INTEGRATING SCIENCE AND POLICY FOR BIODIVERSITY CONSERVATION UNDER CLIMATE CHANGE: ECOSYSTEM-BASED APPROACHES IN THE HORN OF AFRICA

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ABSTRACT: The Horn of Africa, which includes desert rangelands, coastal ecosystems, Rift Valley lakes, and Afromontane forests, is a biologically rich and climate-vulnerable region. The loss of biodiversity and ecological services is being accelerated by climate change, land degradation, overexploitation, and governance issues. Forest restoration, rangeland rehabilitation, watershed management, and community-based conservation are examples of ecosystem-based approaches (EbA) that offer integrated solutions for climate adaptation and biodiversity protection. In order to find strategies to improve the science policy interface in the Horn of Africa, this systematic review synthesized peer-reviewed literature from Web of Science, Scopus, Google Scholar, and PubMed, as well as grey literature from Intergovernmental Authority on Development (IGAD), CBD, IPCC, United Nations Environment Programme (UNEP), EBI, and World Resources Institute (WRI) covering publications from 2012 to 2025. Inclusion criteria targeted English-language studies on ecosystem-based approaches in the Horn of Africa, while studies lacking relevance or methodological rigor were excluded. Data were thematically synthesized across ecosystem contexts, threats, interventions, science-policy mechanisms, and policy frameworks. This review assesses EbA programs, examines ecological and sociopolitical contexts, and analyzes obstacles such as data gaps, capacity constraints, fragmented governance, land tenure insecurity, and the impacts of conflict. A framework that emphasizes cross-border cooperation, indigenous knowledge integration, adaptive management, and decentralized governance mechanisms is proposed based on lessons learned from local and global experiences. Ecosystems and communities can be made more resilient to climate change by strengthening the science-policy interaction through capacity building, participatory governance, and targeted investments.

Keywords: Biodiversity, climate change adaptation, ecosystem-based approaches, Horn of Africa, science policy integration

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INTRODUCTION

The Horn of Africa, which includes distinctive plants and animals in Ethiopia, Somalia, Eritrea, and Djibouti, is acknowledged as a global biodiversity hotspot (CBD, 2018; EBI, 2021; Elmi and Hassan, 2025). Human pressures including deforestation, overgrazing, and land degradation are exacerbating the region's rising temperatures, unpredictable rainfall, and frequent droughts, endangering both biodiversity and local livelihoods (Holland *et al*., 2012; IPCC, 2022; Fashing *et al.*, 2022). Potential avenues for biodiversity protection and climate adaptation in this area are provided by incorporating scientific information into policy through ecosystem-based approaches (EbA) (ASSAR, 2021; Feyissa *et al*., 2025).

Pastoralist livelihoods and grassland ecosystems predominate in arid and semi-arid rangelands, including the Borana and Somali areas. These ecosystems provide grazing, biodiversity corridors, and carbon storage (Gebremedhn *et al*., 2023; Feyissa et al., 2025). Eritrean mangroves and other coastal and marine habitats support carbon sequestration, fisheries productivity, and coastline stabilization (UN, 2024; Beaumont *et al*., 2025). Climate change, habitat loss, and unsustainable land-use practices are putting these ecosystems at greater risk (Williams *et al*., 2021). The region's ecological integrity and the livelihoods it supports are under unprecedented pressure as global temperatures rise and extreme weather events occur more frequently (IPCC, 2022).

An integrated strategy that connects policy execution and scientific research is needed to address these issues. EbAs, which emphasize ecosystem restoration and sustainable management while boosting resilience to climate change, have become a potential framework for biodiversity conservation (Cohen-Shacham *et al*., 2016; CBD, 2020). By combining local expertise, adaptive management, and cross-sectoral cooperation, EbAs provide a means of balancing conservation objectives with socioeconomic growth (Reid *et al*., 2019). EbAs can offer a unified approach to coordinating conservation efforts with climate adaptation plans in the Horn of Africa, where governance structures and resource management systems are frequently dispersed (WRI, 2021). However, equitable resource distribution, stakeholder participation, and strong science policy interfaces are necessary for successful implementation (UNEP, 2023). Despite their recognized potential, significant gaps remain in the implementation of EbAs in the region, including limited empirical evidence on long-term effectiveness (Reid *et al*., 2019; Seddon *et al*., 2020), weak institutional coordination across borders, inadequate financial mechanisms (Buchner *et al*., 2022), and minimal integration of local knowledge into policy frameworks (Doswald *et al*., 2014; Ochieng *et al*., 2017).

This review aims to examine the potential of EbAs to improve biodiversity conservation in the Horn of Africa under climate change by synthesizing key scientific discoveries, policy frameworks, and case studies that demonstrate their effectiveness. Specifically, it aims to identify best practices, implementation gaps, obstacles, and prospects for scaling ecosystem-based solutions in the area through the synthesis of data from peer-reviewed literature, policy documents, and institutional reports.

METHODOLOGY

This review employed a systematic literature review approach to synthesize scientific evidence and policy documents on ecosystem-based approaches for biodiversity conservation in the Horn of Africa.

Search Strategy

A comprehensive literature search was conducted across multiple databases including Web of Science, Scopus, Google Scholar, and PubMed for peer-reviewed articles published between 2012 and 2025. The search utilized combinations of keywords: ecosystem-based adaptation, EbA, biodiversity conservation, climate change adaptation, Horn of Africa, Ethiopia," Somalia, Eritrea, Djibouti, science-policy interface, forest restoration, rangeland management, and wetland conservation.

Additionally, grey literature was sourced from institutional websites including the Intergovernmental Authority on Development (IGAD), Convention on Biological Diversity (CBD), Intergovernmental Panel on Climate Change (IPCC), United Nations Environment Programme (UNEP), Ethiopian Biodiversity Institute (EBI), and World Resources Institute (WRI). Policy documents, national reports, and strategy papers were also reviewed.

Inclusion and Exclusion Criteria

Studies were included if they: (1) focused on the Horn of Africa region (Ethiopia, Somalia, Eritrea, Djibouti, and cross-border areas); (2) addressed ecosystem-based approaches, climate change adaptation, or biodiversity conservation; (3) were published in English; (4) were peer-reviewed articles, books, reports, or official policy documents; and (5) were published between

2012-2025. Studies were excluded if they lacked relevance to the research objectives or had insufficient methodological rigor.

Data Extraction and Synthesis

From each included study, the following information was extracted: author(s), year, geographic focus, ecosystem type, EbA intervention type, key findings, policy relevance, and identified barriers or opportunities. The extracted data were synthesized thematically according to: (1) ecosystem contexts and vulnerabilities; (2) climate change and anthropogenic threats; (3) EbA interventions and outcomes; (4) science-policy interface mechanisms; and (5) policy frameworks and integration pathways. Qualitative synthesis was employed to identify patterns, gaps, and emerging themes across the literature.

RESULTS AND DISCUSIION

Ecosystem context of the horn of Africa

With a mosaic of interrelated ecosystems supporting both distinctive wildlife and human livelihoods, the Horn of Africa is a region of remarkable ecological variety (Marchant, 2021). These ecosystems, which range from desert rangelands to highland forests, are all vital to preserving ecological balance and provide necessary services. However, excessive resource usage, land degradation, and climate change are putting more strain on them. Designing successful conservation and climate adaptation strategies requires an understanding of their unique traits and vulnerabilities.

Forests: Biodiversity Refuges and Climate Regulators

For endemic species like the Ethiopian wolf (*Canis simensis*) and the mountain Nyala (*Tragelaphus buxtoni*), the Afromontane and dry forests of the Horn of Africa, especially in

Ethiopia and South Sudan, are essential havens (EBI, 2021). Additionally, by protecting watersheds, these forests boost agricultural output, sequester carbon, and control regional hydrology. However, their integrity is threatened by deforestation brought on by fuelwood collection, illicit logging, and agricultural development, which lessens their ability to mitigate the effects of climate change (Gole *et al*., 2022). To protect these vital ecosystems, conservation initiatives must place a high priority on community-based forest management, sustainable land-use planning, and reforestation.

Wetlands and Lakes: Hubs of Aquatic Biodiversity

Among Africa's most ecologically significant freshwater systems, the Rift Valley lakes including Lake Turkana and Lake Abaya support a variety of fish species, migrating birds, and regional fisheries (Holland *et al*., 2012; Wendimu and Tekalign, 2024). Additionally, these wetlands serve as natural water storage, preventing droughts and maintaining agricultural irrigation. However, pollution, overfishing, and hydrological changes brought on by climate change are destroying these ecosystems, endangering food security and biodiversity (Ogutu-Ohwayo *et al*., 2023). To protect these essential aquatic habitats, transboundary conservation agreements and integrated water resource management are required.

Rangelands: Sustaining Pastoralist Livelihoods and Carbon Storage

Pastoralist populations in the Borana and Somali regions depend on the large dry and semi-arid rangelands for livestock grazing and forage resources (Flintan *et al*., 2023). Because deep-rooted vegetation stabilizes soils and lessens erosion, these ecosystems are also essential for sequestering carbon. However, protracted droughts, excessive grazing, and land fragmentation are causing desertification, which threatens pastoral livelihoods and ecological resilience (Megersa *et al*., 2024). To preserve these ecosystems in the face of shifting climatic circumstances, sustainable rangeland management which includes drought-resistant forage cultivation and rotational grazing is crucial.

Coastal and Mangrove Ecosystems: Buffers against Climate Extremes

Large mangrove forests that prevent coastline erosion, sustain marine species, and store substantial amounts of "blue carbon" can be found in the Horn's coastal regions, especially in Somalia and Eritrea (UN, 2024). These habitats are essential to fisheries, which give coastal communities food and revenue. However, these habitats are being deteriorated by pollution from urban growth, overharvesting of mangroves for charcoal, and increasing sea levels (Huxham *et al*., 2023). Important tactics to improve coastal resilience include bolstering marine protected areas, encouraging alternative livelihoods, and repairing damaged mangroves.

Interconnected Challenges and the Need for Holistic Approaches

Despite the unique dangers that each ecosystem faces, human activity, wildlife migrations, and hydrological cycles connect them. Deforestation in highlands, for example, might worsen water scarcity downstream, impacting rangelands and wetlands (Elmi and Hassan, 2025). On the other hand, cross-system benefits might result from sustainable management in one sector. By encouraging landscape-scale conservation, climate-smart agriculture, and community-led stewardship, Ecosystem-based Adaptation (EbA) provides a framework to address these connections (Ndubuisi *et al*., 2025). Policymakers and conservationists may create integrated strategies that improve biodiversity conservation and increase climate resilience throughout the Horn of Africa by acknowledging the interdependence of various ecosystems.

Climate change and other threats

Threats to the Horn of Africa's biodiversity are numerous and interrelated. As a threat multiplier, climate change exacerbates already-existing pressures from human activity and governance issues. Extreme weather events, unpredictable rainfall patterns, and more frequent and severe droughts are all consequences of the region's warming rates exceeding global norms (Funk *et al*., 2024). By changing species ranges, phenology, and ecological interactions, these climatic changes put ecosystems under direct stress. Direct anthropogenic forces are also getting stronger at the same time. The main areas of biodiversity are being undermined by habitat loss and fragmentation brought on by urban growth, unsustainable forestry, and agricultural expansion (Ayeni *et al*., 2023). Natural capital is being depleted by overexploitation of resources, such as overfishing in freshwater and marine systems and the unsustainable harvesting of timber and non-timber forest products (Parera *et al*., 2025). Furthermore, conservation efforts are hampered and effective policy implementation is hampered by underlying socio-political factors including fragmented governance, a lack of institutional capacity, and political instability and violence in some regions (Holland *et al*., 2012; ACPC, 2020). The combination of climate change and human-caused hazards calls for immediate and comprehensive conservation strategies.

Ecosystem-based approaches (EbA)

In the Horn of Africa, ecosystem-based approaches (EbA) have become essential tactics for tackling the twin problems of biodiversity loss and climate change. According to Cohen-Shacham *et al*. (2016), these nature-based solutions improve resilience by interacting with natural systems and offer numerous advantages to human communities and ecosystems. Through case studies and best practices, the area has implemented a variety of EbA solutions across varied ecosystems, showcasing their efficacy.

Table 1. Summary of Ecosystem-based Adaptation (EbA) Approaches in the Horn of Africa

Ecosystem Type	EbA Intervention	Key Outcomes	Location/Example	Sources
Afromontane Forests	· Community managed area enclosures; · agroforestry with native shade trees	· 35% increase in woody plant cover; · 40% increase in farmer incomes; · 80% preservation of forest bird diversity	Tigray, Oromia (Ethiopia)	Beyene *et al*. 2024; Gole *et al*. 2022; Megersa and Hailu 2021
Rangelands	· Rotational grazing; · reseeding native grasses; · traditional drought coping + early warning systems	· 25% increase in vegetation cover; · 30% rise in cattle productivity; · 50% reduction in cattle mortality during droughts	Borana (Ethiopia); Somaliland	Sircely *et al*. 2022; Flintan *et al*. 2023; Megersa *et al*. 2024
Wetlands & Lakes	· Terracing; · check dams; · riparian buffer strips; · watershed restoration	· 40% reduction in sediment loads; · improved water quality for 200,000 users; · wildlife corridor restoration	Lake Tana; Awash River (Ethiopia)	CBD, 2018; Lemenih and Techel, 2020; EBI 2021
Coastal & Mangrove	· Mangrove reforestation; · community-managed marine protected areas; · sustainable fishing quotas	· 500+ ha mangrove restored; · 35% increase in fish catches; · 45% fish stock recovery	Red Sea (Eritrea); Puntland (Somalia)	UN, 2024; Huxham *et al*. 2023

		within 3 years		
Transboundary Ecosystems	· Joint cross-border programs; · standardized vulnerability assessments	· 18% increase in plant cover; · reduced grazing-related conflicts	Kenya-Ethiopia border (IGAD initiatives)	Flintan *et al*.,2023; IGAD 2023

Forest Restoration and Sustainable Management

Degradation has been remarkably reversed in Ethiopia's highlands through community forestry and area enclosures (Megersa and Hailu, 2021). Within five years of creating enclosures, research conducted in Tigray found a 35% increase in woody plant cover, along with increases in soil fertility and water retention (Beyene *et al*., 2024). In addition to preserving 80% of the original forest bird variety, agroforestry systems that combine coffee production with native shade trees have increased farmer incomes by 40% (Gole *et al*., 2022). These strategies show how EbA can use science-informed, participatory management to balance conservation with livelihood demands.

Rangeland Rehabilitation for Pastoral Resilience

By rotating grazing and reseeding native grasses, participatory rangeland management in Borana, Ethiopia, has turned degraded grasslands into productive systems (Sircely *et al*., 2022). Over a ten year period, household surveys suggested a 30% rise in cattle productivity, whereas satellite data showed a 25% increase in vegetation cover (Flintan *et al*., 2023). Similar initiatives done in Somaliland reduced cattle mortality during dry spells by up to 50% by combining traditional drought coping techniques with contemporary early warning technologies (Megersa *et al*., 2024). These examples show how combining scientific monitoring with traditional knowledge can improve social and ecological resilience.

Watershed and Wetland Conservation

Terracing, check dams, and buffer strips are examples of integrated soil-water conservation techniques that increased agricultural yields while reducing sediment loads by 40% in the Lake Tana watershed (CBD, 2018). In addition to providing clean water for 200,000 downstream customers, riparian restoration along the Awash River established wildlife corridors that helped endangered animals like the Ethiopian wolf return (Lemenih, 2020**;** EBI, 2021). The watershed-scale thinking required for successful EbA implementation is demonstrated by such interventions.

Coastal and Marine Ecosystem Restoration

Mangrove reforestation projects in Eritrea's Red Sea coast have restored over 500 hectares of critical habitat since 2015, increasing fish catches by 35% and protecting coastal communities from storm surges (UN, 2024). In Somalia's Puntland region, community-managed marine protected areas combined with sustainable fishing quotas allowed fish stocks to recover by 45% within three years (Huxham *et al*., 2023). These successes demonstrate EbA's potential to address both conservation and climate adaptation needs in coastal zones.

Policy Integration and Scaling Up

While these case studies demonstrate the potential of EbA, greater policy integration is necessary for its broader adoption. Although EbA principles have been incorporated into national planning through Ethiopia's Climate Resilient Green Economy strategy, there are still gaps in the local implementation (Reid *et al*., 2019). Despite providing platforms for regional cooperation, transboundary projects like the IGAD Biodiversity Policy Framework require improved financial methods (UNEP, 2023). Future initiatives must concentrate on bolstering communities' land rights, integrating EbA into climate policies, and creating creative funding through carbon markets and ecological service payment (WRI, 2021).

Science-Policy Interface

Researchers, legislators, and communities must work together for EbA to be effectively incorporated into policy. Ethiopia has created a number of national frameworks, such as the Sixth National Biodiversity Strategy and Action Plan (FDRE, 2019; FDRE, 2021; EBI, 2021), National Adaptation Plan (NAP-ETH), and Nationally Determined Contribution (NDC). Cross-border coordination is made possible by regional policies like the IGAD Climate Adaptation Strategy (IGAD, 2023).

However, considerable impediments prevent its integration. Knowledge gaps, restricted data accessibility, insufficient institutional capacity, fragmented governance, and financing constraints impede EbA mainstreaming (ACPC, 2020; CBD, 2018). Socio-political instability and local disputes also decrease the effectiveness of conservation measures (Holland *et al*., 2012). Climate change poses significant challenges to the Horn of Africa's biodiversity hotspot, as warming rates exceed global norms (Funk *et al*., 2024). While Ecosystem-Based Adaptation (EbA) provides integrated solutions, there are still gaps between scientific study and governmental action.

Policy Frameworks for Ecosystem-based Adaptation Integration

An examination of Ethiopia's national plans indicates both a solid ecological underpinning and significant implementation shortcomings. The National Adaptation Plan (NAP-ETH) focuses on watershed restoration using hydrological models; however, it has weak local enforcement. The updated Nationally Determined Contribution (NDC) aims to restore 15 million hectares of land, prioritizing IUCN Red List species; however the financial options are uncertain. The National Biodiversity Strategy and Action Plan (NBSAP) encourage community protected areas based on endemic species protection; however, it does not align with regional frameworks.

Regional Policy Frameworks and Cooperation

Cooperation among Horn of Africa countries is increasingly seen as critical to addressing the transboundary character of climate and biodiversity concerns. The Intergovernmental Authority on Development (IGAD) has been instrumental in promoting collaborative initiatives, including the creation of the Climate Adaptation Strategy (2023), which promotes standardized ecological vulnerability assessments for rangeland management. Regional cooperation through IGAD has resulted in substantial ecological and sociopolitical benefits. The joint Kenya Ethiopia Programme, for example, increased plant cover by 18% while reducing grazing-related conflicts, highlighting the power of coordinated transboundary interventions (Flintan, 2023). Nonetheless, three persistent challenges continue to impede the effective integration of EbA into the region.

First, insufficient knowledge transmission limits research from reaching policymakers; just 22% of EbA studies have direct policy impact; however, focused initiatives such as Ethiopia's Climate Innovation Hub have raised research uptake by 40% (Huxham *et al*, 2023). Second, the absence of indigenous ecological knowledge from 67% of policies undermines cultural and local relevance; Somaliland's Pastoralist Charter stands out as an example of traditional drought forecasting being integrated into official governance (Megersa *et al*., 2024). Third, significant financial constraints, with less than 10% of climate funds devoted to EbA, impede large-scale implementation; nevertheless, new methods such as Kenya's $50 million Green Bond for wetland restoration demonstrate scalable funding routes (CBD, 2020). These instances highlight the importance of integrated governance, strong science-policy links, and diverse financing approaches for scaling EbA in the Horn of Africa.

Pathways for Enhanced Integration

Several pathways are necessary to overcome these hurdles. The first step is to co-produce knowledge by forming rotating scientific policy task forces to enable continual communication and cooperative decision-making. These should include equal representation from ecological researchers, politicians, and local populations to allow for the integration of scientific information with policy demands and indigenous knowledge. The second path focuses on important research areas, such as cost-benefit evaluations of EbA vs traditional "grey" infrastructure and long-term ecological monitoring to track climate and biodiversity trends. The third option entails fostering novel governance mechanisms, such as decentralized County Climate Funds for locally led EbA finance, as well as the establishment of transboundary ecological corridors to sustain biodiversity connection across national borders. A proposed framework for EbA policy integration would proceed in a cyclical manner, from Science to Policy Co-Design, Implementation, Ecological Monitoring, and Feedback, resulting in a continual learning and adaptation cycle.

Figure 1 illustrates the climate–biodiversity nexus in the Horn of Africa as a dynamic and interconnected system, linking climate drivers, ecosystem impacts, livelihoods, and ecosystem-based adaptation (EbA) interventions through bidirectional relationships. Climate stressors such as rising temperatures, variable rainfall, droughts, and extreme events interact with ecosystem processes, leading to habitat degradation, biodiversity loss, and declining ecosystem services, which in turn affect livelihoods and increase vulnerability.

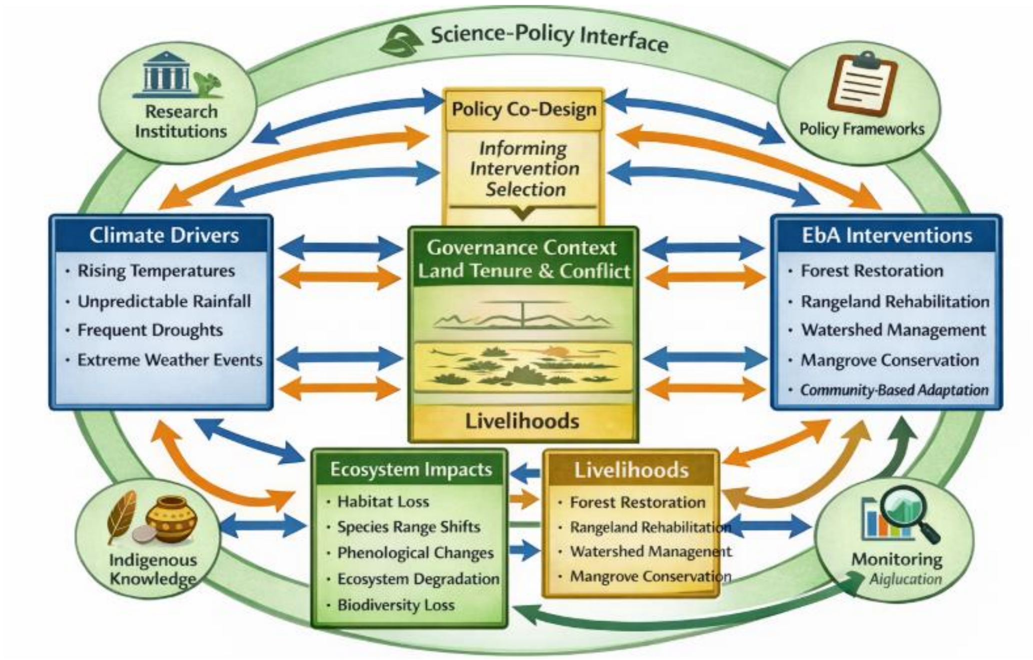

Figure 1. The climate-biodiversity nexus in the Horn of Africa illustrating the pathways from climate drivers to ecosystem impacts and the role of EbA interventions mediated by the science-policy interface.

The framework emphasizes the central role of governance encompassing land tenure, institutional arrangements, and conflict dynamics which cuts across and shapes all components. It also highlights key science–policy interface intervention points at the policy co-design stage, where evidence informs intervention selection, and at the monitoring stage, where evaluation supports adaptive management. A feedback loop from monitoring back to policy co-design underscores iterative learning and adaptive decision making. Overall, the figure demonstrates the complex, non-linear, and adaptive nature of climate biodiversity interactions and the importance of integrated EbA approaches for enhancing resilience and sustainability in the region.

Barriers to Effective Integration

The effective integration of Ecosystem-based Approaches into policy and practice in the Horn of Africa is hampered by a complex set of interconnected barriers. Knowledge gaps and limited data accessibility prevent evidence-based decision-making, while weak institutional capacity at multiple levels of governance undermines the implementation of even well-designed policies. A critical barrier is fragmented governance, where sectoral silos between ministries of environment, agriculture, water, and finance lead to uncoordinated and sometimes contradictory policies. Furthermore, chronic funding constraints limit the scaling up of successful EbA pilot projects, with less than 10% of climate funds targeting nature-based solutions. These challenges are often compounded by socio-political instability and local conflicts, which divert resources and attention away from long-term conservation planning and create an environment where unsustainable resource exploitation can thrive (ACPC, 2020; CBD, 2018; Holland *et al*., 2012).

Future Pathways

To strengthen biodiversity conservation under climate change in the Horn of Africa, a multifaceted approach is required. Key pathways include fostering knowledge co-production among scientists, policymakers, and local communities to ensure that interventions are both scientifically sound and socially relevant (ASSAR, 2021). The adoption of advanced geospatial tools and species distribution models is essential for effective planning, monitoring, and forecasting ecological responses to climate change (IPCC, 2022). Policy mainstreaming is critical, which involves integrating EbA principles into all relevant sectoral and regional development plans to ensure coherence and maximize synergies. Enhanced regional collaboration through bodies like IGAD is necessary for cross-border ecosystem management, given the transboundary nature of many ecosystems and climate impacts (IGAD, 2023). Concurrently, targeted capacity building at both institutional and community levels is needed to empower stakeholders to participate in and lead conservation efforts (ACPC, 2020). Finally, securing sustainable financing through innovative mechanisms such as blended finance, payments for ecosystem services, and green bonds is imperative to scale up successful EbA initiatives and ensure their long-term viability (Feyissa *et al*., 2025).

CONCLUSION

Ecosystem-based approaches are essential for simultaneously addressing biodiversity conservation and climate adaptation in Horn of Africa. The region's unique biodiversity, coupled with its acute vulnerability to climate change, demands solutions that are integrated, sustainable, and equitable. This review has highlighted the significant potential of EbA to deliver multiple benefits for both ecosystems and human communities, from forest restoration in the highlands to mangrove rehabilitation along the coasts. However, realizing this potential requires a concerted effort to strengthen the science-policy interface. This involves bridging critical knowledge gaps, overcoming governance fragmentation, and securing adequate and sustained financing. By prioritizing the integration of local knowledge, investing in capacity building, and fostering robust regional collaboration, stakeholders can enhance the resilience of both ecosystems and communities, securing a more sustainable future for the Horn of Africa in the face of a changing climate.

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