

When Climate Fuels Pests: How Climate Change-Induced Pest Invasion is Reshaping Ecosystems and Livelihoods in East Africa

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Abstract

Pest damage continues to undermine food security and farmers' livelihoods across East Africa, yet a comprehensive synthesis of its cascading ecological and socioeconomic consequences is lacking in the literature. Climate change, through rising temperatures, erratic rainfall, and recurring droughts is fundamentally altering pest behaviour and distribution across the region, driving a phenomenon here described as *pest invasion*: the climate-driven process by which previously contained pests break out of their historical boundaries, colonise new elevations and seasons, and destabilise the ecological relationships that once kept their populations in check. This review therefore aimed to: (i) analyse the impact of climate change on pest dynamics in East Africa, including shifts in distribution and phenology; (ii) examine the ecological consequences of pest proliferation on ecosystem structure and function; (iii) assess the socioeconomic implications for livelihoods and food security; and (iv) evaluate adaptive and area-wide pest management strategies. A qualitative narrative review synthesised peer-reviewed literature (2015-2025) from Google Scholar, ScienceDirect, and JSTOR, screened for empirical rigour, geographic focus, and thematic relevance. Evidence shows that invasive pests, including fall armyworm, desert locusts, false codling moth, and *Prosopis juliflora*, are generating compound burdens of biodiversity loss, yield reduction, and pesticide dependence, disproportionately borne by smallholder farmers, particularly women. Area-wide integrated pest management emerges as an essential response, yet adoption remains constrained by weak policy frameworks, limited extension capacity, and insufficient regional coordination. The review concludes that climate-resilient, gender-responsive, and regionally coordinated pest management systems are essential for long-term food security and ecological sustainability in East Africa.

Keywords: Pest Invasion, Climate Change, Ecosystem Transformation, Livelihoods, East Africa, Invasive Species, Integrated Pest Management.

Introduction

Africa stands on the front lines of a climate crisis it did little to create (Zielinski, 2023). Among the world's regions, it remains one of the most exposed to the consequences of rising temperatures, erratic rainfall, and increasingly unpredictable weather patterns (Mubenga-Tshitaka et al., 2023). What makes this vulnerability so acute is not merely the physical reality of climate change, but the structural conditions that limit the continent's ability to respond. (Ayompe and Epie, 2025). Widespread poverty, constrained financial and technological resources, and an overwhelming dependence on rain-fed agriculture that

leaves farming communities with little buffer against environmental shocks (Oriangi et al., 2024). Over the past several decades, East Africa has experienced significant seasonal variability in rainfall alongside sustained increases in average, maximum, and minimum temperatures (Mubenga-Tshitaka et al., 2023). Agriculture, which accounts for approximately 43% of East Africa's gross domestic product and sustains the livelihoods of roughly 80% of the region's population, is already bearing the visible costs of these changes (Mubenga-Tshitaka et al., 2023). Food systems that millions of people depend on are becoming less reliable, less productive, and more precarious (Abdullahi et al., 2024).

One of the most consequential, yet often underappreciated, pathways through which climate change undermines agriculture in East Africa is through its intensifying effect on pest dynamics (Nega, 2025). Shifts in temperature and precipitation are not merely stressing crops directly, they are actively restructuring the conditions under which pests survive, reproduce, migrate, and cause harm (Skendžić et al., 2021). This phenomenon reflects what scholars describe as a fundamental reorganisation of pest-ecosystem relationships driven by anthropogenic warming (Skendžić et al., 2021). The result is a pattern this review terms *pest invasion*, a process whereby rising temperatures, shifting rainfall, and associated ecological disruptions reverse the established balance between crops, pests, and their natural enemies, enabling pest species to expand their geographic range into previously unsuitable areas, prolong their activity beyond historical seasonal limits, and intensify population growth in ways that overwhelm conventional management responses (Umesh Vishal et al., 2025). In East Africa, this is already visible: the fall armyworm has established itself in highland farming zones once considered too cool to sustain it, and desert locusts have been recorded breeding at altitudes above 2,000 metres where breeding was historically infrequent (Sisay et al., 2019). Unlike the concept of a pest outbreak, which typically describes a discrete and often temporary event, pest invasion captures a more structural shift a change in the baseline conditions governing how pests behave and spread, rather than a deviation from a stable norm. This distinction matters practically, because managing a changed baseline requires anticipatory, systems-level thinking rather than reactive, event-by-event responses.

The scale of the damage caused by invasive crop pests in Africa reinforces this urgency (Mlambo et al., 2024). These pests are responsible for agricultural losses estimated at more than USD 65.5 billion annually across the continent (Assédé et al., 2025). In East Africa specifically, high-profile invasions, most notably the fall armyworm and the desert locust, have devastated harvests, depleted household incomes, and heightened food insecurity across multiple countries within a short span of years (Monica et al., 2024; Nega, 2025). Beyond these headline cases, subtler and slower-moving pest expansions are quietly eroding productivity across a wider range of crops and farming systems, compounding the pressures that smallholder farmers already face from drought, flooding, and market volatility.

Despite growing scholarly attention to the individual dimensions of this problem, the literature has not yet offered a synthesis that brings them together. Studies tend to treat

biophysical aspects of pest dynamics and the socioeconomic vulnerabilities of farming communities as separate lines of enquiry, rarely examining how they interact and reinforce one another. The specific cascading effects of climate-driven pest invasion, how ecological disruptions translate into livelihood losses, how livelihood losses constrain adaptive capacity, and how constrained adaptive capacity in turn amplifies vulnerability to future pest pressure have not been systematically examined as an integrated set of processes. This fragmentation limits the ability of policymakers, extension services, and farming communities to design responses that are contextually grounded, practically implementable, and durable over time. This review addresses that gap by synthesising current evidence through the analytical lens of *pest invasion*, tracing the chain of consequences from climate drivers through ecological disruption to socioeconomic harm, and examining what adaptive strategies exist and what prevents them from being fully realised.

This review is structured along a clear analytical progression from the definition and theorization of pest invasion to climate drivers, ecological consequences, socioeconomic impacts, adaptive strategies including area-wide pest management, and finally to the barriers that constrain those strategies. This structure reflects the actual sequence of causation at work in the field. Accordingly, this review pursues four specific objectives.

1. To analyse how climate change is reshaping pest dynamics in East Africa, including shifts in pest distribution, phenology, and population behaviour;
2. To examine the ecological consequences of intensified pest activity, including effects on biodiversity, trophic cascades, and habitat integrity;
3. To evaluate the socioeconomic implications of pest invasions for rural livelihoods and food security, including crop losses, rising production costs, and gendered dimensions of vulnerability; and
4. To explore adaptive management strategies encompassing IPM, AWPM, climate-smart agriculture, and early warning systems and to identify the specific barriers that limit their adoption across East African contexts.

Methodology

This study employed a qualitative, narrative literature review approach to synthesise current knowledge on how climate change intensifies pest outbreaks, reshaping ecosystems and threatening food security and livelihoods across East Africa. Scientific papers and books were systematically collected from reputable databases, including Google Scholar, ScienceDirect, and JSTOR. The review focused on peer-reviewed articles published between 2015 and 2025, a window chosen to capture contemporary evidence on climate-pest interactions, ecological consequences, socioeconomic impacts, and adaptive management strategies within East Africa's changing environmental context. Studies published before 2015 were also considered where their findings were foundational or otherwise critical to the review's thematic objectives.

The keywords used during the search process included pests, climate change, ecosystem transformation, livelihoods, and East Africa, applied individually and in various

combinations to maximise the breadth and relevance of retrieved literature. In the first stage, titles and abstracts were reviewed for relevance to the guiding themes of the review. Publications were included if they focused on East Africa or offered transferable insights from comparable agroecological regions, addressed at least one of the study's guiding themes, and were published in English. Publications were excluded if they were opinion pieces, editorials, or conference abstracts without original data, or if they examined pest dynamics outside of agricultural or natural ecosystem contexts.

In the second stage, full texts of potentially relevant articles were assessed for quality and relevance. Quality was evaluated based on methodological rigour, including clear study design, appropriate sample sizes, valid analytical methods, and transparency in data collection and interpretation. Relevance was determined by the degree to which a study directly addressed climate-pest interactions, provided empirical data from East Africa or comparable regions, or offered actionable insights for pest management in the region. Where disagreements arose regarding the inclusion of a particular study, these were resolved through group discussion among the authors, with final selections reflecting collective scholarly judgement. The synthesis was organised around four guiding topics: climate-pest interactions, ecological consequences, socioeconomic impacts, and potential strategies for mitigation and adaptation.

Key Findings of the Study

Pest Invasion Under Climate Change

Pest invasion refers to the climate-driven reversal of conventional pest distribution, phenology, and ecological equilibrium (Sorahia et al., 2025). It describes a process whereby previously contained or seasonally limited pest species expand their geographic ranges, extend their activity periods beyond historical norms, intensify their population dynamics, and disrupt established predator-prey relationships. Unlike gradual pest range shifts associated with natural climatic variability, pest invasion denotes a rapid, nonlinear transformation in pest-ecosystem-human interactions (Ravi Sharma et al., 2018). It advances beyond conventional frameworks such as "pest outbreak" or "range expansion" by emphasising the systemic reversal of established ecological relationships under climate forcing

The concept operates through three interconnected dimensions. Spatially, rising temperatures eliminate physiological barriers that once confined pests to particular zones. This enables desert locusts to breed above 2,000 metres and fall armyworm to colonise highland farming areas traditionally considered pest-free, effectively dismantling historical "pest-safe" zones (Early et al., 2018). Temporally, climate change disrupts the phenological synchrony between pests, their host plants, and natural enemies. This produces extended reproductive seasons, asynchronous emergence patterns, and multiple overlapping generations, where historically only one occurred. The result renders calendar-based pest management increasingly ineffective (Skendžić et al., 2021). Trophically, climate stress disproportionately weakens natural pest enemies relative to the pests themselves

(Skendžić et al., 2021). Elevated CO₂ reduces plant nutritional quality, triggering compensatory feeding in herbivores. Simultaneously, parasitoid and predator foraging efficiency is impaired, inverting the ecological balance in favour of pest proliferation. Together, these dimensions reveal how climate change does not merely worsen existing pest problems but fundamentally restructures pest-ecosystem-human interactions (Nega, 2025, Skendžić et al., 2021). This restructuring demands adaptive governance that anticipates nonlinear dynamics rather than reacting to discrete outbreak events.

Global Climate in Transition

Climate is a vital factor shaping the characteristics and distribution of both managed and natural systems, from hydrology and marine ecosystems to terrestrial ecosystems, forestry, and agriculture (Skendžić et al., 2021). It involves long-term changes in environmental factors such as temperature, humidity, and precipitation across many years, and the current trajectory of anthropogenic climate change is unprecedented in its pace and scale. The primary driver of global warming is the increasing concentration of greenhouse gases, chiefly carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), produced by human activities such as fossil fuel combustion and land-use changes (Omotoso & Omotayo, 2024). Since industrialisation began two centuries ago, atmospheric CO₂ has increased from approximately 280 ppm to 416 ppm, trapping heat and enhancing the greenhouse effect (Summerhayes et al., 2024). This warming has resulted in more frequent and intense heat waves, accelerated sea level rise, and increased heavy precipitation events in many regions (Skendžić et al., 2021).

For East Africa, the climatic variables most directly relevant to pest emergence and agricultural systems are shifts in temperature regimes and changes in precipitation patterns (Mubenga-Tshitaka et al., 2023). Rising temperatures expand the geographic range of many pests by enabling their survival at higher altitudes and during previously inhospitable seasons (Nega, 2025). Concurrently, increased rainfall variability, including both more intense wet seasons and more frequent droughts creates conditions that stress crops and disrupt natural pest control mechanisms, rendering agroecosystems more vulnerable to outbreaks (Ngetich et al., 2022). Extreme events such as prolonged dry spells followed by heavy rainfall can trigger synchronised pest emergence, as observed in recent desert locust upsurges, where cyclone-induced rains in the Arabian Peninsula created ideal breeding conditions that subsequently affected East Africa (Mullié et al., 2023). These climate-driven changes in temperature and precipitation directly influence pest population dynamics, including accelerated reproductive cycles, expanded geographical ranges, and altered interactions with natural enemies the very mechanisms that constitute pest invasion (Abbasi, 2025).

Climate Change in East Africa: A Driver of Pest Emergence

East Africa experiences the brunt of climate change, characterised by erratic rainfall, prolonged droughts, and rising temperatures (Ngetich et al., 2022). These changes affect weather patterns and significantly transform ecosystems and agricultural systems

(Skendžić et al., 2021). An underexplored consequence of climate change is the increasing prevalence and impact of pests (Nega, 2025). Pests including insects such as locusts and fall armyworms, as well as microbial pathogens and invasive weeds, are becoming more aggressive and widespread due to shifting climatic conditions (Nega, 2025). East Africa is especially vulnerable to climate variability because of its dependence on rain-fed agriculture and diverse agroecological zones (Nega, 2025). The major climatic changes observed in East Africa that directly drive pest invasion are shifts in temperature regimes, alterations in rainfall patterns, and rising atmospheric CO₂ concentrations (Subedi et al., 2023).

Temperature

Temperature is one of the most important factors affecting the distribution and abundance patterns of plants and insects alike (Cahon et al., 2018). It limits the geographic areas where different crops can be grown and influences the rates of development, growth, and crop yields (Skendžić et al., 2021). Insect physiology is very sensitive to changes in temperature, and the metabolic rate tends to approximately double with an increase of 10°C (Skendžić et al., 2021). This means that warmer conditions directly accelerate insect consumption, development, and movement, influencing fecundity, survival, generation time, population size, and geographic range (Skendžić et al., 2021). In East Africa, increased temperatures are raising pest survival rates, shortening breeding cycles, and expanding the geographic spread of pests such as desert locusts (Nega, 2025). This constitutes the spatial and temporal dimensions of pest invasion in action: pests are not only moving into new territories but are also reproducing faster and more frequently than historical patterns would predict.

Rainfall

Crop production is highly dependent on water availability, and climate change is modifying rainfall distribution, soil moisture retention, evaporation rates, and surface runoff (Alotaibi, 2023). Rainfall accounts for more than 80% of global crop water needs, making variations in seasonal rainfall amounts or distribution patterns highly significant (Skendžić et al., 2021). In East Africa, irregular rainfall that disrupts planting and harvesting cycles creates environments favourable for pest outbreaks (Nega, 2025). Research from Karamoja in Uganda showed vividly how the first rains dramatically transformed the landscape, driving conditions toward being favourable for desert locust breeding, maturation, gregarisation, concentration, and migration (Barasa et al., 2023). This example illustrates how rainfall events that would once have been seasonal norms can now act as triggers for large-scale pest invasions under a changing climate.

Drought and Flood

Droughts and floods weaken plant and human health alike, increasing the vulnerability of crops and livestock to damage (Nega, 2025). The increasing frequency and severity of

droughts can cause widespread crop failure, while simultaneously providing favourable conditions for pest outbreaks in subsequent growing seasons (Nega, 2025). Beneficial predators such as birds, spiders, and parasitic wasps are affected by habitat loss and climate stress, reducing their ability to manage pest populations (Zhou et al., 2024). Pest species that can adapt and evolve under increased temperature conditions thrive and reproduce rapidly, while their natural enemies struggle to maintain their populations (Skendžić et al., 2021).

Elevated CO₂ Concentration

Beyond its role as a greenhouse gas, rising atmospheric CO₂ exerts direct physiological effects on plants that cascade through agroecosystems to influence pest dynamics (Abuelela et al., 2025). Elevated CO₂ levels can increase photosynthetic rates and promote faster plant growth through increased carbon assimilation, while simultaneously reducing stomatal conductance and increasing water-use efficiency (Ainsworth et al., 2025). However, a key consequence for agroecosystems is the alteration of plant tissue quality: elevated CO₂ typically increases carbon-to-nitrogen ratios, reducing the nutritional value of leaves for herbivores (Abuelela et al., 2025). In response, many insects engage in compensatory feeding, consuming more plant material to meet their nitrogen requirements, a behaviour that amplifies overall crop damage (Skendžić et al., 2021). Furthermore, elevated CO₂ can modify plant secondary metabolites and volatile emissions that natural enemies use to locate prey, thereby disrupting biological control and indirectly benefiting pest populations (V et al., 2024).

Pest Impacts on Ecosystem Structure and Function

Pests act as ecological stressors capable of modifying ecosystems both structurally and functionally (Nega, 2025). The effects of these disturbances are amplified when climate change intensifies them (Skendžić et al., 2021). Viewed through the pest invasion framework, these impacts represent the consequences of inverted ecological relationships that once maintained ecosystem stability.

Biodiversity Loss

Many native species are at risk as invasive pests outcompete or prey on indigenous flora and fauna (Abdulahi et al., 2017). For example, invasive species such as *Prosopis juliflora* (mesquite) degrade rangelands in Kenya and Ethiopia, reducing plant diversity and altering soil chemistry (van Wilgen et al., 2024). *Prosopis* suppresses grass growth beneath its canopy by delaying seed germination and reducing plant growth metrics, including root and shoot length, leaf area, stem diameter, and height in competing plant species (Abdulahi et al., 2017). Research from Ethiopia's Allideghi Grassland indicates that *Prosopis* invades new areas, often replacing native plant species and causing significant harm to biodiversity (van Wilgen et al., 2024; Abdulahi et al., 2017).

Trophic Cascades

Changes in pest populations can disrupt food chains in ways that cascade through entire ecosystems (Barasa et al., 2023). For example, locust swarms consume vegetation at a massive scale, leading to food shortages for herbivores and their predators, ultimately destabilising the ecosystem. A participant in a focus group discussion vividly described how the desert locust invasion disrupted vegetation and grassland ecosystems: "The areas where livestock once grazed were left barren within days, as the grass was completely consumed. Even camels, which typically feed on plant leaves, cannot find enough foliage, as locusts have stripped nearly all of this vegetation. Only tough, inedible leaf remnants were left behind"(Barasa et al., 2023).

Habitat Fragmentation

Increased pest control measures, especially through pesticide use, can degrade habitats and affect non-target species (Zhou et al., 2025). The widespread application of chemical pesticides to control pest outbreaks can fragment habitats by eliminating non-target vegetation and reducing populations of beneficial insects that support ecosystem functioning. This fragmentation disrupts ecological connectivity, making it more difficult for species to move, find food, or reproduce, thereby reducing overall ecosystem resilience (Akhter et al., 2024). Over time, ecosystems lose their resilience and ability to recover from disturbances, leading to changes that can become irreversible.

Implications of Pest Invasion for Livelihoods and Food Security

In East Africa, where agriculture accounts for a major portion of employment, pests directly undermine rural livelihoods and food security (Nega, 2025). The changing pest dynamics under climate change threaten to reverse development gains, entrench poverty, and undermine resilience among vulnerable populations.

Crop Losses and Income Reduction

Outbreaks of fall armyworm and desert locusts are causing significant losses in maize, millet, and sorghum the staple crops that feed millions in Uganda, Kenya, and Ethiopia (Monica et al., 2024). Small-scale farmers, who are already vulnerable to climate shocks, face reduced yields and incomes (Kalyebi et al., 2023). In Uganda, fall armyworm infestations have affected up to 75% of maize-growing households in some districts (Kalyebi et al., 2023). The spread of *Prosopis* has led to a significant decline in livestock productivity by displacing vital dry-season grazing areas, with milk yield losses estimated at 10 litres for cattle and annual weight losses of 15 kg per animal (Abdulahi et al., 2017). These are not just numbers; they represent the difference between a household feeding itself and going hungry.

Increased Production Costs

In response to rising pest threats, farmers spend more on pesticides and labour (Kalyebi et al., 2023). However, many cannot afford effective or safe pest control, resulting in poor returns on investment and long-term soil degradation due to chemical misuse. In Uganda, limited knowledge about pest biology and ecology, along with inadequate guidance on appropriate timing and dosage of pesticide use, has led to misuse and overreliance on chemicals, significantly increasing the cost of maize production while also raising potential health and environmental risks.

Food Insecurity

Lower agricultural output drives up food prices, reduces household food availability, and increases reliance on food aid (Barasa et al., 2023). Malnutrition rates, especially among children and pregnant women, increase during pest outbreaks. The study by (Barasa et al., 2023) found that the majority of surveyed households reported having reduced both the number of food items they consumed and the frequency of consumption following locust invasions. Food security that farmers had worked for years to build was dismantled in a matter of days.

Livelihood Diversification and Migration

When faced with declining crop productivity, some households turn to practices such as charcoal burning, fishing, or moving to urban areas, which often place extra pressure on natural resources (Barasa et al., 2023). In pastoral regions, invasive weeds reduce grazing land, harming livestock health and market value. Communities in the Karamoja region have attempted to diversify their livelihoods by engaging in casual labour, relying on remittances, and operating small-scale businesses (Barasa et al., 2023).

Threats to Human Health

Pest invasions and the measures used to control them pose direct and indirect threats to human health (Abdulahi et al., 2017). *Prosopis juliflora* poses significant health risks: its sharp thorns lead to skin irritation, painful wounds, and in severe cases, infections that can result in limb amputation or even blindness (Hussain et al., 2020). The widespread application of chemical pesticides introduces significant health risks to farming communities, with farmers and their families exposed to acute poisoning and chronic health conditions, including respiratory problems, skin disorders, and potential long-term effects such as cancers and reproductive issues (Zhou et al., 2025). Environmental contamination from pesticide use, including the accumulation of pyrethroids and organophosphates in Ugandan aquatic ecosystems, further compounds these risks (Baguma et al., 2023).

On the other hand, climate change is also expanding habitats for disease-vector mosquitoes, causing the spread of malaria, dengue, chikungunya, and yellow fever in East Africa (Obame-Nkoghe et al., 2024). In Uganda, irregular rainfall patterns lead to prolonged water stagnation and additional mosquito breeding sites (Nabatanzi et al., 2022). Malaria

reduces labour productivity, causes work absences, and forces households to spend limited resources on treatment, reducing savings and investments in food production (Katushabe et al., 2024).

Case Studies of Large-Scale Pest Invasions in East Africa

Desert Locust Swarm (2020–2021)

The most severe locust outbreak in 70 years destroyed thousands of hectares of farmland and pasture across East Africa (Mulli   et al., 2023). The outbreak was linked to cyclones in the Arabian Peninsula and warming of the Indian Ocean, both associated with climate change (Salih et al., 2020), and caused over USD 8.5 billion in damage while drastically increasing food insecurity across the affected countries (Barasa et al., 2023).

The invasion stemmed from a locust outbreak in the Arabian Peninsula in mid-2018, triggered by two major cyclones that created ideal breeding conditions (Mulli   et al., 2023). By early 2019, swarms had migrated to Saudi Arabia and Iran; by mid-2019, they had spread into northern Ethiopia and northern Somalia, eventually reaching Kenya by the end of the year. When Cyclone Pawan struck the Horn of Africa, conditions for locust proliferation intensified further. By February 2020, swarms had invaded South Sudan, Tanzania, Eritrea, Djibouti, and Uganda (Barasa et al., 2023).

Fall Armyworms in Uganda

First detected in 2016, the fall armyworm has become a major pest for maize farmers across Uganda. Surveys have revealed that over 80% of maize fields in central and western Uganda have been affected (Kalyebi et al., 2023). According to a study by (Ajam et al., 2024), there is a significant negative relationship between rainfall and *S. frugiperda* damage while high temperature rises are reported to favour *S. frugiperda* multiplication and potentially lead to higher damage levels. This case demonstrates how temperature and rainfall variability the key climatic variables identified in the climate-pest interactions section, interact with pest biology and farm management practices to determine outbreak severity.

Maize is the major food crop affected, though the pest has a wide range of cereals as hosts (Kalyebi et al., 2023). Yield reductions range from 8.3 to 20.6 tonnes per hectare, which for a smallholder farmer translates not just to economic loss but to genuine food insecurity for the household (Kalyebi et al., 2023). The livelihood consequences yield reductions, increased production costs, and trade disruptions that mirror the socioeconomic pathways outlined in the preceding section, underscoring that the fall armyworm is not simply an agricultural problem, but a climate-pest-livelihood problem requiring integrated responses.

Invasive Prosopis in Northern Kenya

Prosopis juliflora L. is one of the world's worst woody invasive plants (Dakhil et al., 2021). It was introduced to Ethiopia in the early 1980s to address desertification in overgrazed arid and semi-arid regions, a well-intentioned intervention that became an ecological disaster (Abdulahi et al., 2017). The plant develops dense, thorny thickets that can reach 12 metres

in height, invading rangelands, reducing grazing areas for livestock, and fuelling conflicts over natural resources (Bekele et al., 2024). Pastoralists report lower livestock productivity, greater distances travelled in search of forage, and heightened resource conflicts (Abdulahi et al., 2017).

The *Prosopis* case illustrates a different dimension of pest invasion: the unintended consequences of human interventions designed to address climate-related challenges (Bekele et al., 2024). Initially introduced to combat desertification itself a climate-driven process *Prosopis*'s extreme drought resistance and deep taproot allow it to outcompete native species under conditions of increasing aridity. The ecological consequence is biodiversity loss through displacement of native grasses and the creation of what researchers call a "green desert" (Abdulahi et al., 2017). The livelihood impacts, such as reduced livestock productivity, increased migration distances, resource conflicts, and direct health risks from thorn injuries, illustrate how pest invasion can unfold not just through insects but through any organism whose ecological relationships with the surrounding environment are disrupted by climate change.

Strategies for Adaptation and Pest Management

Integrated Pest Management

Integrated pest management (IPM) combines biological, cultural, and chemical control methods (Zhou et al., 2024). Encouraging natural predators, crop rotation, resistant plant varieties, and reducing pesticide use can sustainably lower pest populations (Zhou et al., 2024). During locust invasions, the most effective farmer responses combined pesticide spraying with biological control methods such as the use of poultry and other animals, and physical interventions including chasing insects and excavating egg pods (Barasa et al., 2023).

Climate-Smart Agriculture

Climate-smart agriculture practices such as intercropping, mulching, timely harvesting, drought-tolerant crop varieties, and agroecological methods that promote biodiversity can enhance natural pest control and build resilience against climate and pest pressures (Sekabira et al., 2022). To manage fall armyworms, farmers in Ethiopia and Kenya employ synthetic insecticides and plant extracts, manually pick larvae, and fill damaged maize cobs with soil as a pest control method (Sekabira et al., 2022).

Early Warning Systems

Effective pest monitoring and early warning systems are essential for the timely identification and management of pest outbreaks, directly addressing the need for proactive rather than reactive interventions (Nega, 2025). FAO's locust monitoring programmes and remote sensing tools provide real-time data to support community response efforts (FAO, 2020).

Regional Collaboration

East African countries should cooperate on pest surveillance, data exchange, and coordinated response plans through organisations such as IGAD or the East African Community. During the desert locust outbreak, the deployment of six spray aircraft at coordination centres in Ethiopia and Kenya demonstrated the value of regional coordination (FAO, 2020).

Farmer Training and Extension Services

Given that pest invasion renders historical knowledge partially obsolete, continuous updating of farmer knowledge is essential. Research in Uganda by (Kalyebi et al., 2023) found that while 84–92% of farmers could identify fall armyworm by physical characteristics, only 4–8% could do so from crop damage symptoms alone. This indicates gaps between identification and practice. Extension programmes should focus on translating pest identification skills into integrated management practices, including safe pesticide handling and biological control methods.

Gender-Sensitive Approaches

Women play a critical role in preserving natural resources and cultivated biodiversity, which are key assets against biotic and abiotic stresses (Sekabira et al., 2022). Research from Uganda's Kumi and Iganga districts highlighted that women demonstrate greater awareness of pesticide risk than men, yet men typically handle purchasing and applying pesticides a pattern that exposes both crops and families to unnecessary risk (Erbaugh et al., 2003). Gender-sensitive approaches must include training programmes accessible to women, development of pest management technologies appropriate for women's roles in farming, women's inclusion in extension worker recruitment, and reforms to land tenure and credit access policies that currently limit women's ability to invest in sustainable pest management.

Area-Wide Pest Management: Responding to Pest Invasion at Scale

Having established the climate drivers of pest invasion and their ecological and socioeconomic consequences, this section examines area-wide pest management (AWPM) as a strategic framework for responding to large-scale pest invasions in East Africa. According to Monica et al., (2024), the large-scale invasion of pests into the environment presents both challenges and opportunities for AWPM in Africa. Traditional control methods, such as chemical pesticides, dominate but pose significant risks to human health, the environment, and biodiversity (Zhou et al., 2024). Moreover, uncoordinated field-by-field management allows for rapid reinvasion, making such efforts unsustainable (Monica et al., 2024). Area-wide pest management offers a holistic solution by synchronising pest control across large areas, reducing pesticide use, increasing biodiversity, and maintaining ecological balance directly countering the trophic and spatial dimensions of pest invasion.

Documented AWPM successes include biological control of cassava mealybugs, integrated strategies for mango fruit flies in East Africa, and management of false codling moths via sterile insect techniques in South Africa, highlighting the importance of community involvement, policy support, and transboundary collaboration (Monica et al., 2024).

The potential scale of AWPM's impact is underscored by the consequences of its absence. During the 2020–2021 desert locust upsurge, pesticides were applied across approximately 1.6 million hectares of land in East Africa to control desert locust spread, but significant portions of these applications were either unfit for purpose or lacked efficacy against the locusts (Mulli   et al., 2023). Human factors such as limited awareness, inadequate training, weak extension systems, and the socioeconomic diversity of farmers continue to hinder AWPM adoption (Monica et al., 2024). But these are barriers to be addressed, not reasons to abandon the approach.

Discussion of the Findings

The synthesis of evidence presented in this review yields a coherent and sobering picture of how climate change, pest dynamics, and human vulnerability interact across East Africa. The following key findings represent the core of what this review has established, organised along the four objectives set out in the introduction.

Climate Change is Actively Restructuring Pest Dynamics

Climate change is not simply worsening existing pest problems it is rewriting the rules under which pests operate. Rising temperatures are accelerating insect metabolic rates, expanding pest geographic ranges to higher altitudes, and increasing reproductive capacity in species such as fall armyworm and desert locusts (Skend  i   et al., 2021; Nega, 2025). These changes constitute spatial invasion. Increased rainfall variability, including both prolonged droughts and intense flood events, creates conditions that trigger synchronised pest outbreaks, as demonstrated most dramatically by the 2020–2021 desert locust upsurge following cyclones in the Arabian Peninsula (Salih et al., 2020; Mulli   et al., 2023). Elevated atmospheric CO₂ concentrations compound these dynamics by altering plant physiology and triggering compensatory feeding behaviour in herbivorous insects trophic invasion in its most direct form (Thompson et al., 2017; Skend  i   et al., 2021). Together, these climate drivers constitute a fundamental restructuring of pest-ecosystem relationships, which this review conceptualises as pest invasion.

Pest Invasion is Disrupting Ecological Balance

Climate-driven pest invasions are disrupting ecological balance through multiple, interconnected pathways. Biodiversity loss is occurring as invasive species such as *Prosopis juliflora* displace native species across vast rangelands in Kenya and Ethiopia (Abdulahi et al., 2017 ; van Wilgen et al., 2024), while fall armyworm and desert locusts reduce plant cover across agricultural landscapes. Trophic cascades triggered by locust swarms have wiped out vegetation across entire grazing areas, as testified by affected communities in Karamoja (Barasa et al., 2023), where even camels could not find adequate foliage after

invasion. Habitat fragmentation from intensive pesticide use is simultaneously reducing the populations of the very natural enemies, parasitoids, predators, and pollinators whose recovery would be essential for restoring ecological balance. These findings confirm that each dimension of pest invasion- spatial, temporal, and trophic is actively reshaping the ecosystems upon which East African livelihoods depend.

The Socioeconomic Burden Falls Disproportionately on the Most Vulnerable

The socioeconomic consequences of pest invasion are severe and inequitably distributed. Fall armyworm is causing yield reductions of 8.3 to 20.6 tonnes per hectare in Uganda, affecting up to 75% of maize-growing households in some districts (Kalyebi et al., 2023). Livestock losses from *Prosopis* invasion include milk yield reductions of 10 litres per cow and annual weight losses of 15 kg per animal (Abdulahi et al., 2017). Desert locust invasions have directly reduced household food consumption patterns, with the majority of affected households reducing both the number and frequency of meals (Barasa et al., 2023). These impacts are disproportionately borne by women, who face heightened food insecurity, increased production costs, and limited access to extension services and pest management resources (Erbaugh et al., 2003; Sekabira et al., 2022). Pest invasion, therefore, is not merely an ecological phenomenon, but rather is a social justice issue.

Adaptive Strategies Exist but Face Systemic Barriers

A range of adaptive strategies, including IPM, AWPM, climate-smart agriculture, early warning systems, regional collaboration, farmer training, and gender-sensitive approaches, have demonstrated effectiveness in East African contexts (Sekabira et al., 2022; Monica et al., 2024). However, their adoption is constrained by an interlocking set of systemic barriers: weak institutional and policy frameworks; limited access to scientific knowledge and technology among smallholders; inadequate pest monitoring and response systems; climate vulnerability and environmental degradation that amplify the consequences of management failures; poverty and socioeconomic inequality that restrict investment in sustainable practices; poor data collection and decision support; and cross-border coordination failures (Day et al., 2022; Yami et al., 2025). These barriers do not operate in isolation, they interact and reinforce one another, creating a systemic trap that keeps East African farming communities in reactive, chemically dependent management postures (Monica et al., 2024). Breaking out of this trap requires interventions that are as interconnected as the barriers themselves.

Pest Invasion Demands a New Management Paradigm

Perhaps the most important overarching finding of this review is that pest invasion demands a fundamentally different approach to pest management. Historical management frameworks built on stable baselines, calendar-based interventions, and reactive responses to discrete outbreaks are increasingly inadequate in the face of

nonlinear, system-level changes in pest dynamics. The three dimensions of pest invasion, spatial, temporal, and trophic, each require specific adaptive responses that historical frameworks are not designed to provide. Effective governance of pest dynamics under climate change requires anticipatory rather than reactive systems, landscape-level rather than field-level management, and regionally coordinated rather than nationally fragmented responses (Monica et al., 2024). The evidence synthesised in this review makes clear that this transition is not merely desirable but urgently necessary.

Barriers to Tackling Pests, Climate Change, and Ecological Degradation

Barriers to addressing pest issues, climate change, ecosystem degradation, and human livelihoods in East Africa are linked and complex. Rather than operating in isolation, these obstacles interact in mutually reinforcing ways, creating systemic challenges that undermine the region's ability to build resilience and achieve sustainable development.

Weak institutional and policy frameworks, combined with weak regulatory enforcement, exacerbate the downward pressure on pesticide prices by enabling unregistered products, counterfeits, and other low-cost products to circulate easily (Day et al., 2022). Many East African countries lack coherent policies that integrate pest management, climate adaptation, and ecosystem protection. Fragmented governance and poor enforcement result in poor coordination among the agricultural, environmental, and health sectors (Yami et al., 2025).

Limited access to scientific knowledge and technology leaves smallholder farmers without current information on pest surveillance, climate-smart practices, and early warning systems. Poor rural infrastructure and digital gaps hinder the timely sharing of knowledge and technologies (Choruma et al., 2024).

Inadequate pest monitoring and response systems result from a lack of investment in pest forecasting tools, diagnostic labs, and rapid response mechanisms (Monica et al., 2024). Many countries still depend on reactive measures rather than preventive integrated pest management. This systemic weakness interacts directly with the cross-border coordination challenge: even when neighbouring countries possess monitoring data, incompatible systems and the absence of data-sharing protocols prevent the integrated regional picture necessary for anticipating transboundary pest movements.

Poverty and socioeconomic inequality restrict farmers' ability to invest in sustainable practices or adapt to climate shocks (Manono & Mwami, 2026). Women and youth often lack land rights, access to credit, and extension services, increasing their vulnerability. This economic constraint serves as a foundational barrier that magnifies all others. Cross-border pest invasions remain difficult to manage without strong regional coordination, and differences in national strategies and capacities block unified responses (Barasa et al., 2023).

Interconnections among Barriers and Implications for Strategy Design

These barriers interact in mutually reinforcing ways. Recognising their interconnections is essential for designing effective interventions. The strategies outlined in the previous

sections IPM, climate-smart agriculture, AWPM, early warning systems, regional collaboration, farmer training, and gender-sensitive approaches must be implemented as integrated components of a coherent response rather than as standalone initiatives, requiring inclusive, well-funded approaches that combine local knowledge, science, policy innovation, and regional cooperation.

Recommendations

These policy recommendations aim to build resilience among East African farming systems by integrating science-based, participatory, and ecologically sustainable approaches to pest and climate challenges. While the preceding strategies section documented existing adaptive practices and management approaches, this section offers forward-looking policy prescriptions designed to address the barriers identified earlier and create enabling conditions for sustainable pest management at scale. Given the pest invasion framework developed in this review, these recommendations prioritise adaptive, flexible, and regionally coordinated approaches that can respond to nonlinear pest dynamics.

Strengthen Regional and Local Pest Management Coordination

East African governments should develop and support cross-border AWPM strategies coordinated through bodies such as the East African Community or IGAD, to effectively control migratory pests such as desert locusts and fall armyworms. Governments should allocate dedicated funding for cross-border surveillance teams, harmonise data collection protocols, and establish joint rapid response mechanisms that can deploy resources across national boundaries without bureaucratic delays (Barasa et al., 2023).

Mainstream Integrated Pest Management into National Policy Frameworks

National agricultural policies should prioritise IPM approaches that combine biological, cultural, and minimal chemical methods. Policy reforms should include removal of subsidies that favour chemical pesticides, registration requirements that incentivise lower-risk products, and national IPM strategies with dedicated implementation budgets. Reducing pesticide overuse will protect biodiversity and delay resistance build-up in pest populations.

Integrate Climate-Smart Agriculture into Extension Services

Governments should incorporate climate-smart agricultural practices into national extension services, scaling up approaches such as drought-tolerant crops, crop rotation, intercropping, and agroecology through farmer-to-farmer extension networks, integration into agricultural training curricula, and performance-based financing for extension agents who demonstrate effective IPM promotion (Sekabira et al., 2022).

Operationalise Early Warning and Surveillance Systems

Governments and regional bodies should invest in operationalising early warning and surveillance systems using satellite data, remote sensing, and local monitoring to predict

pest outbreaks and climate anomalies (Barasa et al., 2023; Osae et al., 2024). These systems must include ground-based monitoring networks, decision-support tools for farmers, communication systems for remote communities, and contingency funding for rapid deployment of control measures when warnings are issued.

Expand Farmer Education and Extension Services

Governments and development partners should expand farmer training programmes focused on pest identification, non-chemical control methods, and sustainable practices. Extension reforms should include recruitment and training of additional extension personnel, development of locally adapted training materials in local languages, use of digital platforms and mobile technologies, and integration of pest management into farmer field schools and demonstration plots (Kalyebi et al., 2023).

Ensure Gender-Sensitive Programming

Programmes must be gender-sensitive, ensuring that women and men involved in smallholder farming have equitable access to information, resources, and decision-making opportunities. Policy recommendations include targeting women for training in IPM and safe pesticide use, ensuring women's representation in extension worker recruitment, designing extension programmes at times and locations accessible to women, and reforming land tenure and credit access policies that currently limit women's ability to invest in sustainable pest management (Sekabira et al., 2022).

Enforce Ecological Safeguards and Promote Sustainable Use of Invasive Species

Governments should establish regulatory frameworks for monitoring and controlling invasive species such as *Prosopis juliflora*, while simultaneously exploring opportunities for sustainable utilisation, including charcoal production, livestock feed, soil conservation, and gum extraction (Abdulahi et al., 2017; Kamiri et al., 2024). Policies should include reforestation guidelines, land use planning, and community-led restoration initiatives to protect rangelands and biodiversity.

Conclusion

As climate change has accelerated in East Africa, pest dynamics are shifting in ways that threaten ecosystems and livelihoods alike. Warmer temperatures, irregular rains, and extreme weather events create ideal conditions for *pest invasion* the climate-driven reversal of conventional pest distribution (spatial invasion), phenology (temporal invasion), and ecological equilibrium (trophic invasion) and the consequences are being felt by millions of smallholder farmers, pastoralists, and rural communities across the region.

This review set out to achieve four objectives, and the synthesis of peer-reviewed literature has addressed each of them. Regarding the first objective, the review established those rising temperatures accelerate insect metabolic rates, expand pest geographic ranges to higher altitudes, and increase reproductive capacity in species such as fall armyworm and desert locusts constituting spatial and temporal invasion. Increased rainfall variability

triggers synchronised pest outbreaks, as demonstrated by the 2020–2021 desert locust upsurge, while elevated CO₂ concentrations amplify these dynamics through trophic invasion.

In relation to the second objective, the review documented multiple pathways through which climate-driven pest invasions disrupt ecological balance: biodiversity loss through displacement of native species by invasives such as *Prosopis juliflora*; trophic cascades resulting from vegetation removal by locust swarms; and habitat fragmentation caused by both pest damage and intensive pesticide applications. Each represents an outcome of pest invasion, where established ecological relationships are reversed.

Concerning the third objective, the review quantified the socioeconomic burden: yield reductions of 8.3–20.6 tonnes per hectare from fall armyworm in Uganda; milk yield losses of 10 litres per cattle and annual weight losses of 15 kg per animal from *Prosopis*-induced pasture degradation; and documented reductions in household food consumption following locust invasions. These impacts are disproportionately borne by women, who face heightened food insecurity, increased production costs, and limited access to extension services and pest management resources.

With respect to the fourth objective, the review synthesised evidence on adaptive strategies including IPM, AWPM, climate-smart agriculture, early warning systems, regional collaboration, farmer training, and gender-sensitive approaches. Critically, the analysis identified the interlocking barriers that impede these strategies, demonstrating how they interact systemically and therefore how responses must be similarly integrated to be effective.

The evidence synthesised here makes clear that climate-driven pest invasions are not isolated phenomena but systemic challenges that link ecological degradation, agricultural vulnerability, and human welfare in mutually reinforcing ways. Understanding these dynamics as pest invasion, a fundamental reversal of historical ecological relationships, provides a conceptual foundation for designing responses that match the scale and nature of the challenge. Addressing these challenges requires moving beyond fragmented, reactive approaches toward integrated, science-based, and regionally coordinated responses that address the underlying drivers while building adaptive capacity at community, national, and regional levels. Without such integrated measures, climate-driven pest pressures will continue to exacerbate ecological degradation, entrench poverty, and undermine food security across East Africa.

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