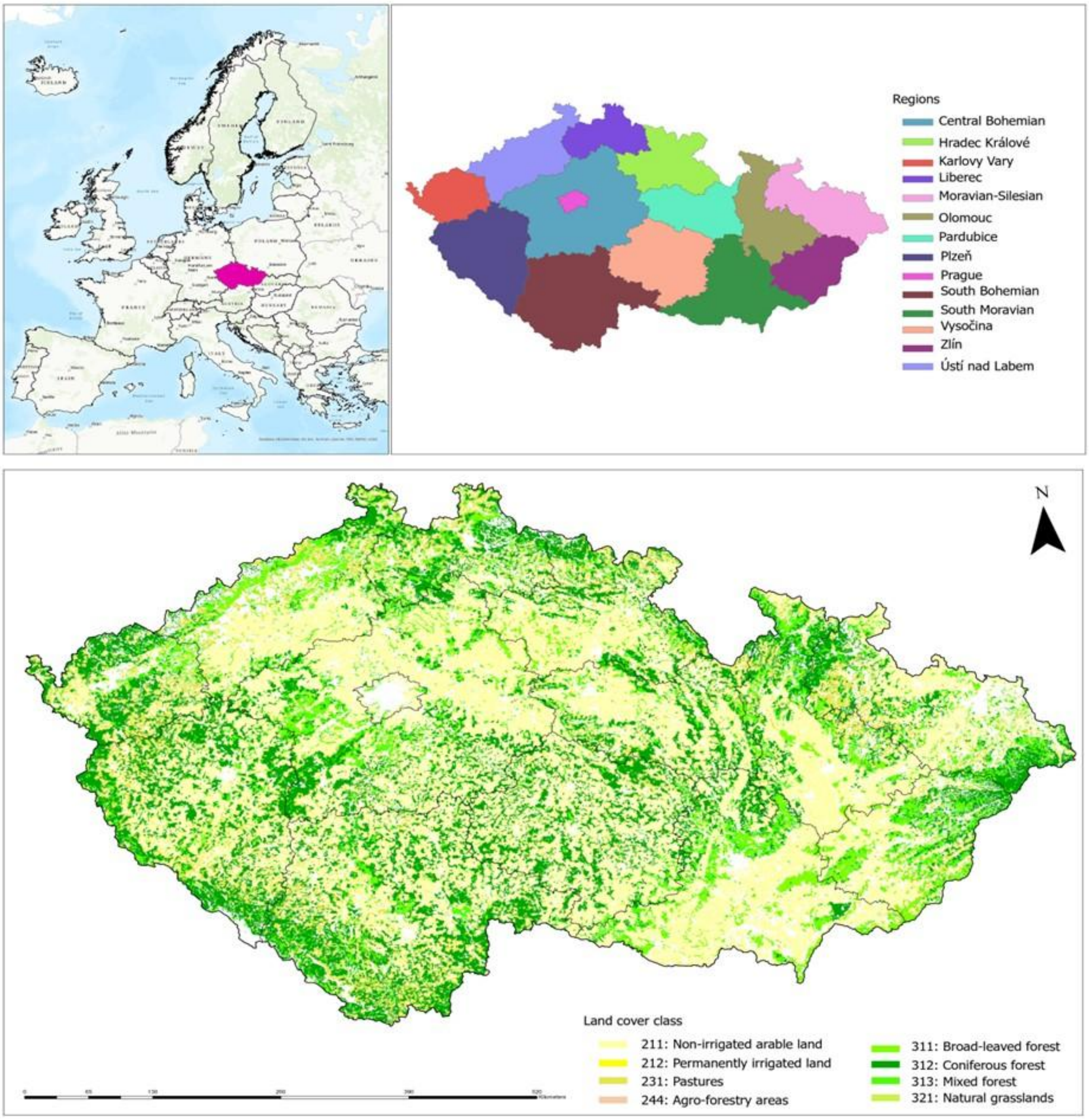


Fig. 1: Map of the study area in the Czech Republic. Top left: Location of the Czech Republic within Europe. Top right: Administrative regions (NUTS 3 level) of the Czech Republic. Bottom: Land cover classification showing forests, arable land, pastures, grasslands, and agroforestry areas.

4.1.2 Ghana (Mangrove Forests)

The Amanzule Wetland, located in the Ellembelle and Jomoro Municipalities in Ghana's Western Region, stretches from the Ankobra River estuary to the Côte d'Ivoire border (Fig. 2). It is positioned approximately 5°00′N to 5°15′N latitude, 2°40′W to 2°20′W longitude and spans an area exceeding 38,000 hectares (BirdLife International, 2024). The wetland hosts mangrove forests and associated ecosystem services, providing vital ecological, economic, and social functions to the surrounding communities and beyond. The wetland also comprises swamps, floodplains, and the country's only known peat swamp and largest swamp forest (Danso et al., 2021; Carrasquilla-Henao et al., 2019). It is a habitat for diverse flora and fauna, supporting numerous species of fish, birds, and primates (Obubu et al. 2022), and supports the livelihoods of over 50,000 people, particularly in fishing, tourism, transportation, and transboundary trade between Ghana and Côte d'Ivoire. Several communities, such as Azulenloano, Ampain, and New Bakanta, depend on these ecosystem services.

Despite its ecological and economic value, the wetland lacks formal conservation protection, resulting in unsustainable land use practices that threaten its biodiversity and ecosystem services (BirdLife International, 2024). The Important Bird and Biodiversity Areas (IBA) assessment categorises it as "very unfavourable", with limited management actions taken to ensure sustainable use (BirdLife International, 2024). Conservation efforts are crucial to prevent further habitat degradation, and there is growing advocacy for the legal protection of the Amanzule wetland in Ghana.

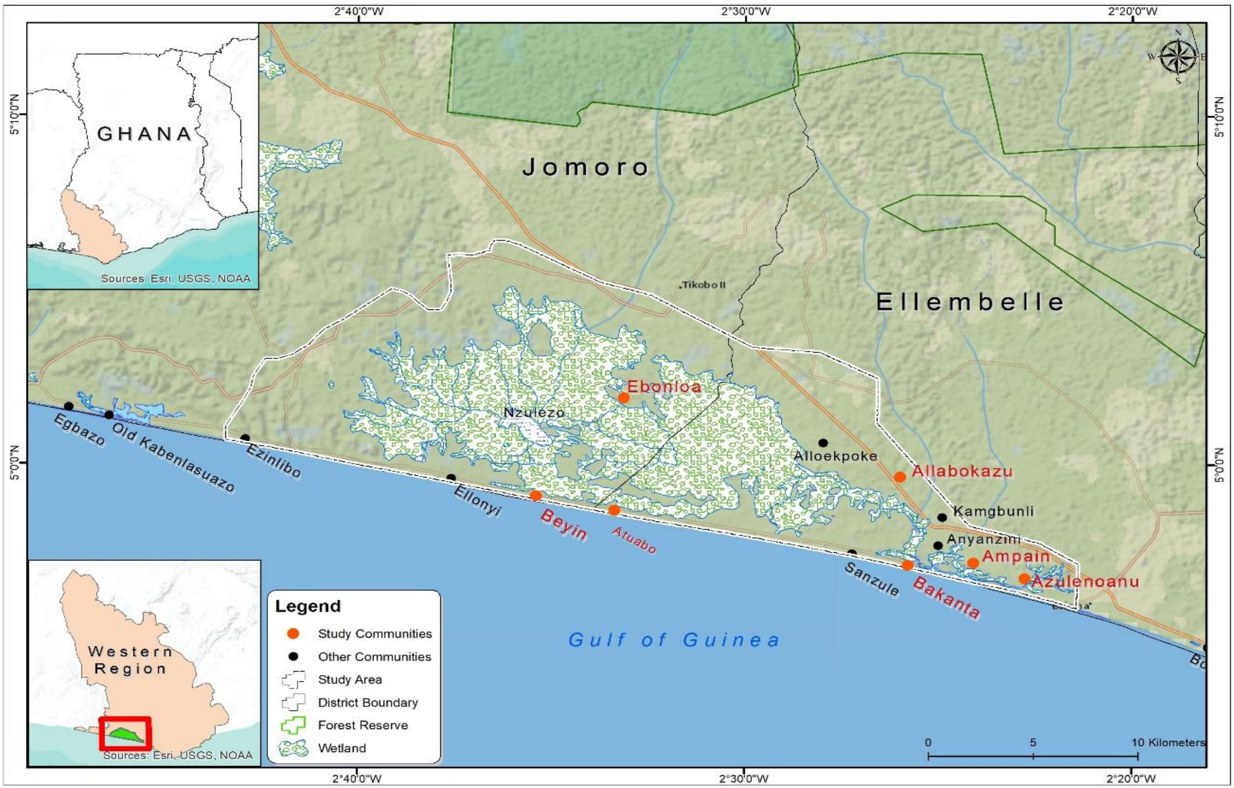


Fig. 2: Map of the Greater Amanzule Wetland study area in southwestern Ghana, showing the studied communities (Adarkwah et al. 2024). The inset, forest reserves, wetlands, and district boundaries are overlaid for spatial context.

4.2 Justification for the Selection of Temperate and Mangrove Ecosystems and Medicinal Plants as an Ecosystem Service

4.2.1 Justification for the Selection of Temperate and Mangrove Ecosystems

This study examines two ecologically distinct forest ecosystems: temperate forests and mangrove forests. Their selection is based on their differing vulnerabilities to climate and land use change, their importance in providing ecosystem services, and their contrasting socio-environmental settings. Temperate and mangrove forests experience climate change impacts, but in different forms. Temperate forests are increasingly affected by droughts, pest outbreaks, and forest fires, whereas mangrove forests face sea-level rise, coastal erosion, and storm surges. Both ecosystems are also essential for biodiversity conservation and for sustaining livelihoods through services such as medicinal plants, timber, fisheries, and cultural values.

At the same time, both forest types are subject to land use pressures, including deforestation, resource overexploitation, excessive agrochemical use, and infrastructure development, which intensify climate-related vulnerabilities. Studying these ecosystems together makes it possible to examine how similar drivers manifest under contrasting ecological and socioeconomic conditions. It also provides insights into local adaptation and management strategies that can inform broader approaches to sustainable forest management. By including both temperate and mangrove ecosystems, this study highlights how climate and land use change affect forest ecosystem services, with particular attention to medicinal plants.

4.2.2 Justification for the Selection of Medicinal Plants as an Ecosystem Service

Medicinal plants were selected as a key provisioning ecosystem service because of their ecological, economic, and cultural significance in both study countries. In the Czech Republic's temperate forests, they are ranked among the second most valued NWFPs, particularly for their cultural importance and use in traditional and complementary medicine (Pokladnikova and Selke-Krulichova, 2018; Purwestri et al., 2023b). In Ghana, medicinal plants play a critical role in primary healthcare, especially in rural areas with limited access to formal medical services. They also provide income and employment for households near forests (Asigbaase et al., 2023). Their importance is further heightened in contexts of high poverty and weak infrastructure, making them both a health asset and an economic safety net.

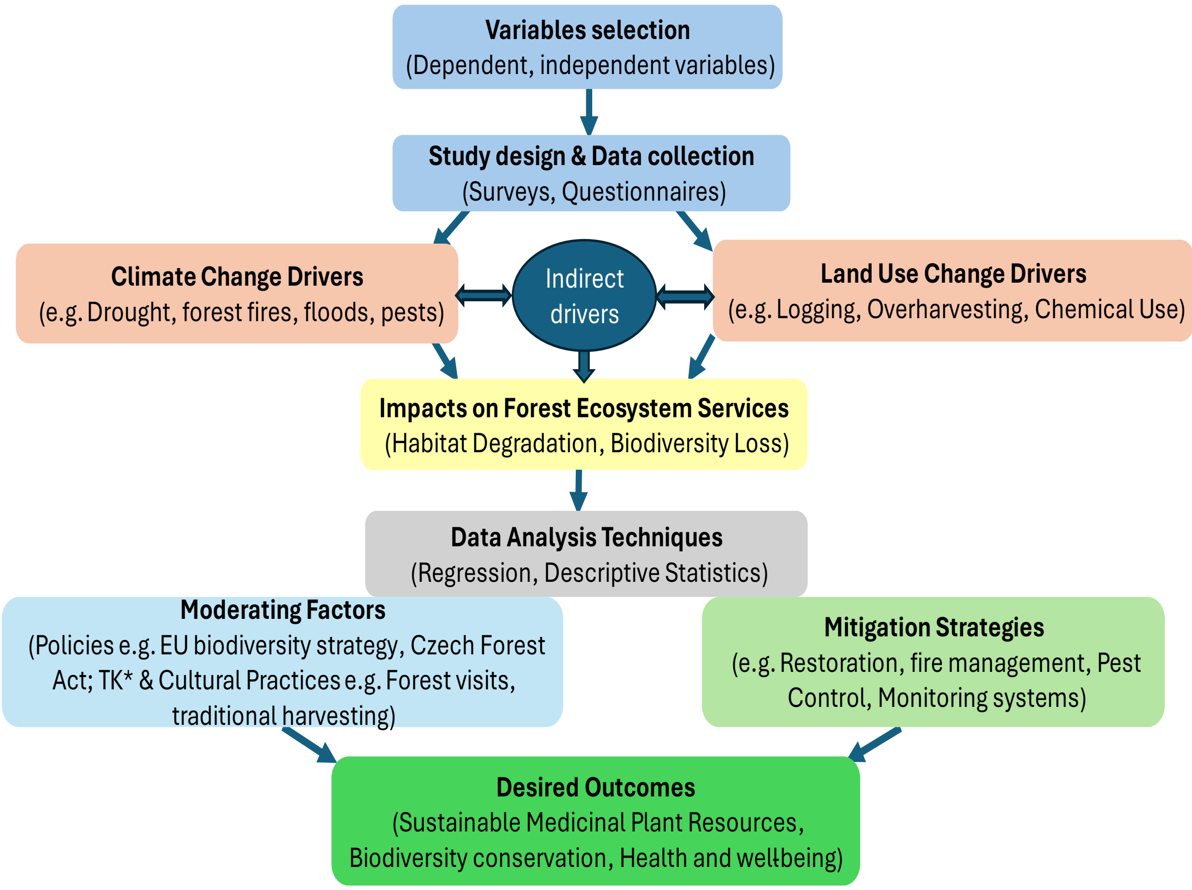
Despite their value, medicinal plant resources in both ecosystems are increasingly under threat. In Ghana, unsustainable practices such as overharvesting, agricultural expansion, mining, and logging, combined with climate pressures, have caused the decline of several species, including some that are endangered (Asigbaase et al., 2023). In the Czech Republic, climate and land use pressures such as droughts, pest outbreaks, and habitat degradation (Fanta & Petřík, 2018) also undermine medicinal plants' sustainability. Species such as *Betonica officinalis* and *Althaea officinalis* are now listed on the IUCN Red List due to ecological stress and habitat degradation (IUCN, 2024).

Therefore, Medicinal plants were chosen for their cross-cutting relevance in ecological and socioeconomic contexts. Their differential exposure and response to climate and land use change in temperate and mangrove ecosystems make them an appropriate focus for examining ecosystem service vulnerability. Focusing on medicinal plants also provides insights into local perceptions, environmental stressors, and management responses that are critical for developing sustainable and culturally responsive conservation strategies.

4.3 Research Approach and Design

This study employs a mixed-methods approach to assess perceptions of climate and land use change and their impacts on forest ecosystem services, focusing on medicinal plant availability in the temperate forests of the Czech Republic and the mangrove forests of Ghana. The research follows a unified methodological framework that integrates quantitative and qualitative approaches while allowing for context-specific adaptations, consistent with established guidance on mixed-methods design (Creswell and Clark, 2017).

The quantitative component comprised structured surveys and logistic regression analysis in both study areas, complemented by a review of relevant literature. In Ghana, qualitative methods such as focus group discussions (FGDs) and key informant interviews (KIIs) were also conducted to capture community-level perspectives that could not be addressed through surveys alone. In both countries, surveys and literature reviews provided a common analytical basis, while in Ghana, the framework was extended with FGDs and KIIs to incorporate stakeholder perspectives and generate deeper insights into local realities of climate and land use change. The analysis was guided by the conceptual frameworks presented in Figure 3.



* TK: Traditional Knowledge; **Note**: Indirect drivers and moderating factors are included for theoretical relevance, but data on these variables were not collected in this study.
Fig. 3: Conceptual framework

4.4 Data Collection Methods

4.4.1 Primary Data Collection (Czech Republic)

Primary data were obtained from a national survey conducted in 2022 using computer-assisted web interviewing (CAWI) (CZSO, 2022). CAWI was selected for its suitability in reaching geographically dispersed respondents and for maximising response rates (Hutson et al., 2024; Kleespies et al., 2024). The questionnaire was pre-tested to ensure clarity and relevance (Asah & Blahna, 2020).

The survey targeted participants aged 18–65 across all 14 regions of the Czech Republic, with a minimum sample size of 1,500, including 53 forest owners (Table 1). Forest owners were surveyed separately, given their central role in managing and conserving ecosystem services (Tiebel et al., 2021). Their responses were analysed to assess management strategies within their jurisdictions, while public responses provided broader insights into perceptions of factors influencing medicinal plant availability across the country.

Table 1: Number of respondents interviewed per region in the Czech Republic

Study region	Public	Forest owners
	Respondents (%)	Respondents (%)
Capital City- Prague	184 (12.30)	4 (7.5)
Central Bohemia	187 (12.50)	7 (13.2)
South Bohemian	92 (6.10)	7 (13.2)
South Moravian	167 (11.10)	6 (11.3)
Karlovy Vary	43 (2.90)	0
Vysocina	73 (4.90)	7 (13.2)
Liberec	63 (4.20)	2 (3.8)
Hradec Králové	79 (5.30)	3 (5.7)
Moravian-Silesian	171 (11.40)	3 (5.7)
Olomouc	90 (6.00)	4 (7.5)
Pardubice	73 (4.90)	4 (7.5)
Pilsen	80 (5.30)	1 (1.9)
Usti	115 (7.70)	2 (3.8)
Zlín	83 (5.50)	3 (5.7)
Total	1500 (100)	53 (100)

Data are presented as n (%)

4.4.2 Survey Structure and Variable Categories

Closed-question surveys, as employed in this study, are widely used in research examining environmental drivers and conservation practices (Jayathilake et al., 2021; Kleespies et al., 2024). This methodological approach enhances response consistency and enables robust quantitative analysis (Kleespies et al., 2024). Accordingly, this study employed a structured questionnaire with closed-ended questions to analyse sociodemographic characteristics, climate change and land use change drivers affecting medicinal plant availability, and forest management strategies in the Czech Republic.

Table 2 presents the dependent variable ("Do any factors affect the availability of medicinal plants in the forest?") alongside independent variables such as drought, pests and diseases, forest fires, and excessive chemical use—all recognised as key climate and land use drivers affecting forest ecosystem services. These variables were coded as binary responses (Yes = 1, No = 0) to facilitate statistical modelling. These drivers were selected based on prior studies demonstrating their significant impact on forest ecosystems, with an emphasis on the European context. For instance, excessive chemical use (Shah et al., 2023), drought events in Central Europe (Seidl et al., 2017), and the occurrence of floods, pests and diseases, and forest fires across Europe (Hlásny et al., 2021; Copernicus Climate Change Service, 2023) have been widely reported as major environmental pressures. In Central and Eastern Europe, including the Czech Republic, legal frameworks restrict large-scale deforestation (Forest Europe, 2020); however, forest degradation driven by cumulative land use impacts remains an ongoing concern for biodiversity and for sensitive understory species such as medicinal plants (Chytrý et al., 2021).

4.5 Selection and Definition of Independent Variables

The selection of climate change and land use change variables was guided by three key factors: (i) a literature review of climate change impacts on forest ecosystems, (ii) expert consultations with forestry researchers, climate scientists, and policymakers, and (iii) field observations of ecosystem conditions and local perceptions. The following sections show ecosystem-specific variable selection using climate change proxies in the temperate and mangrove forests.

4.5.1 Ecosystem-Specific Variable Selection

Since direct quantification of climate change impacts is challenging with perception-based studies, this study employs climate-sensitive variables as proxies. In the temperate forest, climate change was selected, including its variables such as drought, flooding, forest fires, and pest outbreaks, as these have been identified as major stressors affecting forest health and biodiversity (Seidl et al., 2017). Land use change variables such as logging, overexploitation and excessive chemical use were also selected due to their impact on forest ecosystems and potentially medicinal plants.

In the mangrove, climate change variables considered include temperature changes, sea-level rise, storms, and coastal flooding, as these factors directly affect mangrove ecosystems, leading to habitat loss, erosion, and biodiversity decline (Evadzi et al., 2018). Land use change variables include deforestation, illegal small-scale mining, sand winning, and overexploitation of medicinal plants, all of which degrade forest ecosystems. Such land use changes can also indirectly contribute to climate change by reducing carbon storage capacity and disrupting ecosystem functions (Lorencová et al., 2013).

Table 2: Description of the study variables

Variable	Description
A. Sociodemographic variable (Descriptive)	
Age	Ages of respondents (categorised into 18 - 29 years=1, 30 - 44 years=2, 45 - 59 years=3, 60+ years=4)
Gender	Gender of respondents (1=male/female= 0)
Education	Highest educational level ("Basic"=1, High school without graduation (HSNG)"=2, "High school with graduation (HSG)"=3, "Higher"=4)
B. Dependent variable (Logistic regression)	
Dummy (Do any factors affect the availability of medicinal plants in the forest? yes=1, no=0	
C. Independent variables: Climate and Land Use Change (Logistic regression)	
Climate change	Dummy (Climate change affects the availability of medicinal plants; yes=1, no=0)
Flood	Dummy (Flood affects the availability of medicinal plants; yes=1, no=0)
Drought	Dummy (Drought affects the availability of medicinal plants; yes=1, no=0)
Pest and Disease	Dummy (Pest and diseases affect the availability of medicinal plants; yes=1, no=0)
Overexploitation	Dummy (Overexploitation affects the availability of medicinal plants; yes=1, no=0)
Excessive Chemical use	Dummy (Excessive chemical use affects the availability of medicinal plants; yes=1, no=0)
Logging	Dummy (Logging affects the availability of medicinal plants; yes=1, no=0)
Forest fires	Dummy (Forest fires affect the availability of medicinal plants; yes=1, no=0)
D. Descriptive variable: Management and adaptation strategies	
What forest management or adaptation strategies are implemented within your forest administration to mitigate the effects of climate change and land use change drivers on the availability of medicinal plants?	

4.5.2 Definition of Climate Change Proxies and Land Use Change Variables

Additionally, land use factors such as chemical use, overexploitation, and illegal mining are examined separately to distinguish their anthropogenic influences, though they indirectly contribute to climate change (Lorencová et al., 2013). This approach aligns with climate science literature, where such variables are commonly used as indicators of climate change impacts on ecosystems (IPCC, 2014). To ensure clarity, each driver is categorised into climate and land use change drivers, detailing their relevance and potential impacts on medicinal plant populations.

In this study, Climate Change is defined as long-term shifts in temperature, precipitation, and extreme weather patterns that impact forest ecosystems. Manifestations include forest disturbances such as droughts, fires, floods, and pest outbreaks (Seidl et al., 2017). Manifestations of climate change are defined as follows:

- **Floods:** The excessive accumulation of water due to heavy rainfall or snowmelt, leading to soil erosion, root damage, and the loss of nutrient-rich topsoil, negatively affecting forest ecosystems (Suchara et al., 2021).
- **Drought:** Prolonged water scarcity that stresses plant physiology, reduces soil moisture, and diminishes forest productivity (Waseem et al., 2023).
- **Pests and Diseases:** Infestations by harmful insects and pathogens that weaken trees and understory vegetation, disrupting plant health and ecosystem balance (Hlásny et al., 2021).
- **Forest Fires:** Uncontrolled wildfires that destroy habitats, reduce biodiversity, and impact medicinal plant availability, particularly in drought-stressed regions (Mir et al., 2021; Singh et al., 2024).
- **Storms:** Intense weather events characterised by strong winds and heavy rainfall, leading to tree damage, soil erosion, and disruption of forest ecosystems (Seidl et al., 2011).
- **Rising Temperature:** Long-term shifts in global and regional temperature patterns affecting species distribution, phenology, and overall ecosystem stability (IPCC, 2019).

- **Sea-Level Rise:** The gradual increase in ocean levels due to glacier melting and thermal expansion, causing saltwater intrusion and loss of coastal forest habitats (Oppenheimer et al., 2019).

In this study, land use change is defined as human-induced modifications of the natural landscape, often altering ecosystem functions and biodiversity. Key drivers include deforestation, agricultural expansion, urbanisation, and mining activities. Land use change drivers used in this study are defined as follows:

- **Deforestation:** The large-scale removal of forests for agriculture, urban expansion, leading to habitat loss and biodiversity decline (Smith et al., 2020).
- **Logging**: Logging refers to the removal of trees for timber, which can disrupt forest structure and microhabitats, potentially increasing the vulnerability of shade-tolerant medicinal plants to competition and contributing to habitat loss (Bitomský et al., 2019; Snyder et al., 2021). However, logging can also create canopy openings that favour the growth and yield of certain light-demanding medicinal plant species, depending on canopy conditions and site-specific factors (Jaroszewicz et al., 2024).
- **Excessive Use of Chemicals**: The application of pesticides and herbicides contaminates soils and water bodies, harming non-target species and reducing medicinal plant biodiversity (Chen et al., 2016; Chakraborty, 2019; Pavela et al., 2021).
- **Infrastructure Development:** Road and building construction that fragments habitats and increases deforestation pressures (Engert et al., 2025).
- **Slash-and-Burn Farming Practices:** The clearing and burning of forests for cultivation, which contributes to soil degradation and deforestation (Appiah et al., 2010).
- **Illegal Small-Scale Mining:** Unregulated mining activities that lead to deforestation, soil erosion, and contamination of water sources (Mensah et al., 2015).

- **Sand Winning:** The extraction of sand from riverbeds and coastal zones causes habitat destruction and erosion (Pandey et al., 2023).
- **Invasive Species:** Non-native species introduced to ecosystems, out-competing native plants and altering forest composition (Liebhold et al., 2017).
- **Grazing of Mangroves by Livestock:** The browsing of mangrove vegetation by domestic animals leads to habitat degradation and reduced ecosystem services (Hoppe-Speer and Adams, 2015).

4.6 Primary Data Collection (Ghana)

In Ghana, structured and semi-structured household surveys were administered in seven communities within the catchment area of the mangrove forests in Ellembelle and Jomoro Municipalities of the Western Region. A total of 400 respondents were selected using stratified random sampling to ensure diverse representation. To complement the surveys, focus group discussions (FGDs) were conducted in all seven communities (Azuleloano, Ampain, Atuabo/Asem Nda, Allabokazo, Bakanta, Benyin, and Ebonloa) with 8–10 participants per session (Hennink, 2014). Two FGDs were held in each community in June 2024, conducted in the local language. The discussions explored the importance of mangrove ecosystem services, observed climate and land use changes, and their effects on medicinal plant availability. Participants also identified key drivers of land use change, including oil and gas activities and the expansion of rubber plantations into critical areas.

Key informant interviews (KIIs) were conducted with representatives of forestry institutions, municipal authorities, and conservation organisations. The Forestry Commission of Ghana provided insights into national policies, regulatory frameworks, and challenges in forest conservation. Officials from the Ellembelle and Jomoro Municipal Assemblies highlighted local climate impacts, deforestation, and related environmental issues. Conservation organisations such as Hen Mpoano described their role in promoting sustainable land use and biodiversity conservation. Together, these methods provided complementary perspectives on how climate and land use pressures influence mangrove ecosystem services, particularly medicinal plants, and the effectiveness of management responses.

4.6.1 Study Sample Size and Sampling Approach

The sample size for the survey was determined using Yamane's (1967) formula (Equation 1), applying a 95% confidence level and a 5% margin of error:

$$n = \frac{N}{1+N(e)^2} \text{ ---------------- } (1)$$

where n represents the calculated sample size, N is the total number of households across the seven communities and refers to the margin of error (0.05). Using this equation and available population data, the estimated sample size was 401. An average of approximately 57 respondents was allocated to each of the seven selected communities. A combination of stratified random and purposive sampling techniques was used to select respondents from communities within the Amanzule wetland, ensuring alignment with the study's objectives.

4.6.2 Survey Structure and Variables

Structured and semi-structured questionnaires were used to gather data from local communities. Questions focused on perceptions of climate change effects, land use change, forest management, and adaptation strategies. The questionnaire also covered the importance of mangrove ecosystem services. The selection of study variables was informed by a literature review on key drivers of forest ecosystem service change, with particular reference to climate and land use pressures as outlined by Damiani et al. (2023). It included closed-ended questions with predefined answers and open-ended ones for detailed responses. To evaluate the influence of environmental stressors on medicinal plant availability, respondents were also asked whether they perceived specific climate and land use pressures (e.g., coastal flooding, illegal mining) as affecting availability. These responses were captured as binary variables (Yes = 1, No = 0) to support statistical modelling. The questionnaire was pre-tested with selected households to ensure clarity and reliability, and was administered with the assistance of three trained enumerators from the study communities.

Table 3 presents the dependent variable (*"Do any factors affect the availability of medicinal plants in the mangrove forest?"*) alongside independent variables, including coastal flooding, forest fires, and excessive chemical use**,** all of which are recognised as critical climate change and land use factors influencing mangrove forest ecosystem services.

Table 3: Description of the study variables

Variable	Description
A. Sociodemographic Variable (Descriptive)	
Age	Ages of respondents (categorised into 18 - 24 years=1, 25 - 34 years=2, 35 - 44 years=3, 45 – 54= 4, 55 - 60+ years=5)
Gender	Gender of respondents (1=male/female= 0)
Education	The highest educational level of the respondents (No education =1, Primary=2, JSS/JHS*=3, SSS/SHS*=4, Higher (Tertiary) =5.
B. Dependent Variable (Logistic regression)	
Dummy (Do any factors affect the availability of medicinal plants in the mangrove forest? yes=1, no=0	
C. Independent Variables: Climate and Land Use Change (Logistic Regression)	
Erratic rainfall	Dummy (Erratic rainfall affects the availability of medicinal plants; yes=1, no=0)
Rising temperature	Dummy (Rising temperature affects the availability of medicinal plants; yes=1, no=0)
Sea level rise	Dummy (Sea level rise affects the availability of medicinal plants; yes=1, no=0)
Coastal flooding	Dummy (Coastal flood affects the availability of medicinal plants; yes=1, no=0)
Storms	Dummy (Storms affect the availability of medicinal plants; yes=1, no=0)
Deforestation	Dummy (Deforestation affects the availability of medicinal plants; yes=1, no=0)
Forest fires	Dummy (Forest fires affect the availability of medicinal plants; yes=1, no=0)
Slash and burn farming practice	Dummy (Slash and burn farming affects the availability of medicinal plants; yes=1, no=0)
Infrastructure development	Dummy (Infrastructure development affects the availability of medicinal plants; yes=1, no=0)
Excessive chemical use	Dummy (Excessive chemical use affects the availability of medicinal plants; yes=1, no=0)
Overexploitation	Dummy (Overexploitation affects the availability of medicinal plants; yes=1, no=0)
Illegal small-scale mining	Dummy (Illegal small-scale mining affects the availability of medicinal plants; yes=1, no=0)
Grazing of mangroves by livestock	Dummy (Grazing of mangroves affects the availability of medicinal plants; yes=1, no=0)
Sand wining	Dummy (Sand winning affects the availability of medicinal plants; yes=1, no=0)
Invasive species	Dummy (Invasive species affects the availability of medicinal plants; yes=1, no=0)
D. Descriptive Variable: Adaptation and Management Strategies	
What adaptation or management strategies are used in your community to reduce the impacts of climate and land use changes on the availability of medicinal plants?	

*JSS/JHS=Junior Secondary School/Junior High School, SSS/SHS = Senior Secondary School

4.7 Secondary Data Collection

In addition to primary data, the study relied on secondary data sources, including historical climate data, land use change records, and relevant policy documents on forest conservation and climate adaptation. Unlike the Ghana side, which relied on primary data to ascertain the available ecosystem services in the mangrove ecosystem, the Czech side relied on Purwestri et al. (2023b) classification of ecosystem services in the country.

4.8 Data Analysis

The collected survey data were analysed using logistic regression analysis conducted in Stata® 17.0 software and descriptive statistics. The choice of these methods was guided by their suitability for analysing relationships between the study variables and highlighting key patterns in the study (Mooi et al., 2018a and b).

4.8.1 Logistic Regression Analysis

Logistic regression was applied to assess the relationship between climate and land use drivers (e.g., drought, pests, excessive chemical use, logging, and floods) and medicinal plant availability. This method estimates how independent variables (Shi et al., 2021) affect the probability of medicinal plants being perceived as available, using the following model:

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \text{ -------------- (2)}$$

Where:

p = Probability that factors affect the availability of medicinal plants.

logit(p) = log-odds of p.

β_0 = intercept term.

$\beta_1, \beta_2, \ldots, \beta_n$ = coefficients for each driver.

$X_1, X_2, \ldots, X_n$ = Independent variables (climate and land use factors).

This analysis quantified the significance and magnitude of each driver's effect, identifying the key factors influencing medicinal plant availability. Model fit was evaluated using pseudo-R^2 values (da Silva et al., 2024). Independent variables were tested at a significant level of 0.05. Following regression, marginal effects were calculated to interpret how unit changes in predictors influenced the probability of medicinal plant availability, providing clearer and more policy-relevant insights (Williams, 2012).

4.8.2 Descriptive statistics

Descriptive statistics were used to summarise respondent demographics (age, gender, and education) to confirm the representativeness of the survey sample (Barratt et al., 2017; Mooi et al., 2018b). They were also applied to present graphical summaries of forest management strategies and to rank ecosystem services, highlighting the relative importance of medicinal plants within temperate and mangrove forests. Descriptive analysis was essential for highlighting data patterns and contextualising regression findings (Mooi et al., 2018b).

4.8.3 Alignment of Data Analysis with Objectives and Hypotheses

The combination of logistic regression and descriptive statistics ensured that inferential and contextual dimensions of the study were addressed. Logistic regression was applied to test hypotheses concerning the effects of climate and land use drivers on medicinal plant availability (Objectives 1 and 2). Descriptive statistics were used to examine respondent characteristics, rank forest ecosystem services, and summarise forest management strategies (Objectives 3 and 4). Together, these approaches supported the development of policy-relevant insights for enhancing the resilience of forest ecosystem services (Objective 5).

4.9 Ethical Considerations

Ethical standards were strictly observed throughout the study. All participants provided informed consent prior to participation, and no personal identifiers were collected, ensuring anonymity and confidentiality. In the Czech Republic, data collection was undertaken by STEM/MARK Inc., an independent research agency, in compliance with national and institutional ethical guidelines. In Ghana, the author conducted data collection directly, following ethical protocols. Participants were fully informed about the objectives of the study, potential risks, and their right to withdraw at any time, after which they voluntarily agreed to participate. The study was non-invasive, relying exclusively on surveys, interviews, and secondary data analysis, with no experimental interventions that could pose risks to participants or ecosystems.

4.10 Study Limitations

This study was conducted in two ecologically and socioeconomically distinct contexts: temperate forests in the Czech Republic and mangrove forests in Ghana. These differences in climate, biodiversity, ecosystem characteristics, and governance structures created inherent methodological challenges and limited the scope for direct comparison. To address this, the analysis emphasised how climate and land use change affect forest ecosystem services within each context, rather than attempting to establish direct equivalence.

The study also relied on self-reported survey data from the public, forest owners, and local communities. This introduces potential limitations such as recall bias, subjective interpretation, and social desirability effects, which may influence the accuracy of responses. These challenges are common in perception-based research but were mitigated through careful questionnaire design, triangulation with secondary sources, and complementary qualitative methods where applicable. These limitations were considered in the interpretation of results, allowing the conclusions to be interpreted with appropriate caution and within the scope of the study.

5. RESULTS

This chapter presents the findings of the study. It begins with descriptive statistics on respondent characteristics and forest ecosystem services in the Czech Republic and Ghana, providing context for understanding patterns in perceptions and reported changes. The chapter then presents the logistic regression outputs, which identify the key drivers influencing medicinal plant availability in temperate and mangrove ecosystems. The results are organised according to the study objectives, progressing from general assessments of ecosystem services to analyses of management strategies and adaptation measures.

5.1 Results: Czech Republic

5.1.1 Respondent characteristics

The survey covered a diverse demographic profile that captured a broad range of sociodemographic characteristics throughout the Czech Republic. Most participants were 30 or older, with a substantial representation of people 60 or older. The gender distribution was nearly equal, with slightly more women (51%) than men (49%) participating. Most respondents had completed high school, with or without a degree, while some held higher education qualifications. Details are presented in Table 4.

Table 4: Respondents' characteristics

Variable	Categories	Frequency	Percentage
Age	18-29	242	16.13
	30-44	426	28.40
	45-59	357	23.80
	60+	475	31.67
Gender	Male	736	49.07
	Female	764	50.93
Education	Basic	47	3.13
	*HSNG	701	46.73
	*HSG	529	35.27
	Higher	223	14.87

*HSNG= high school nongraduate/apprenticeship; HSG= high school graduate

5.1.2 Perception of Ecosystem Services from the Temperate Forest Ecosystem

The analysis of 1,500 respondents across the Czech Republic (Purwestri et al., 2023b) highlights varying perceptions of forest ecosystem services (Table 5). The highest-ranked service was the role of forests as a natural habitat for plants and animals (mean score: 4.6), with 72.6% of respondents rating it as very important. NWFPs such as berries, mushrooms, and medicinal plants ranked second (mean score: 4.2), with 48.9% rating them as very important. Within this category, medicinal plants were consistently recognised as part of the most valued provisioning services. A comparable level of importance was attributed to forests as a source of clean water, which ranked third (mean score: 4.2), with 50.4% selecting the highest rating. Among regulating services, erosion prevention and flood protection ranked fourth and fifth, with mean scores of 4.1 and 4.0, and 46.1% and 43.2% of respondents identifying them as very important, respectively. Wood provisioning followed with a mean score of 3.9 (ranked sixth), with 36.1% considering it very important, placing it below NWFPs. Recreation and ecotourism ranked seventh (mean score: 3.8), with 30.7% of respondents rating it as very important. Although a substantial minority valued this service, it ranked lower than most provisioning and regulating services. Carbon sequestration was ranked eighth (mean score: 3.7), with 32.3% rating it as very important.

The lowest-ranked service was aesthetic value (mean score: 2.3), with 42.9% of respondents rating it as unimportant. It was the only service for which no respondents selected the highest rating. Figures 4–8 illustrate the range of ecosystem services identified in temperate forests in the Czech Republic.

Table 5: Perception of Temperate Forest Ecosystem Services (N=1,500)[1]

Rank	Category	Service	Perception Score (Mean± SD)	Distribution of Responses (%)
1	Cultural Services	Natural habitat for plants and animals	4.6± 0.8	1 (1.3%), 2 (1.4%), 3 (9.3%), 4 (15.4%), 5 (72.6%)
2	Provisioning Services	NWFPs: berries, mushrooms, medicinal plants	4.2± 1.0	1 (1.8%), 2 (3.6%), 3 (18.7%), 4 (27.0%), 5 (48.9%)
3	Provisioning Services	Clean water source	4.2± 1.0	1 (1.1%), 2 (3.6%), 3 (20.2%), 4 (24.7%), 5 (50.4%)
4	Regulating Services	Erosion prevention	4.1± 1.0	1 (1.9%), 2 (3.1%), 3 (22.1%), 4 (26.9%), 5 (46.1%)
5	Regulating Services	Flood protection	4.0± 1.0	1 (2.1%), 2 (6.1%), 3 (22.0%), 4 (26.6%), 5 (43.2%)
6	Provisioning Services	Wood source	3.9± 1.1	1 (2.6%), 2 (6.8%), 3 (27.7%), 4 (26.9%), 5 (36.1%)
7	Cultural Services	Recreation and ecotourism	3.8± 1.1	1 (3.6%), 2 (6.7%), 3 (29.5%), 4 (29.5%), 5 (30.7%)
8	Regulating Services	Carbon sequestration	3.7± 1.1	1 (3.3%), 2 (6.8%), 3 (34.8%), 4 (22.8%), 5 (32.3%)
9	Cultural Services	Aesthetic value	2.3± 1.2	1 (42.9%), 2 (6.1%), 3 (25.3%), 4 (25.7%), 5 (0.0%)

Source: Purwestri et al. 2023b; [1] Data are presented as % (n) or mean±sd, scoring system: (1=not important, 5=very important)

5.1.3 Examples of Ecosystem Services from the Temperate Forest Ecosystem

Figures 4–8 present visual examples of the ecosystem services outlined in Table 5. These images illustrate how temperate forests in the Czech Republic provide multiple services, ranging from biodiversity habitat and water regulation to NWFPs and recreation. As discussed in the literature review, such services are central to ecological functioning and cultural traditions. The figures also highlight the ongoing importance of these services despite growing pressures from climate change and land use change.

Fig. 4: Provision of wood from the forest (Left to Right) Photo: Miroslav Hajek

Fig. 5: Support for Watershed and Game (Photo: Miroslav Hajek; *Our Natural Treasure* Project (2017-2019)

Fig. 6: Forest visits (Photo: Miroslav Hajek) and skiing service (Photo: Krkonoše)

Fig. 7: NWFPs provision (Mushrooms and Berries) (Photo: Miroslav Hajek)

Fig. 8: Medicinal Plants (Left to Right: Motherwort and Common Linden) (Photo: Vojtěch Herman, and Josef Tecl, BioLab 2025)

5.1.4 Climate Change and Land Use Change Drivers Affecting Temperate Medicinal Plant Availability

The marginal effects from the regression analysis illustrate the influence of various climate change and land use change factors on medicinal plant availability in forest ecosystems (Table 6). The key drivers affecting medicinal plant availability are climate change and excessive chemical use.

i. Climate Change Drivers Affecting Temperate Medicinal Plant Availability

Climate change, as a collective variable, exhibited a statistically significant negative effect on medicinal plant availability (dy/dx = -0.0387, p = 0.001), confirming its adverse impact.

However, when considering specific climate-related disturbances, none exhibited statistically significant effects. Flooding (dy/dx = 0.0104, p = 0.279) showed a positive effect, though it was not statistically significant. Drought (dy/dx = 0.0115, p = 0.360) had a small positive effect, but its insignificance suggests that it does not directly determine medicinal plant presence. Pests and diseases (dy/dx = -0.0088, p = 0.494) and forest fires (dy/dx = 0.0040, p = 0.710) showed weak and statistically insignificant effects, indicating a minimal role in shaping medicinal plant populations.

ii. Land Use Change Drivers Affecting Temperate Medicinal Plant Availability

Among land use change factors, excessive chemical use had a statistically significant negative effect on medicinal plant availability (dy/dx = -0.0270, p = 0.020). Conversely, overexploitation of medicinal plants (dy/dx = -0.0078, p = 0.480) and logging (dy/dx = 0.0127, p = 0.239) showed no significant influence.

Table 6 Marginal Effects of Climate and Land Use Change Drivers Affecting Medicinal Plant Availability

Variable	dy/dx	Std. Error	z	P>[z]	95% Conf. Interval	
Climate Change Drivers						
Climate Change	-0.0387*	0.0115	-3.36	0.001	-0.0612	-0.0161
Flood	0.0104	0.0096	1.08	0.279	-0.00847	0.0294
Drought	0.0115	0.0125	0.92	0.360	-0.0131	0.0361
Pest and Diseases	-0.0088	0.0129	-0.68	0.494	-0.0340	0.0164
Forest Fires	0.0040	0.0107	0.37	0.710	-0.0170	0.0249
Land Use Change Drivers						
Overexploitation of medicinal plants	-0.0078	0.0111	-0.71	0.480	-0.0296	0.0139
Excessive Chemical Use	-0.0270*	0.0116	-2.32	0.020	-0.00499	-0.00421
Logging	0.0127	0.0108	1.18	0.239	-0.00845	0.0339

** p<0.05

Logistic Regression Results:
Number of observations: 1500
LR $chi^2(8)$ = 33.70
Prob > chi^2 = 0.0000
Log likelihood = -519.43285
Pseudo R^2 = 0.0314

5.1.5 Logistic Regression Model Performance

The logistic regression model had a pseudo-R^2 of 0.0314, indicating limited explanatory power. The likelihood ratio chi-square test (LR χ^2 (8) = 33.70, $p < 0.0000$) suggests that the model is statistically significant overall, meaning the selected predictors improve model fit compared to a null model. However, the low pseudo-R^2 suggests that much of the variability in medicinal plant availability remains unexplained, highlighting the need for further analysis of individual predictor significance and effect sizes.

5.1.6 Management strategies for sustainability of Temperate Forest ecosystem services

Fig. 9 presents the implementation of specific forest management measures among forest owners interviewed in the Czech Republic. The most adopted measure is forest restoration, with 30.2% of forest owners engaging in this practice. Organic agriculture (22.6%) and landscape protection (22.6%) are also widely implemented, indicating a significant focus on sustainable land use practices. Pest and invasive species control is applied by 17% of forest owners, while soil and water protection measures (9.4%) are less commonly adopted. Forest fire protection is implemented by only 5.7% of respondents. Additionally, participation in the Natura2000 (EU conservation project) is low, with only 3.8% of forest owners engaged in this conservation initiative. Rural development schemes are implemented by 7.5% of respondents. A notable 54.7% of forest owners do not implement any of the listed management measures, representing a significant proportion of respondents.

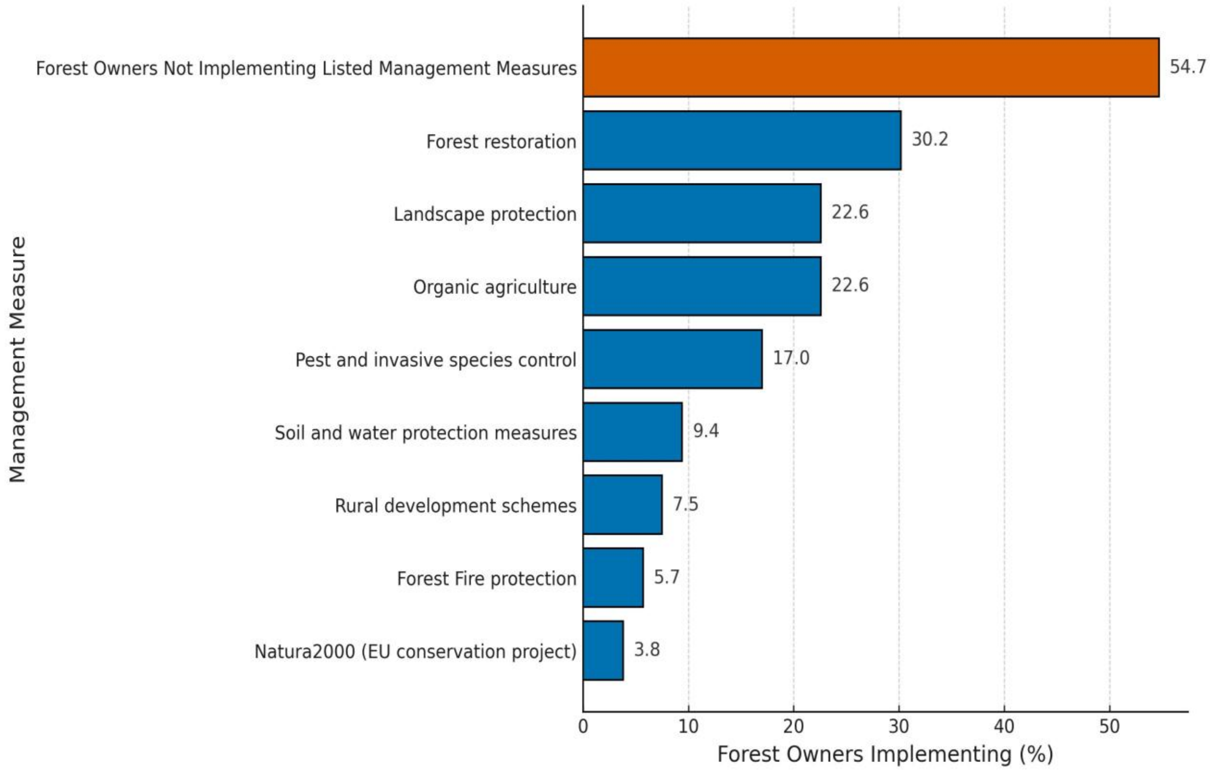


Fig. 9: Implementation of forest management strategies (Multiple responses)

5.1.7 Summary of Key Findings of the Czech Study

Key findings of the study include:

- The Czech Forest provides various ecosystem services, including Wood and NWFPs such as medicinal plants, mushrooms and berries.
- Climate change and the land use change variable - excessive chemical use emerged as a significant negative driver of medicinal plant availability.
- The climate change proxies, ie flooding, drought, pests and diseases and forest fires, had insignificant effects on medicinal plant availability.
- The land use change variables, overexploitation and logging had an insignificant impact on medicinal plant availability.
- About 55% of forest owners did not implement any of the forest management strategies covered in the study, indicating significant gaps in conservation efforts.

- Forest restoration, organic agriculture and land protection were the most implemented management strategies, while others, such as fire prevention and participation in Natura 2000 projects, were low.

5.2 Results: Ghana

5.2.1 Respondents characteristics

The study surveyed 401 respondents, capturing diverse demographic and socio-economic backgrounds (Table 7). By age, the largest group was 25–34 (33.42%), followed by 35–44 (29.43%). Respondents aged 45–54 accounted for 17.96%, while those aged 18–24 represented 15.21%. The least represented group was those 55 years and above (3.99%).

The sample was slightly male-dominated, with men comprising 54.11% (n = 217) and women 45.89% (n = 184). Although the difference is modest, it indicates somewhat higher male participation. Educational attainment showed significant variation. Over half of respondents (56.36%) had completed primary education, while 28.68% reported Junior Secondary/Junior High School (JSS/JHS) as their highest level. A smaller share (5.24%) had reached Senior Secondary/Senior High School (SSS/SHS), and only 1.25% had tertiary education. Additionally, 8.48% had no formal education, highlighting disparities in educational access across the surveyed population.

Table 7: Respondents' Background Characteristics (N 401)

Variable	Frequency	Percentage (%)
Age Group		
18-24	61	15.21
25-34	134	33.42
35-44	118	29.43
45-54	72	17.96
55-60+	16	3.99
Sex		
Men	217	54.11
Women	184	45.89
Educational level		
No formal education	34	8.48
Primary	226	56.36
JSS/JHS	115	28.68
SSS/SHS	21	5.24
Higher (Tertiary)	5	1.25

5.2.2 Perception of Ecosystem Services from the Mangrove Forest Ecosystem

Perceptions of ecosystem services provided by the mangrove forests in the Amanzule wetlands varied across categories (Table 8). Among provisioning services, fish provision, including shelter and spawning grounds, ranked first, with 95.24% of respondents rating it very important. Other key services included medicinal plants (86.53%, ranked fifth), wood provision (71.82%, ranked ninth), and support for germination and growth (70.93%, ranked tenth). These services play a critical role in local subsistence and livelihoods.

Regulating services were also highly valued. Flood protection (94.70%, ranked second) and storm protection (93.02%, ranked third) received strong recognition, followed by biodiversity protection (87.69%, ranked fourth), water quality maintenance (87.00%, ranked sixth), and soil erosion prevention (85.00%, ranked seventh). The role of mangroves in trapping and filtering pollutants was also considered important (76.50%, ranked eighth). By contrast, water salinity regulation was rated less highly (58.25%, ranked twelfth).

For cultural services (recreation, education, and research), 66.00% of respondents rated them very important, ranking them eleventh overall. These results show that while fish and regulating services dominate local priorities, medicinal plants occupy a comparatively high position among provisioning services, ranking fifth overall in importance.

Table 8: Perception of the selected forest ecosystem services in the Mangrove Forest

Rank	Category	Service	Very Important (%)	Distribution of Responses (%)
1	Provisioning	Fish provision, shelter, and spawning grounds	95.24	VI (95.24), I (4.51), U (0.25), Ind (0), DK (0)
2	Regulating	Flood protection	94.70	VI (94.70), I (4.04), U (0.51), Ind (0.76), DK (0)
3	Regulating	Storm protection	93.02	VI (93.02), I (6.98), U (0), Ind (0), DK (0)
4	Regulating	Biodiversity protection	87.69	VI (87.69), I (12.31), U (0), Ind (0), DK (0)
5	Provisioning	Collection of NWFPs	86.53	VI (86.53), I (11.47), U (0.50), Ind (0.75), DK (0.75)
6	Regulating	Water quality maintenance	87.00	VI (87.00), I (9.75), U (0.50), Ind (1.00), DK (1.75)
7	Regulating	Soil erosion prevention	85.00	VI (85.00), I (13.75), U (0.25), Ind (0.25), DK (0.75)
8	Regulating	Trapping & filtering of pollutants	76.50	VI (76.50), I (20.25), U (0), Ind (1.25), DK (2.00)
9	Provisioning	Wood	71.82	VI (71.82), I (22.94), U (4.74), Ind (0.25), DK (0.25)
10	Provisioning	Support for germination and growth	70.93	VI (70.93), I (18.80), U (8.52), Ind (0.75), DK (1.00)
11	Cultural	Recreation, education, research	66.00	VI (66.00), I (30.00), U (0.75), Ind (1.50), DK (1.75)
12	Regulating	Water salinity regulation	58.25	VI (58.25), I (32.00), U (4.25), Ind (2.25), DK (3.25)

Source: Field data; Very Important= VI, Important = I, Unimportant = U, Indifferent = I, Don't Know = DK

5.2.3 Examples of Ecosystem Services from the Mangrove Forest Ecosystem

This section presents images illustrating selected examples of ecosystem services provided by the mangrove forests in the Amanzule wetlands, as classified in Table 8. Some of these include locally important wood resources (Fig. 10), sources of medicinal plants (Fig. 11), fish (Fig. 12), shrimp and crabs (Fig. 13), and recreational and tourism opportunities (Fig. 14). These illustrations provide visual examples of how mangrove forests contribute to subsistence, livelihoods, and cultural practices in coastal communities.

Fig. 10: Wood for firewood and local roofing materials (Photo: Author)

Fig. 11: Mangrove forests: a source of medicinal plants (Photo: Author)

Fig. 12: Fishing and fish provision (Photo: Author)

Fig. 13: Crabs and Shrimps (Photo: Adarkwah, 2024)

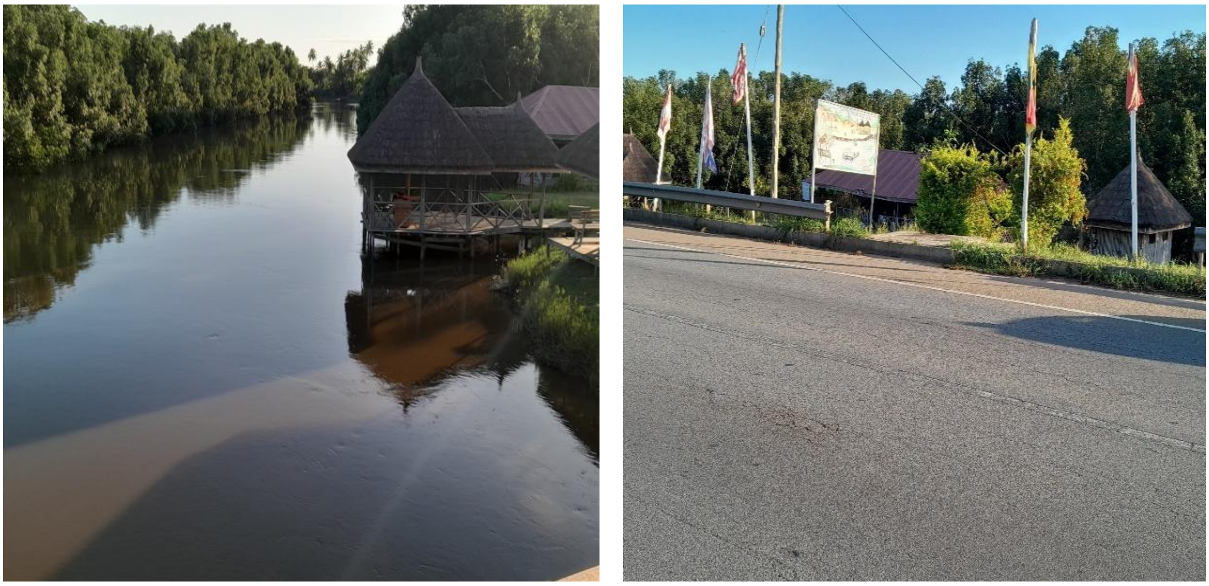


Fig. 14: Mangrove Forest ecosystem used for recreation (Photo: Author)

5.2.4 Climate Change and Land Use Change Drivers Affecting Medicinal Plant Availability in the Mangrove Ecosystem

The marginal effects from the regression analysis illustrate the influence of various climate change and land use change factors on medicinal plant availability in mangrove forest ecosystems (Table 9). The key drivers affecting medicinal plant availability include changes in temperature, coastal flooding, deforestation, excessive chemical use, overexploitation, and illegal small-scale mining.

i. Climate Change Drivers Affecting Medicinal Plant Availability in the Mangrove Ecosystem

Among the climate change factors, temperature changes and coastal flooding exhibited statistically significant effects on medicinal plant availability. Temperature changes had a positive and significant effect ($dy/dx = 0.09043$, $p = 0.025$). Coastal flooding also had a statistically significant positive impact on medicinal plant availability ($dy/dx = 0.095954$, $p = 0.037$). Conversely, erratic rainfall ($dy/dx = -0.002314$, $p = 0.786$), sea level rise ($dy/dx = 0.0036143$, $p = 0.658$), storms ($dy/dx = 0.000763$, $p = 0.916$), and forest fires ($dy/dx = 0.0054691$, $p = 0.197$) had statistically insignificant effects on medicinal plant availability.

ii. Land Use Change Drivers Affecting Medicinal Plant Availability in the Mangrove Ecosystem

Several land use change factors significantly influenced medicinal plant availability. Deforestation had a significant adverse effect (dy/dx = -0.01059, p = 0.042). Excessive chemical use exhibited a substantial adverse effect (dy/dx = -0.061344, p = 0.036). Overexploitation had a statistically significant adverse effect (dy/dx = -0.0023363, p = 0.046). Illegal small-scale mining also negatively affected medicinal plant availability (dy/dx = -0.012933, p = 0.0419). Sand winning, in contrast, was positively associated with perceived availability (dy/dx = 0.0083, p = 0.038). Other land use factors, such as slash-and-burn practices (dy/dx = 0.0048328, p = 0.527), infrastructure development (dy/dx = 0.01151, p = 0.172), grazing of mangroves by livestock (dy/dx = 0.0016588, p = 0.916), and invasive species (dy/dx = -0.0042191, p = 0.680), did not show statistically significant effects on medicinal plant availability.

Table 9: Marginal Effects of Climate and Land Use Change Drivers Affecting Medicinal Plant Availability in the Mangrove Forest Ecosystem

Variable	dy/dx	Std. Err.	z	P>|z|	[95% Conf. Interval]
Erratic rainfall	-0.002314	0.00851	-0.27	0.786	-0.018988 - 0.01436
Rising Temperature	0.09043*	0.00801	1.13	0.025	0.06656 - 0.24741
Sea Level Rise	0.0036143	0.00817	0.44	0.658	-0.012398 - 0.019627
Coastal Flooding	0.095954*	0.00765	1.25	0.037	0.05394 - 0.64585
Storms	0.000763	0.00726	0.11	0.916	-0.013462 - 0.014988
Deforestation	-0.01059*	0.00882	0.01	0.0420	0.00176 - 0.037388
Forest fires	0.0054691	0.00424	1.29	0.197	-0.002832 - 0.013771
Slash and Burn	0.0048328	0.00764	0.63	0.527	-0.010149 - 0.019814
Infrastructure Development	0.01151	0.00843	1.37	0.172	-0.005003 - 0.028023
Excessive Chemical Use	-0.061344*	0.06812	-0.90	0.036	0.019483 - 0.092142
Overexploitation	-0.023363*	0.00531	-0.44	0.0460	-0.012743 - 0.0807
Illegal Small-Scale Mining	-0.012933*	0.01787	-0.72	0.0419	-0.007949 - 0.052083
Grazing of Mangroves by Livestock	0.0016588	0.01571	0.11	0.916	-0.029131 - 0.032449
Sand Winning	0.008267*	0.00398	2.08	0.038	0.000467 - 0.016067
Invasive Species	-0.0042191	0.01023	-0.41	0.680	-0.024266 - 0.015828

** $p<0.05$

Logistic Regression Results:

Number of observations: 387
LR $chi^2(16) = 86.12$
Prob > $chi^2 = 0.0000$
Log likelihood = -32.73108
Pseudo $R^2 = 0.5681$

5.2.5 Perceived Community-Based Management and Adaptation Strategies for Sustaining Mangrove Ecosystem Services

Figure 15 presents the management strategies implemented to conserve the mangrove ecosystem in the Amanzule wetland area. The most widely adopted strategy is growing awareness (98.98%). Reforestation (97.19%) and mangrove nurseries (95.66%) are also extensively practised (Fig. 16). Policy interventions include prohibiting mangrove cutting (97.7%), prohibiting sand-winning (97.7%), and coastal zone planning (94.13%). Additionally, monitoring and evaluation (97.96%) and prevention of pollution (95.41%) are key strategies to maintain environmental quality. Economic and traditional approaches, such as alternative livelihoods (86.99%), incentives for conservation (91.07%), and traditional management systems (78.32%), are also in place to reduce pressure on mangrove resources.

The establishment of protected areas (92.09%) ensures long-term conservation. However, policies to conserve mangroves (69.13%) and traditional management systems show relatively lower implementation levels. While Figure 15 presents only the percentage of "yes" responses for each strategy, the full breakdown, including "no" responses, is available in Appendix 2. FGDs supported these findings, revealing a range of community-driven and livelihood-based strategies. These included nursery establishment, reforestation, awareness campaigns, enforcement of local bans on unsustainable practices, and collaboration with NGOs such as Hen Mpoano. Some participants also reported being engaged by oil and gas companies to grow vegetables for institutional catering. These farms, often near the wetlands, are now integrated into local livelihoods.

Two illustrative quotes from FGD participants reflect these dynamics:

> *"Some of our communities have banned cutting mangroves, but some still cut for woodfuel and roofing materials. We need bylaws and traditional authorities to help enforce the ban, but we will need an alternative livelihood so the cutting will stop completely."* — FGD participant, Allabokazo.
>
> *"Sometimes the NGOs, such as Hen Mpoano, come to train and support us in mangrove nurseries and replanting."* — FGD participant, Beyin.

These narratives highlight the interplay of traditional knowledge, local enforcement, external support, and policy initiatives in shaping mangrove conservation. Figure 6 shows mangrove nurseries and seedlings established by local communities during site visits.

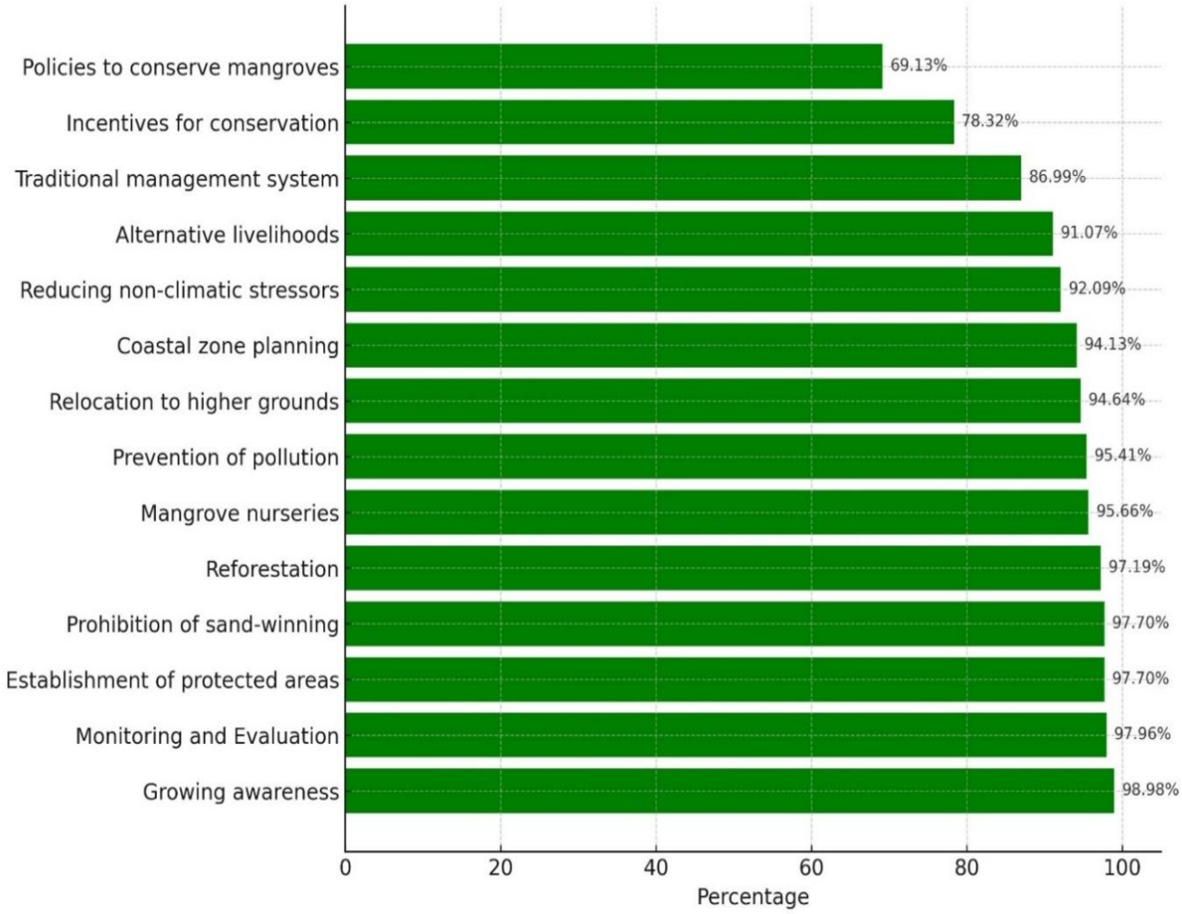


Fig. 15: Perceived community-based management and adaptation strategies for sustaining mangrove ecosystem services in the study area (Multiple responses)

Fig. 16: Community-based mangrove nurseries and seedlings established in the Amanzule wetlands as part of local reforestation activities (Photo: author).

5.2.6 Summary of Key Findings

- Rising temperature and coastal flooding (both climate change drivers) were found to increase the perceived availability of medicinal plants significantly.
- Other climate-related variables, including erratic rainfall, sea-level rise, and storms, showed no statistically significant influence.
- Land use change drivers such as deforestation, excessive chemical use, overexploitation, and illegal small-scale mining significantly reduced medicinal plant availability.
- Sand winning showed a statistically significant positive association with perceived medicinal plant availability, contrary to expectations.
- Other land use drivers, including forest fires, slash-and-burn agriculture, infrastructure development, grazing, and invasive species, did not exhibit significant effects.
- Reported community strategies included awareness creation, reforestation, establishment of mangrove nurseries, and restrictions on mangrove cutting and sand winning.
- Respondents frequently reported community-led strategies and the involvement of institutional actors such as the Forestry Commission and district assemblies, while formal policy implementation and traditional governance systems were cited less frequently.

6. SYNTHESIS OF RESULTS

6.1 Synthesis of Results: Manifestation of Climate Change in the Temperate and Mangrove Forests

This chapter synthesises empirical findings from the case studies conducted in the temperate forest (Czech Republic) and mangrove forest (Ghana). Drawing on the regression analyses and results presented in section 5, it explores the distinct ways in which climate and land use change affect forest ecosystems, specifically temperate and mangrove forests. While both forest types experience climate-related stressors, their manifestation is shaped by ecological, geographical, and socio-economic contexts. The synthesis does not aim at a direct comparison between countries but rather highlights ecosystem-specific patterns in climate-induced changes as perceived by local respondents. The findings show that climate change and land use change influence the availability of medicinal plants in both ecosystems, though with considerable variation. Table 10 presents the statistically significant marginal effects of climate and land use change drivers, as derived from the regression models. Only drivers with negative marginal effects were classified as threats. These effects are further visualised in Figure 17. Together, these results illustrate both overlapping and divergent pressures, forming the basis for the broader discussion and policy implications presented in section seven.

Table 10: **Statistically Significant Climate and Land Use Change Drivers Affecting Medicinal Plant Availability in Temperate and Mangrove Forests**

Ecosystem Type	**Climate Change Drivers**	**Statistically Significant Climate Variables & Effects**	**Land Use Change Drivers**	**Statistically Significant Land Use Variables & Effects**
Temperate Forest Ecosystem	Drought, Flood, Pest and Disease Outbreaks, Forest Fires	Climate Change (composite): dy/dx = -0.0387, p = 0.001 *(classified as a threat)*	Overexploitation, Logging, Excessive Chemical Use	Excessive Chemical Use: dy/dx = -0.0270, p = 0.020 *(classified as a threat)*
Mangrove Forest Ecosystem	Erratic Rainfall, Rising Temperature, Coastal Flooding, Sea-Level Rise, Storms	Rising Temperature: dy/dx = 0.09043, p = 0.025 Coastal Flooding: dy/dx = 0.095954, p = 0.037 *(not classified as threats)*	Deforestation, Overexploitation, Illegal Small-Scale Mining, Excessive Chemical Use, Sand Winning	Deforestation: dy/dx = -0.01059, p = 0.042 Overexploitation: dy/dx = -0.0023363, p = 0.046 Illegal Small-Scale Mining: dy/dx = -0.012933, p = 0.0419 Excessive Chemical Use: dy/dx = -0.061344, p = 0.036 *(all classified as threats)* Sand Winning: dy/dx = 0.008267, p = 0.038 *(not classified as a threat)*

Note: Only variables with negative marginal effects were classified as threats. Positive values suggest no perceived negative impact.

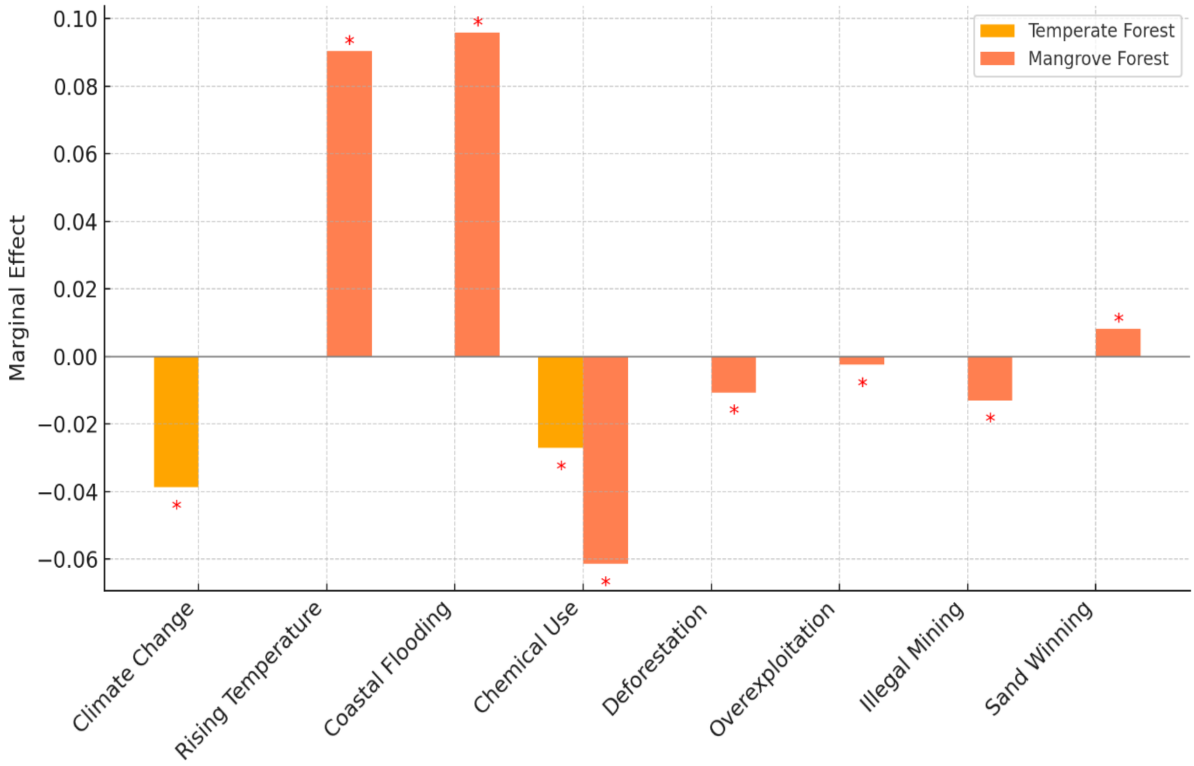


Fig. 17: Marginal effects of statistically significant climate and land use change drivers on medicinal plant availability in temperate and mangrove forests

6.2 Climate Change Effects

As summarised in Table 10 and Figure 17, climate change is perceived to influence medicinal plant availability in both forest ecosystems, though the nature and direction of these effects vary. In the temperate forest, only the composite climate change variable showed a statistically significant negative effect, indicating an overall perception of climate-related stressors affecting medicinal plant availability. However, individual manifestations such as drought, forest fires, or pest outbreaks were not independently significant. In the mangrove forest, while rising temperature and coastal flooding were statistically significant, their positive marginal effects suggest these factors were not perceived as threats. These locally experienced variations underscore the ecosystem-specific nature of climate-related impacts.

6.3 Land Use Change Drivers

As presented in Table 10 and Figure 17, land use change was a statistically significant factor influencing medicinal plant availability in both forest ecosystems, though with different drivers. In the temperate forests, excessive chemical use emerged as the only significant land use change driver, showing a negative marginal effect on medicinal plant availability. In the mangrove forests, several land use change drivers were statistically significant, including deforestation, overexploitation, illegal small-scale mining, and excessive chemical use, all of which exhibited negative marginal effects. Sand winning also showed statistical significance but had a positive marginal effect, indicating it was not perceived as a threat by respondents. These results reflect the ecosystem-specific pressures that shape the availability of medicinal plants.

6.4 Summary of Observed Management Strategies in the Two Study Areas

Respondents in both forest regions reported a range of forest management strategies aimed at mitigating the effects of climate and land use change. These strategies reflect ecological variation, local knowledge systems, and differing governance contexts. In the temperate forests, responses tended to emphasise formalised, state-supported approaches such as:

- Forest restoration through reforestation
- Tree species diversification
- Pest and disease control
- Landscape protection practices (e.g., ecological corridors)
- Use of organic farming methods near forest areas
- Fire prevention (noted by fewer respondents)
- Participation in formal conservation schemes

In contrast, respondents in the mangrove forest described more community-driven and livelihood-integrated approaches, including:

- Community-led mangrove nursery establishment
- Reforestation and enrichment planting
- Environmental awareness and education initiatives
- Enforcement of local bans on unsustainable activities (e.g., mangrove cutting, sand mining)
- Promotion of alternative livelihoods
- Participation in conservation programmes facilitated by NGOs and traditional authorities

These strategies are presented in Figure 9 (temperate forest) and Figure 15 (mangrove forest), as previously discussed in the results chapter. The contrasts underscore how forest management responses are shaped by institutional structures, environmental pressures, and cultural norms in each ecosystem.

6.5 Summary of Reported Forest Ecosystem Services

Respondents in both study areas reported a range of forest ecosystem services falling under provisioning, regulating, and cultural categories (Table 11). These services reflect the ecological characteristics and socio-economic priorities of each region. The temperate forests were primarily valued for NWFPs, including berries, mushrooms, and medicinal plants, as well as timber. Cultural and recreational uses such as hiking, education, and research were also commonly cited. Regulating services mentioned by respondents included flood protection, erosion control, clean water supply, carbon sequestration, and, to a lesser extent, air purification.

The mangrove forest respondents emphasised the subsistence value of ecosystem services. Key provisioning services included the supply of fish and shellfish, firewood, medicinal plants, and building materials. Regulating services such as flood and erosion control, water quality maintenance, storm buffering, and salinity regulation were considered essential. Cultural and spiritual values, along with uses for education and local knowledge transmission, were also recognised. The summary presented in Table 11 captures the main ecosystem services reported across both forest types. For detailed distributions and rankings, refer to Table 5 (temperate forests) and Table 8 (mangrove forests).

Table 11: Summary of Reported Forest Ecosystem Services in the Temperate and Mangrove Forest Ecosystem

Ecosystem Service Type	Temperate Forests	Mangrove Forests
Provisioning Services	NWFPs (e.g., berries, mushrooms, medicinal plants) Wood	Fish, crabs, shrimps Firewood Medicinal plants Building materials
Regulating Services	Clean water supply Erosion control Flood protection Carbon sequestration Air purification	Water quality maintenance Soil erosion prevention Flood protection Storm buffering Salinity regulation
Cultural Services	Recreational use Educational and research uses	Educational and research uses, spiritual values

7. DISCUSSION

This study found that climate change and land use drivers influence forest ecosystem services in both temperate and mangrove systems, with particular implications for medicinal plants. While climate-linked disturbances were more prominent in the Czech context, land use pressures dominated in Ghana, underscoring the vulnerability of ecosystem services to multiple stressors. The following sections discuss these findings in relation to existing literature and consider their implications for conservation and management.

7.1 Medicinal Plant Ecosystem Service in the Temperate and Mangrove Forests

7.1.1 Temperate Forests

Temperate forests provide a diverse array of ecosystem services, including timber production, recreation, and NWFPs. Among NWFPs, medicinal plants are especially important. In the Czech Republic, they are the second most valued ecosystem service after "natural habitat for plants and animals" (Purwestri et al., 2023b; see Table 5), highlighting their enduring societal, cultural, and therapeutic value (Šišák et al., 2016; Pawera et al., 2017).

The country has a long-standing tradition of using medicinal plants such as peppermint (*Mentha piperita*), chamomile (*Matricaria chamomilla*), and fennel (*Foeniculum vulgare*) for healing and wellness. Other widely used species include *Melissa officinalis*, *Plantago lanceolata*, and the flowers of *Tilia cordata* (small-leaved lime), all of which are typically gathered as NWFPs for domestic and alternative medicinal uses (Knotek et al., 2012; Amri et al., 2017; Neis et al., 2019). Public engagement with medicinal plants remains high and reflects a broader European pattern of interest in complementary and traditional therapies (Kemppainen et al., 2018; Pokladnikova and Selke-Krulichova, 2018; Dubánková, 2020).

Czech forest policy supports public access to specific NWFPs under Forest Act No. 289/1995 Coll., allowing the collection of certain medicinal plants, mushrooms, and berries while aiming to balance access and conservation goals (Šišák et al., 2016). National botanical initiatives, such as the PLADIAS database, have compiled extensive species distribution data, with over 13 million records across nearly 5,000 vascular plant taxa, thereby advancing biodiversity documentation (Wild et al., 2019; Chytrý et al., 2021; PLADIAS, 2024). The Czech forest also supports a range of native and rare medicinal plant species, including *Arnica montana*, *Fumaria officinalis*, and *Agrimonia eupatoria* (Kaplan et al., 2019; Wild et al., 2019). Despite this strong cultural and institutional foundation, ecological studies on medicinal plant regeneration, harvesting impacts, and habitat resilience remain limited. These knowledge gaps raise concerns about the long-term sustainability of these species.

7.1.2 Mangrove Forests

Mangrove forests are indispensable to coastal communities in Ghana, providing a wide range of ecosystem services, including firewood, medicinal plants, shoreline stabilisation, salinity regulation, and habitat for fish and shellfish (Awuku-Sowah et al., 2024). In this study, medicinal plants were ranked fifth among NWFPs (see Table 8), yet they remain culturally, spiritually, and economically significant within traditional healthcare systems and livelihoods. Local knowledge identifies multiple plant species (eg, *Avicennia germinans*, *Rhizophora racemosa*, and *Laguncularia racemosa*) as valuable for treating malaria, ulcers, cardiovascular ailments, wounds, and gastrointestinal issues (Awuku-Sowah et al., 2024; Adarkwah et al., 2024; Asante et al., 2023). Community members often use different plant parts, including bark, leaves, and roots to prepare decoctions, pastes, and infusions for healing and spiritual protection (Awuku-Sowah et al., 2022; Nabeelah Bibi et al., 2019). In addition to their medicinal uses, mangrove species also contribute to local economies. For example, *Rhizophora* bark is used to tan fishing nets, and its roots are used in constructing artisanal fish traps. This reflects the diverse functions these plants serve in supporting coastal livelihoods (Asante et al., 2023).

The perceived value of medicinal plants varies across communities, shaped by environmental conditions, cultural priorities, and levels of access to ecosystem resources. A study in Sanwoma village, for instance, identified medicinal plants as the third most valued mangrove service, after firewood and construction material. Nearly half of the residents in that community reported actively harvesting mangrove species for medicinal purposes (Asante et al., 2023). This pattern underscores the link between biodiversity use, cultural traditions, and subsistence needs in mangrove-dependent communities. Despite their high cultural and therapeutic value, community members noted that access to certain medicinal plants has become increasingly difficult. This perception is often associated with broader environmental changes in mangrove ecosystems, including habitat degradation caused by deforestation, saltwater intrusion, and illegal mining (Adarkwah et al., 2024; Dali et al., 2023; Asante et al., 2023). These concerns emphasise the need to examine how environmental pressures are affecting the availability of medicinal plant resources. This issue is addressed in the next section.

7.2 Impact of Climate Change on Medicinal Plant Availability

7.2.1 Impact of Climate Change on Medicinal Plant Availability in the Temperate Forest

The regression analysis confirms a statistically significant negative relationship between climate change and the availability of medicinal plants in temperate forests. Climate change, as an individual predictor, had a clear adverse effect, underscoring the vulnerability of temperate forests to climatic stressors. This finding aligns with existing literature, which identifies prolonged droughts, pest infestations, forest fires, and flooding as key manifestations of climate change in the Czech Republic (Hlásny et al., 2021). These disturbances have degraded forest ecosystems and contributed to a decline in species richness, including medicinal plants. For instance, the IUCN (2024) reports increasing threats to species such as *Betonica officinalis* and *Althaea officinalis*, both of which are sensitive to changing environmental conditions.

Further evidence is provided by Čermák et al. (2021), who reported declining climatic suitability for *Picea abies* (Norway spruce), a species with known medicinal value, due to rising temperatures and reduced precipitation. Similar patterns are observed across Central Europe, where climate change has led to falling groundwater levels, reduced forest productivity, and increased plant mortality (Naumann et al., 2021). In Mediterranean regions, Pollastrini et al. (2018) found that drought stress has altered the yield and chemical composition of medicinal plants, reinforcing the broader vulnerability of temperate flora to climatic variability.

While these findings confirm a negative ecological trend, it is important to note that the study results are perception-based rather than derived from direct ecological measurements. As Millner and Ollivier (2016) note, public perceptions of environmental change are often influenced more by media narratives and policy focus than by detailed scientific observation. This may explain why some specific climate stressors (eg, drought, flooding, pests, and forest fires) did not show statistically significant effects in the regression model. These disturbances may impact medicinal plants in indirect or gradual ways that are not easily recognised by non-experts. Asah and Blahna (2020) also observed that limited ecological knowledge can constrain the public's ability to accurately perceive environmental risks, especially regarding forest species with complex habitat dynamics.

Despite their limitations, perception-based findings offer valuable insights into how environmental change is experienced and interpreted by the public. They contribute to a growing body of literature that emphasises the role of local knowledge and cultural values in forest ecosystem assessments (Pawera et al., 2017; Wolfslehner et al., 2019). These insights are especially valuable in settings with limited ecological monitoring, as they can reveal early signs of environmental change observed by local communities, often before such changes are documented through scientific research.

7.2.2 Impact of Climate Change on Medicinal Plant Availability in the Mangrove Forest

In contrast to the temperate forest findings, regression analysis in the mangrove ecosystem revealed a positive association between climate change proxies, specifically rising temperatures and coastal flooding, and the perceived availability of medicinal plants. Although climate change is widely recognised as a source of ecological stress, these results suggest that under specific conditions, certain climatic factors may temporarily enhance the growth or availability of medicinal plants in mangrove environments. This interpretation is supported by qualitative insights from focus group discussions. Several participants observed that *"some herbs come back faster after flooding" or "like wet ground."* Others noted that hotter weather seemed to trigger the reappearance of particular species. One respondent from Atuabo explained, *"The weather changes fast, and it gets hotter these days. But some of the medicinal plants grow more when the sun is stronger, like 'nunum' and 'Awommaa guwakyi',"* referring to African Basil and *Phyllanthus* sp. Similarly, a participant from Ampain commented, *"Flooding is a major problem here, but it transports black soil that makes the plants grow well."*

These perceptions align with ecological studies. Rising temperatures in tropical systems like Ghana may enhance photosynthesis and biomass production under certain conditions, particularly when water and nutrient availability are sufficient (Inoue et al., 2022). Many mangrove-associated plant species are heat-tolerant and benefit from moderate warming. In some cases, higher temperatures have also been linked to increased production of bioactive compounds that contribute to the medicinal value of plants (Alum, 2024).

Coastal flooding, when moderate, can deliver nutrient-rich sediments that improve soil fertility and stimulate plant growth (Wigand et al., 2021). Mangrove forests are effective at trapping these sediments, which can facilitate habitat expansion for fast-growing, disturbance-tolerant medicinal species (Krauss et al., 2014). These dynamics help explain local perceptions of increased medicinal plant abundance following flooding. However, these benefits are not universal. Prolonged or excessive flooding may result in salinity stress, reduced oxygen availability, and waterlogging, which can inhibit plant regeneration and survival (Chen and Ye, 2014; Zhang et al., 2025).

Key informant interviews reinforced these limitations. As one local herbalist noted, *"Species like African Basil and Mint seem to do well in warmer, occasionally flooded places. However, Phyllanthus sp. struggles when there is too much water."* These findings highlight the species-specific and context-dependent nature of climate change impacts on medicinal plants. While certain climatic shifts may contribute to short-term increases in availability, they do not necessarily ensure long-term ecological resilience. Conservation strategies must therefore be tailored to address the differentiated responses of medicinal species and to manage both the opportunities and risks associated with climate variability.

7.3 Role of Land Use Change Impacting Medicinal Plant Availability

7.3.1 Land Use Change Effect on Medicinal Plants in the Temperate Forest

In the temperate forests of the Czech Republic, excessive chemical use emerged as the only statistically significant land use factor negatively associated with medicinal plant availability. Regression results from this study confirm that respondents perceive agrochemical inputs, particularly synthetic fertilisers and pesticides, as major threats to the persistence of medicinal species in forest and peri-forest landscapes. These findings are consistent with ecological research showing that chemical-intensive practices degrade soil quality, harm non-target species, and reduce biodiversity (Chen et al., 2016; Sharma et al., 2019; Pavela et al., 2021). Such inputs can alter the ecological conditions needed for medicinal plant growth, reproduction, and regeneration. Over time, these disruptions may erode the availability of culturally and therapeutically important medicinal species, which could diminish the provisioning role of forests and affect local health and wellbeing.

Although this study is based on perception, it is supported by empirical studies and offers meaningful insight into how the public understands ecological change. As Millner and Ollivier (2016) note, public awareness of environmental risks is often shaped by visible changes and media narratives. In this context, perception-based data can serve as early signals of broader ecological change that may not yet be reflected in formal monitoring systems.

Growing concern over chemical use reflects wider sustainability challenges associated with intensive land management practices, which have implications for both agricultural ecosystems and forest biodiversity (Sharma et al., 2019; Wolfslehner et al., 2019). In temperate forest contexts, this concern underscores the ecological risks associated with chemical-intensive land use practices. As shown by the regression results derived from perception-based data in this study, excessive agrochemical use degrades the environmental conditions necessary for medicinal plant sustainability. These findings indicate the need for more integrated land use strategies that prioritise biodiversity conservation and forest ecosystem health.

7.3.2 Land Use Change Effect on Medicinal Plants in the Mangrove Forest

Multiple land use change drivers in mangrove ecosystems significantly affect medicinal plant availability. Regression analysis identified illegal small-scale mining, deforestation, overexploitation of mangroves, and excessive chemical use as key threats. These findings were supported by FGDs and KIIs:

> *"Once the machines clear the land, even the roots are gone, and the mangrove forest that gave us herbs is now a pit."*
>
> *"The chemicals from farming, 'galamsey [small-scale illegal mining]', and waste are killing our medicinal herbs. Some have disappeared and do not even come back."*
>
> *"The oil companies and rubber farmers came and cleared part of our forest for oil and gas facilities and rubber plantations. Since then, we have lost a lot of mangrove forest and medicinal plants."*

These local narratives corroborate the statistical evidence of reduced medicinal plant availability and align with regional studies documenting the degradation of mangrove ecosystems across West Africa (Feka, 2015). Illegal mining, in particular, is highly destructive. Its unregulated extraction methods cause deforestation, soil degradation, and water pollution through toxic substances such as mercury, thereby limiting mangrove regeneration (Obodai et al., 2024).

Deforestation driven by agricultural expansion and infrastructure development, including oil and gas installations, is consistent with findings by Adarkwah et al. (2024) and Karki et al. (2018), who describe how such changes fragment habitats, alter microclimates, and disrupt natural regeneration processes. These disturbances reduce ecological resilience and increase interspecies competition, particularly affecting medicinal plants sensitive to environmental shifts (Adnan and Hölscher, 2011).

The overexploitation of mangroves for medicinal, domestic, and commercial purposes also contributes significantly to species depletion. While mangroves are widely known for their therapeutic uses (Awuku-Sowah et al., 2023), unsustainable extraction practices, especially without conservation strategies, align with previous observations of declining species diversity and abundance (Feka, 2015).

Chemical runoff from agriculture and industrial activities further exacerbates these challenges. Pollutants leach into mangrove soils and waterways, compromising plant health and reducing regeneration capacity (Chakraborty et al., 2023). These impacts correspond with broader findings that link weak regulatory enforcement and land use intensification to ecosystem degradation in West African coastal regions (Quenum et al., 2023; Ofori et al., 2023b).

A noteworthy result is the positive association between sand winning and perceived medicinal plant availability. While typically considered ecologically harmful, this association may reflect short-term ecological dynamics. Singh et al. (2022) noted that fast-growing, disturbance-tolerant herbs often colonise areas cleared by sand extraction. Improved visibility and access may also shape perceptions of abundance. However, these short-term gains may obscure long-term ecological risks. As Shackleton and Pandey (2014) argue, temporary increases in valuable species should not be interpreted as indicators of ecosystem health. These findings underscore the complex and often contradictory impacts of land use change in mangrove ecosystems. They highlight the need for locally informed management strategies that address both immediate access to medicinal plants and the long-term sustainability of mangrove habitats.

7.3.3 Perceived Interactions Between Land Use Change and Climate Change

While the regression model assessed land use and climate drivers as independent variables, findings from the mangrove forest suggest that local communities perceive these pressures as interconnected. FGDs and KIIs revealed that land use activities, such as deforestation, illegal mining, and agrochemical runoff, were viewed as intensifying the impacts of climate-related stressors. As one participant from Bakanta explained:

> *"It is not only the heat or the floods that are our problems. When you cut the mangroves and also burn the bush, the problems become worse."*

Respondents described how land degradation reduces the mangrove's capacity to mitigate the impact of climate variability, altering the effects of temperature changes and flooding. While the regression model shows that certain herbs may benefit from warmer conditions and periodic flooding, these advantages were often seen as limited to less disturbed environments. In degraded areas, similar climatic events were perceived as more damaging, suggesting that land use change may influence how climate variability affects medicinal plant availability. These local perceptions reflect findings across West Africa and other tropical regions, where overlapping anthropogenic and climatic pressures are known to compromise ecosystem stability (Feka, 2015; Reyes-García et al., 2019; Kolka et al., 2016).

In the temperate forest, although no qualitative data were collected, the regression results suggest a potential feedback loop. Excessive agrochemical use was negatively associated with medicinal plant availability. These pressures can disrupt biodiversity and diminish forest resilience to climate-induced disturbances, such as drought or pest outbreaks (Pavela et al., 2021; Seidl et al., 2017). When the natural capacity of forests to moderate environmental stress is weakened, climate stressors may have more severe and lasting impacts, further reducing the suitable environmental conditions for medicinal species.

Together, these findings highlight the importance of recognising and addressing the interlinked nature of climate and land use stressors. The IPBES Global Assessment Report (2019) warns that ignoring these interactions may lead to underestimating ecosystem vulnerability. In both ecosystems studied, a failure to integrate land governance and climate adaptation could undermine long-term conservation goals. Coordinated strategies that combine land restoration, biodiversity protection, and climate resilience, guided by scientific data and local perspectives, are essential for sustaining medicinal plant resources in the face of compounding pressures.

7.4 Management and Adaptation Strategies

7.4.1 Czech Republic: Forest Management in Temperate Ecosystems

The findings show that while some forest owners in the Czech Republic engage in sustainable forest practices, the adoption of management strategies remains uneven. Among the strategies listed in the survey, forest restoration (30.2%) was the most commonly reported, followed by organic agriculture and landscape protection (both 22.6%). Forest restoration is particularly relevant for climate adaptation, as it enhances forest structure, increases species diversity, and improves resilience to stressors such as drought, heat, and pest outbreaks (Seidl et al., 2017). Maintaining canopy cover and stabilising soils through restoration supports the growth and persistence of medicinal plants by improving habitat conditions.

Some respondents identified organic agriculture as a means of reducing synthetic chemical use, a key factor associated with declining medicinal plant availability in the regression model. This is supported by prior research showing that organic practices improve soil quality and reduce risks to beneficial organisms (Chen et al., 2016; Pavela et al., 2021). By limiting agrochemical inputs, such approaches promote healthier ecosystems that favour medicinal plant regeneration.

Other strategies, such as pest control (17%), soil and water protection (9.4%), and fire prevention (5.7%), were less frequently implemented. Although these measures may not directly target climate or chemical pressures, they are key in maintaining overall forest health. For example, soil and water conservation enhances moisture retention and reduces erosion (EEA, 2024; Climate ADAPT, 2023), which could contribute to more stable habitat conditions for medicinal plants. Landscape protection supports connections between forest habitats, helping reduce extreme weather impacts and limit biodiversity loss (Hoffmann et al., 2025). Integrated fire and pest management are also essential components of climate-resilient forestry, helping areas withstand climate change exacerbations (Seidl et al., 2017; Oliveras Menor et al., 2025).

Despite the potential benefits of these practices, more than half of the respondents (54.7%) reported not implementing any of the management strategies listed. This may reflect limited resources, low awareness, or inadequate policy support. It could also indicate reliance on informal practices, such as selective thinning or natural regeneration, which were not captured by the survey. These practices may be informed by traditional knowledge and can contribute to maintaining biodiversity and ecosystem function.

Participation in formal conservation programmes was particularly low. Only 3.8% of respondents reported engagement with Natura 2000, and 7.5% participated in rural development schemes. This suggests weak alignment between private forest management and institutional conservation frameworks, a pattern also reported in other European contexts (CEEWeb, 2019).

It is also worth noting that approximately 50% of forests in the Czech Republic are publicly owned and managed by large entities such as Lesy ČR and the Army Forests (Janová et al., 2022). These organisations typically follow coordinated forest management plans. Because this study focused exclusively on private forest owners, the findings represent only part of the national forest management picture. To promote wider uptake of sustainable forest strategies, more tailored advisory services, financial support, and enhanced policy integration are needed. Extension programmes should be designed to meet the needs of small-scale forest owners while recognising the contribution of informal practices. Strengthening these connections may help align national forest policy goals with the day-to-day practices of forest owners and contribute to the long-term sustainability of medicinal plant resources.

7.4.2 Ghana: Management Strategies in the Mangrove Ecosystem

The findings reveal a high level of community awareness and involvement in mangrove management strategies across the Amanzule wetlands to help sustain medicinal plant availability. Most respondents reported familiarity with key interventions such as reforestation (97.19%), nursery establishment (95.66%), and community monitoring (97.96%). These strategies were widely implemented locally, often supported by NGOs and traditional authorities. This community engagement aligns with earlier studies that highlight the central role of local actors in sustaining mangrove ecosystem services in Ghana (Aheto et al., 2016; Asante et al., 2017; Owusu-Achiaw and Osei-Owusu, 2023).

Respondents also identified various regulatory and planning interventions, including community-imposed bans on sand winning and mangrove cutting, coastal zone planning, and the relocation of settlements affected by sea-level rise. These actions demonstrate local commitment to conservation, although they are often weakened by the absence of formal legal protection for the Amanzule wetlands and poor enforcement of environmental regulations (BirdLife International, 2024; Adarkwah et al., 2024).

In addition to ecological initiatives, respondents emphasised the importance of economic and cultural strategies. These included alternative livelihoods (91.07%), traditional management systems (86.99%), and conservation incentives (78.32%). For example, oil and gas companies have contracted some community members to supply vegetables, promoting income diversification. However, using agrochemicals on farms near the wetlands raises concerns about runoff and ecosystem pollution. Comparable challenges have been documented in Vietnam and Papua New Guinea, where agricultural expansion without adequate regulation has contributed to wetland degradation (Walker et al., 2020; Wang and Gu, 2021).

Notably, these local management practices support broader conservation objectives and contribute to the availability of medicinal plants, which are an essential provisioning service in the Amanzule wetlands. Community members especially valued nursery establishment and reforestation for restoring plant species used in traditional medicine. Despite these efforts, respondents frequently noted the lack of tools, financial support, and consistent institutional follow-up, which limits the sustainability of their initiatives.

Although awareness of local and community-driven strategies was high, familiarity with national conservation frameworks was relatively low (69.13%). This highlights a disconnect between policy-level conservation efforts and their implementation or understanding at the community level. As one local NGO representative noted, *"We know how to protect the forest, but we cannot do enough without money and support."* A focus group participant commented, *"Sometimes the 'big people [the political class]' come to talk, but nothing changes. We are the ones here with the mangroves, and we need help to protect them."*

These governance and implementation challenges are comparable to those reported in Southeast Asia and the Pacific, where overlapping responsibilities, limited coordination, and funding shortfalls have slowed mangrove conservation progress (Friess et al., 2016; Sasmito et al., 2019). Similar patterns have been observed in Ecuador, the Philippines, and Cameroon, where civil society actors have taken on crucial roles in bridging governance gaps and promoting local stewardship (Bustamante et al., 2018; Feka, 2015; Friess et al., 2022).

Long-term mangrove conservation in Ghana requires stronger institutional backing, clearer legal protection, and the integration of traditional knowledge into formal governance. Collaboration among communities, NGOs, and state agencies and sustained financial support are critical for maintaining ecosystem health and securing medicinal plant resources. These governance challenges reflect broader global patterns, as similar coordination and implementation gaps have been observed in Latin America, Asia, and Africa (Segaran et al., 2023; Friess et al., 2016).

7.5 Policy Implications

The findings of this study highlight several areas where national and regional policy frameworks could be strengthened to support forest resilience and secure medicinal plant resources. Key policy measures are as follows:

Temperate Forest

- Integrate NWFPs, including medicinal plants, into national forest policy to ensure recognition and sustainable use.
- Regulate agrochemical use more strictly, given its adverse impacts on medicinal plant availability.
- Align Czech Forest policy with EU frameworks, such as the Biodiversity Strategy for 2030, and deepen engagement with conservation initiatives like Natura 2000.
- Incorporate climate adaptation measures more explicitly into forest planning, including drought-tolerant species, species diversification, and ecosystem-based approaches.

Mangrove Forest

- Grant formal protection status to the Amanzule Wetland for stronger regulatory backing and long-term management capacity.
- Strengthen co-management frameworks involving traditional authorities, local communities, and state institutions to improve accountability and shared stewardship.
- Prioritise financing and implementation of national climate adaptation plans at the district level, embedding them in local development strategies to translate policy into action.

7.6 Practical Recommendations

Beyond policy-level measures, this study also identifies practical steps that communities, forest owners, and local institutions can take to strengthen adaptation, improve conservation, and safeguard medicinal plant resources. These practical recommendations include:

Temperate Forest

- Strengthen advisory support for private forest owners, including financial incentives for forest restoration, pest control, and environmentally friendly practices.
- Expand restoration efforts to improve resilience against drought, pests, and other climate-related stressors while sustaining biodiversity and medicinal plant resources.

Mangrove Forest

- Boost local enforcement capacity to address illegal mining and unsustainable harvesting practices.
- Support alternative livelihoods such as ecotourism, agroforestry, and incentive-based conservation programmes to reduce pressure on mangrove resources and enhance community resilience.
- Enhance environmental awareness campaigns and community-driven initiatives, building on existing conservation efforts with stronger technical and institutional support.

7.7 Reflection on Research Hypotheses

This study tested two hypotheses (climate change and land use change) and addressed two research questions (importance of medicinal plants and management strategies). The findings are as follows:

❖ **Climate change (H_{01}/H_1):**

- In the Czech temperate forests, climate change had a statistically significant negative effect on medicinal plant availability, leading to the rejection of the null hypothesis. Climate drivers such as temperature rise and coastal flooding were statistically significant in the Ghanaian mangroves. However, they were not widely perceived as threats, so the null hypothesis was not rejected in that context.

- **Land use change (H_{02}/H_2):**
  - In the Czech Republic, excessive chemical use in agriculture and forestry significantly reduced medicinal plant availability. In Ghana, land use pressures such as deforestation, mining, and overexploitation strongly negatively affected medicinal plant availability. The null hypothesis was rejected in both cases, confirming land use change as a major driver.
- **Relative importance of medicinal plants (RQ1):**
  - In the Czech Republic, medicinal plants were valued but ranked below services such as biodiversity conservation and water-related benefits. In Ghana, medicinal plants ranked among the most important services, reflecting strong community dependence on them for health and livelihoods.
- **Management strategies (RQ2):**
  - In the Czech Republic, management approaches were mainly formal and policy-driven, linked to conservation regulations and national forest policy frameworks. In Ghana, management strategies were mainly community-based and tied to local livelihoods and traditional practices, though with limited institutional support.

The findings demonstrate that while climate change and land use change affect medicinal plant availability, land use drivers consistently negatively influence across both contexts. Climate change impacts are more context-specific, with adverse effects perceived in temperate forests but less clearly recognised as threats in mangrove ecosystems. Furthermore, the relative importance of medicinal plants and the types of management strategies differ between the two countries, reflecting the influence of ecological conditions, governance structures, and community dependence on forest resources.

7.5 Study Limitations

Building on the methodological limitations discussed in Chapter 3, this section reflects on additional constraints encountered during the interpretation of the results. While this study offers valuable insights into the impacts of climate and land use change on forest ecosystem services (medicinal plants) in two contrasting contexts, several limitations should be acknowledged.

First, differences in forest governance structures and respondent categories may limit direct comparability between the two contexts. In the Czech Republic, climate and land use change drivers were assessed through a large-scale national survey of 1,500 public respondents, while forest management strategies were explored through interviews with 53 private forest owners. In Ghana, 400 community members responded to both sets of questions in a communally managed mangrove forest context. These differences reflect varying institutional settings and modes of forest ownership, which shape how people perceive and respond to environmental change.

Second, the cross-sectional nature of the study captures conditions at a single point in time. As a result, it cannot track long-term trends or evaluate the effectiveness of adaptation strategies over time. Future research could benefit from longitudinal approaches to better understand the dynamics of ecosystem change and community responses. Despite these limitations, the study provides context-specific findings that enhance our understanding of forest vulnerability and adaptive management under changing environmental conditions.

8. CONCLUSION

This study examined how climate and land use change affect forest ecosystem services, focusing on medicinal plants in temperate forests of the Czech Republic and mangrove ecosystems in Ghana. Applying a unified methodological framework across contrasting ecological and socio-economic contexts demonstrated how similar drivers manifest differently, while also showing the value of combining scientific and community-based perspectives.

The findings reveal that climate change and land use pressures undermine medicinal plant availability in distinct ways. In the Czech Republic, climate-linked disturbances, compounded by chemical use and intensive forestry, were most critical. In Ghana, land use drivers such as deforestation, illegal mining, and overharvesting posed the most significant threats. Across both regions, medicinal plants consistently emerged as highly vulnerable, reflecting their dual role as livelihood and cultural resources and as indicators of broader ecosystem resilience.

Methodologically, the study shows how perception-based assessments combined with mixed-methods analysis can provide nuanced insights into ecosystem service vulnerability across regions. Conceptually, it underscores that safeguarding medicinal plants and associated ecosystem services requires context-specific strategies. It also points to common principles such as participatory governance, stronger policy integration of NWFPs, and recognition of local knowledge. Together, these insights contribute to the development of conservation approaches that are ecologically grounded and socially responsive, offering lessons for forest resilience in a changing global environment.

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APPENDICES

Appendix 1: Perceived importance of mangrove forest ecosystem services among respondents

	Perception	Ranking (%)				
	Ecosystem services	Very important	Important	Unimportant	Indifferent	I don't know
1	Wood	71.82	22.94	4.74	0.25	0.25
2	Fish provision, shelter and spawning grounds	95.24	4.51	0.25	0	0
3	Collection of NWFPs	86.53	11.47	0.50	0.75	0.75
4	Biodiversity protection	87.69	12.31	0	0	0
5	Storms protection	93.02	6.98	0	0	0
6	Flood protection	94.70	4.04	0.51	0.76	0
7	Water quality maintenance	87.00	9.75	0.50	1.00	1.75
8	Trapping & filtering of pollutants	76.50	20.25	0	1.25	2.00
9	Soil erosion prevention	85.00	13.75	0.25	0.25	0.75
10	Water salinity regulation	58.25	32.00	4.25	2.25	3.25
11	Recreation, education & research	66.00	30.00	0.75	1.50	1.75
12	Providing support for germination and growth	70.93	18.80	8.52	0.75	1.00

Appendix 2: Perceived community-based management and adaptation strategies for sustaining mangrove ecosystem services.

	Management and adaptation strategies	Yes (%)	No (%)
1.	Growing awareness	98.98	1.02
2.	Mangrove nurseries	95.66	4.34
3.	Reforestation	97.19	2.81
4.	Policies to conserve mangroves	69.13	30.87
5.	Traditional management system	86.99	13.01
6.	Alternative livelihoods	91.07	8.93
7.	Incentives for conservation	78.32	21.68
8.	Prevention of pollution in mangrove areas	95.41	4.59
9.	Monitoring and Evaluation	97.96	2.04
10.	Establishment of protected areas	97.70	2.30
11.	Reducing non-climatic stressors, e.g. Human disturbance	92.09	7.91
12.	Prohibition of sand-winning	97.70	2.30
13.	Coastal zone planning	94.13	5.87
14.	Relocation of communities to higher grounds	94.64	5.36

Appendix 3: Survey Questionnaire for Czech Study

Czech University of Life Sciences Prague
Faculty of Forestry and Wood Sciences

A. Respondent Data

Age of respondents: ……………..

Current weight: … kg, weighing scale used □ digital or □ non-digital
Current height: …. Cm, height measurement used: □ digital or □ non-digital

Mark the chosen criteria by X

Gender

Man	
Woman	

Education

Elementary	
vocational training branch	
high school with the Maturita Award	
University	

Residential information

Size of the place of residence?

Less than 1000 inhabitants	
1 000 - 4 999 inhabitants	
5 000 - 19 999 inhabitants	
20 000 - 99 999 inhabitants	
100 000 more than	

Distance of resident place to the nearest Forests: …………. in km

District:

- □ Hl. město Praha
- □ Středočeský
- □ Jihočeský
- □ Plzeňský
- □ Karlovarský
- □ Ústecký
- □ Liberecký
- □ Královéhradecký
- □ Pardubický

- ☐ Vysočina
- ☐ Jihomoravský
- ☐ Olomoucký
- ☐ Zlínský
- ☐ Moravskoslezský

Google map of the municipality of the respondent's residential location

Connection to the Czech forestry

- ☐ Forest owner, continue to below questions (F)
- ☐ Forest manager (at management level), continue to below questions (F)
- ☐ Work directly in the Czech forest-based sector (employee)
- ☐ Work in the value-chain of the Czech forest-based sector
- ☐ Obtained a formal education in the Czech forest-related sector
- ☐ A close family has a relation with the Czech forestry
- ☐ Not connected

B. Follow-Up Questionnaire for the Forest Managers/Owners

1. What is the total size of your forest property/ the forest you manage? (Please include all the plots you take care of, even if they are split)
   - ☐ 1 ha or less
   - ☐ 1-4 ha
   - ☐ 5-9 ha
   - ☐ 10-24 ha
   - ☐ 25-99 ha
   - ☐ 100-129 ha
   - ☐ 200 ha or more

2. What kind of forest are you taking care of?
   - ☐ Private non-industrial forest (individual or family owned)
   - ☐ Private forest (company or another legal person)
   - ☐ State forest
   - ☐ City forest (municipality or city forest)
   - ☐ Cooperative
   - ☐ Church

C. Forest Ecosystem Services

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1. Which products and services do you perceive as the most important:

very important	Rather important	Neither important nor unimportant	rather unimportant	Not important at all	I don´t know	
5	4	3	2	1	0	Production of oxygen and ability of trees to purify the air

very important	Rather important	Neither important nor unimportant	rather unimportant	Not important at all	I don´t know	
5	4	3	2	1	0	Wood production (firewood, wood as construction material, wood for decorations)
5	4	3	2	1	0	Collection of mushrooms, berries, herbal medicine, and other non-wood forest products
5	4	3	2	1	0	Water retention function/reservoir of pure natural water
5	4	3	2	1	0	Protection of floods
5	4	3	2	1	0	Mitigation of climate and carbon sequestration by trees
5	4	3	2	1	0	Prevention of soil erosion
5	4	3	2	1	0	Reduction of dust and noise pollution
5	4	3	2	1	0	Natural habitat of game, birds and insects
5	4	3	2	1	0	Employment opportunities and supporting of rural development
5	4	3	2	1	0	Public space for recreational activities (hiking, geocaching, camping, hunting, bird watching etc.)
5	4	3	2	1	0	Provision of sport activities (e.g., running races)
5	4	3	2	1	0	Other provisions/services to improve the human's health, e.g., place of rehabilitation center, forest bathing/therapy, etc.
5	4	3	2	1	0	Forest contribution to landscape beauty
5	4	3	2	1	0	Cultural and spiritual importance (legends, fairy tales)
5	4	3	2	1	0	Meditation and relaxation (enable to coexist with nature)

2. Do you depend on medicinal plants in any way?

☐ Yes

In what ways (please tick as many as apply)

- ☐ Personal use
- ☐ Collection for sale
- ☐ Manufacture of medicine
- ☐ Spiritual use
- ☐ Naturopathic/herbal practice
- ☐ Any other uses (specify)

....

How was/is the frequency of use of medicinal plants before and during the COVID-19 pandemic?

Before the COVID pandemic	**After the COVID pandemic**
☐ Never	☐ Never
☐ Rarely, less than 6 times per year	☐ Rarely, less than 6 times per year
☐ 1-3 times per month	☐ 1-3 times per month
☐ 1-2 times per week	☐ 1-2 times per week
☐ More than 3 times per week	☐ More than 3 times per week
☐ Daily	☐ Daily

☐ No

3. Do any factors affect the availability of medicinal plants in the forest?

☐ Yes No

4. To what extent do you agree with the following as affecting medicinal plants?

STATEMENTS	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
	5	4	3	2	1
Climate change					
Flooding					
Drought					
Pest and disease attack					
Over-exploitation of the medicinal plants					
Excessive use of chemicals					
Logging					
Forest fires					

5. Are you involved in programs/associations/projects/labels / legal obligations in which you commit to implementing management measures in the forests under your charge or surrounding areas? Have you received subsidies, technical assistance, payments, etc.?

	Yes	No	Subsidies	technical assistance	payment for ecosystem services	Other
Forest restoration						
Organic or environmentally friendly agriculture						
Forest fire management						
Pest and Invasive species control						
Landscape conservation						
/Soil and water protection measures						
Natura2000						
Rural development schemes						
Other, please specify						

Appendix 4: Survey Questionnaire for Ghana Study

Exploring Mangrove Forest Ecosystem Services and Drivers/factors Shaping their Availability and Management in Ghana

A. Respondent Data

1. What is your name? :……
2. What is your Tel No? ………
3. GPS location of area………………………………………………………………………………
4. What is your age? :……………………………………………………………………………….
5. How long have you lived in this community?:………………………………….
6. What is your gender? 1. Male [ ] 2. Female [ ]
7. How many years have you been in school?:…………………………………….
8. What is your level of education? 1. [ ] Primary 2. [ ] Junior High School 3. [ ] MSLC 4. [ ] Senior High School 5. [ ] Tertiary 6. [ ] No formal education
9. Do you have any other form of training? 1. [ ] Yes 2. [ ] No, If Yes, Specify…………………
10. Household Size?..........Distance of resident place to the nearest Mangrove Forests: ……… (m / km)
11. What is your occupation? 1. [ ] Fishing 2. [ ] Crop farming 3. [ ] Livestock) 4. [ ] Fish smoking 6. [ ] Medicinal plant collection/harvesting 7. [ ] Mangrove cutter/fuelwood/charcoal 8. [ ] Others (Specify)…………………..
12. What is your religion? 1. [ ] Christian 2. [ ] Muslim 3. [ ] Traditionalist 4. [ ] Other (Specify)…………………………………………..

A. Mangrove Forest Ecosystem Services

6. Which products and services do you perceive as the most important? Very important= 5; Rather important= 4; Neither important nor unimportant= 3; rather unimportant= 2; I don´t know= 1

5	4	3	2	1	**Ecosystem services**
					Provisioning services
					Wood production (firewood, charcoal, wood), etc.
					Provision of fish, shrimps, crabs, clams etc.
					Collection of non-wood forest products e.g. herbs, livestock feed, bush meat
					Regulatory service
					Protection of biodiversity, including wildlife, etc
					Protection against storms
					Protection against floods
					Maintenance of water quality
					Trapping and filtering of pollutants

5	4	3	2	1	**Ecosystem services**
					Prevention of soil erosion
					Cultural service Recreational /swimming and spiritual importance, specify…………
					Meditation and relaxation (enable to coexist with nature)
					Educational and research visits
					Supporting service Fish shelter and spawning grounds
					Propagules germination and growth

7. To what extent do the following affect the availability of mangrove services? Strongly disagree=1; Disagree= 2; Neither agree nor disagree= 3; Agree= 4; strongly agree= 5.

Factors affecting ecosystem services	5	4	3	2	1	**Specify the services affected**
Erratic rainfall						
Changes in temperature						
Sea level rise						
Storms						
Coastal flooding						
Wildfire						
Invasive species						
Over-exploitation for fuel, wood, salt, farm, agric, et						
Grazing of mangrove seedlings by livestock						
Land conversion e.g. urbanization, settlements, infrastructure.						
Illegal small-scale mining						
Pollution						
Sand winning						
Others ……………………………..						

8. Have you experienced changes due to climate change in your area? (Interviewer should explain climate change to the interviewee) 1. Yes [ ] 2. No [ ]

9. If yes, what are your observed changes due to climate change in the past 10 years? 5 = Very high change, 4 = high change; 3 = medium change; 2= low change; and 1= No change.

Variables	1	2	3	4	5
increase in temperature					
decrease in rainfall					
increase in rainfall intensity					
increase in coastal flooding					
sea level rise					
Increase in storms/wind					

10. To what extent do the changes in the rainfall pattern affect the availability of the following forest ecosystem services? 1= Strongly disagree; 2= Disagree; 3= Neither agree nor disagree; 4= Agree; and 5= Strongly agree.

5	4	3	2	1	**Ecosystem services**
					Provisioning services
					Reduced access to wood due to mangrove die-off by drought.
					Reduced access to fish, shrimps, crabs, etc due to decreased rainfall.
					Decline in non-wood mangrove products due to drought eg. snails, mushrooms
					Reduced fodder because of mangrove dieoff caused by drought.
					Reduced access to traditional herbal medicines because of the declined rain.
					Reduce access to quality water.
					Regulating services
					Decreased cooling of the air due to mangrove die-off by drought.
					Decrease in coastal protection and flood control due to mangrove die-off by drought.
					Cultural services
					Declining natural beauty of mangroves due to drought conditions.
					Decline recreational activities and spirituality.
					Decline in educational and research visits.
					Supporting services
					Declining fish breading sites due to drier conditions.
					Decline propagules germination and growth.

11. To what extent do the changes in the temperature affect the availability of the following mangrove services? 1= Strongly disagree; 2= Disagree; 3= Neither agree nor disagree; 4= Agree; and 5= Strongly agree.

5	4	3	2	1	**Ecosystem services**
					Provisioning services
					Decline in wood due to decreased growth/death from increased temperature.
					Reduced access to fish, shrimps, crabs, etc., due to changes in temperature.
					Reduced access to non-wood mangrove products eg. snails, mushrooms
					Declining Fodder due to increasing temperature.
					Reduced access to traditional herbal medicines.
					Regulating services
					Decreased cooling of the air.
					Decrease in coastal protection and flood control due to mangrove die-off.
					Cultural services
					Declining natural beauty of mangroves due to mangrove die-off.
					A decline in culture and spirituality due to mangrove die-off.
					Decline in educational and research visits.
					Supporting services
					Declining fish breeding sites due to changes in temperature.
					Decline propagules germination and growth.

12. To what extent does sea level rise affect the availability of the following forest ecosystem services? 1= Strongly disagree; 2= Disagree; 3= Neither agree nor disagree; 4= Agree; and 5= Strongly agree.

5	4	3	2	1	Ecosystem services
					Provisioning services
					Reduced access to wood due to mangrove die-off by flood.
					Reduced access to fish, shrimps, crabs etc.
					Reduced access to non-wood mangrove products due to flood.
					Fodder depletion as a result of mangrove dieoff due to flood.
					Reduced access to traditional herbal medicines due to flood.
					Regulating services
					Decreased cooling of the air due to mangrove die-off from flood.
					Decrease in coastal protection and flood due to mangrove die off by flood.
					Poor freshwater runoff and tidal water flushing on mangroves.
					Cultural services
					Damage to natural beauty of mangroves due to flood.
					A decline in culture and spirituality due to mangrove die-off.
					Decline in educational and research visits.
					Supporting services
					Declining fish breading sites due to sea level rise and wave activity.
					Declines growth of other vegetation eg. Medicinal, Bamboo etc

13. To what extent does storms/strong wind affect the availability of the following forest ecosystem services? 1= Strongly disagree; 2= Disagree; 3= Neither agree nor disagree; 4= Agree; and 5= Strongly agree.

5	4	3	2	1	Ecosystem services
					Provisioning services
					Destruction of mangroves by storms.
					Reduced access to fish, shrimps, crabs due to destruction of habitat
					Destruction of non-wood mangrove products due to storms.
					Decline in Fodder because of decline in mangrove due to storm impact.
					Reduced access to herbal medicines due to destruction by storms.
					Regulating services
					Decreased cooling of the air due to mangrove destruction by storms.
					Decrease coastal protection and flood control due to mangrove destruction.
					Cultural services
					Damage to natural beauty of mangroves due to destruction by storms.
					A decline in culture and spirituality due to destruction of mangroves.
					Decline in educational and research visits due to mangrove destruction.
					Supporting services
					Destruction of fish breeding sites due to destruction of mangroves.
					Destruction of the growth of other vegetation eg. Medicinal, Bamboo etc.

14. Do you depend on medicinal plants in any way? 1. Yes [ ] 2. No [ ]
15. In what ways? (please tick as many as applies) 1 [ ] Personal use 2 [ ] Collection for sale 3 [ ] Manufacture of medicine 4 [ ] Spiritual use

5 [ ] Naturopathic/herbal practice 6 [ ] Any other uses (specify) ....

16. To what extent do you agree with the following affecting medicinal plants? 1= Strongly disagree;2= Disagree;3= Neither agree nor disagree; 4= Agree; 5=Strongly agree.

5	4	3	2	1	**Driver**
					Erratic rainfall
					Changes in temperature
					Sea level rise causing erosion and flooding
					Over-exploitation of the medicinal plants
					Slash and burn farming practices
					Excessive use of chemicals
					Deforestation for agriculture
					Mangrove extraction
					Forest fires
					Infrastructure development
					Others (Specify)……………………..

17. Where do you harvest medicinal plants? (Tick all that Apply)
1. [ ] Mangrove forest in the community 2. [ ] outside the mangrove forest in the community 3. [ ] farmlands in the community 4. [ ] Others (Specify)………………………

18. Who controls access to medicinal plants in the community? 1. [ ] District Assembly 2. [ ] Forestry Commission 3. [ ] Traditional Authority 4. [ ] Individual owners 5. [ ] Others……………….

19. Are you involved in managing the mangrove forests in your area? 1. Yes [ ] 2. No [ ]

20. Do you have any management system in place for the mangrove forest in this community? 1. Yes [ ] 2. No [ ] 3. [ ] No idea

21. If yes, what are your adaptation and mitigation management measures to minimize impacts?

Management measures	**Yes**	**No**
Growing awareness among the people		
Cultivation of mangroves		
Reforestation and reclamation of mangrove areas to promote accretion		
Policies/laws to ensure conservation, and imposition of social controls		
Traditional management system (beliefs in myths, taboos, folklore).		
Alternative livelihoods (eg ecotourism, fishing, and cottage industries)		
incentives for conservation on private and community lands		
Prevention of pollution in mangrove areas		
Monitoring and evaluation		
Establishment of protected areas		
Reducing non-climatic stressors, e.g. disturbance from settlements		

Prohibition of sand winning and dredging to remove sediments in mangrove areas		
Coastal zone planning, removal, and redesign of structures		
Sea defense construction/creating flood-protection barriers		
Relocation of communities to higher grounds		
Other, please specify		

22. Will your household support an environmental programme that would seek to conserve mangrove forests if it does not cost your household anything? 1. Yes [ ] 2. [ ] No 3. [ ] Not certain

23. If Yes, what are the reasons? 1. [ ] It will help protect mangroves for sustainable use. 2. [ ] It will directly benefit me 3. [ ] Help continuous provision of mangrove services. 4. [ ] Because my work depends on mangrove services. 5. [ ] Others (specify)……………….

24. If No, what are the reasons? 1. [ ] I don't see it importance 2. [ ] My work does not depend on mangroves 3. [ ] Responsible institutions have to help 4. [ ] Others (specify)……………………….

25. Who should pay for the conservation of mangrove forests? 1. [ ] Government 2. [ ] People who benefit from it 3. [ ] Companies working in the communities 4. [ ] All the above 5. [ ] Others (specify)…………

Appendix 5: Focus Group Discussions/Key Informant Interview Questions (Ghana study)

1. What ecosystem services do you get from the mangrove ecosystem?
2. Which ecosystem services are relevant to you?
   2.1 Do pebble ranking.
   2.2 Which products and services do you perceive as the most important? Very important= 5; Rather important= 4; Neither important nor unimportant= 3; rather unimportant= 2; I don´t know= 1

5	4	3	2	1	Ecosystem services
					Provisioning services
					Wood production (firewood, charcoal, wood), etc.
					Provision of fish, shrimps, crabs, clams etc.
					Collection of non-wood forest products e.g. herbs, livestock feed, bush meat
					Regulatory service
					Protection of biodiversity, including wildlife, etc
					Protection against storms
					Protection against floods
					Maintenance of water quality
					Trapping and filtering of pollutants
					Prevention of soil erosion
					Cultural service
					Recreational /swimming and spiritual importance, specify…………
					Meditation and relaxation (enable to coexist with nature)
					Educational and research visits
					Supporting service
					Fish shelter and spawning grounds
					Propagules germination and growth

3. What are the problems or issues the mangroves pose?
4. Categorise the services into provision, cultural, regulatory, and support services.
5. What kind of crops or plants do well in the ecosystem?
6. Do you have an individual management strategy for the mangroves? What are they?
7. Determine the mangrove health (intact or not/disturbed or not).
8. Identify the mangrove species in the study area.