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Climate and Sustainable Agriculture Research

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Synergistic Development of Biodiversity Conservation and Food Security in Tropical Island Eco-Agricultural Systems

Arjun Patel*

Department of Sustainable Agriculture, University of Seychelles, Victoria, Seychelles

ABSTRACT

This study focuses on the synergistic development of biodiversity conservation and food security in tropical island eco-agricultural systems, addressing the unique challenges of limited land resources, high ecological sensitivity, and vulnerability to climate change (e.g., typhoons, sea-level rise) in tropical island regions. Employing a mixed-methods approach—including field surveys (1,800 farms across 6 tropical island regions), ecological modeling (InVEST model, 2021–2024), and participatory action research—we identify key conflicts and synergies between biodiversity conservation and food production: (1) monoculture plantations (e.g., palm oil, sugarcane) reduce local plant diversity by 45–55% but contribute 60–70% of island food supply; (2) traditional agroforestry systems maintain 80–90% of native biodiversity but have 20–30% lower crop yields than monocultures; (3) climate change-induced extreme events (typhoons, droughts) reduce both biodiversity (15–20% loss of pollinator species) and food production (25–35% yield decline). We evaluate five eco-agricultural practices: diversified agroforestry (mixing food crops with native trees), pollinator-friendly hedgerows, rainwater harvesting + organic farming, intercropping of staple crops with nitrogen-fixing plants, and community-managed conservation areas. Results show that diversified agroforestry increases native plant diversity by 35–45% and improves crop yield stability by 30% (reducing typhoon-induced losses), while pollinator-friendly hedgerows boost pollinator abundance by 50–60% and increase fruit crop yields by 25%. Regional case studies (Hainan Island, China; Seychelles; Trinidad and Tobago) reveal context-specific barriers: limited access to organic fertilizers (Hainan), lack of community governance mechanisms (Seychelles), and insufficient market channels for eco-friendly crops (Trinidad and Tobago). The study concludes that integrated interventions—such as organic input subsidies, community-based conservation training, and eco-labeled crop markets—can increase the adoption rate of biodiversity-friendly practices by 40% while maintaining or increasing food self-sufficiency rates by 15%. These findings provide a scientific basis for balancing ecological protection and food security in tropical island eco-agricultural systems, supporting the achievement of UN Sustainable Development Goals (SDGs 2, 13, 15).

Keywords: Tropical Island; Eco-Agriculture; Biodiversity Conservation; Food Security; Agroforestry; Pollinator Protection; Climate Resilience; Sustainable Development Goals

1. Introduction

1.1 Background

Tropical islands cover only 3% of the global land area but host 15–20% of the world's terrestrial biodiversity, including 60% of endemic plant and animal species (UNEP, 2023). These regions are also home to over 60 million people, with 70% of rural communities dependent on agriculture for livelihoods and food supply (FAO, 2022). However, tropical islands face unique challenges in balancing biodiversity conservation and food security:

Land Scarcity: Over 80% of tropical islands have less than 10,000 km^2 of land, with arable land accounting for only 15–20% of total area (World Bank, 2023). This forces intensive land use, often leading to deforestation of native forests (converted to monoculture plantations) and loss of biodiversity.

Ecological Sensitivity: Tropical islands have fragile ecosystems—soil erosion rates are 2–3 times higher than continental regions (due to steep slopes and heavy rainfall), and endemic species are highly vulnerable to habitat destruction (IUCN, 2022). For example, on the Seychelles, 40% of endemic plant species are threatened by the expansion of coconut plantations (Patel et al., 2023).

Climate Vulnerability: Tropical islands are among the regions most affected by climate change—typhoons destroy 20–30% of agricultural crops annually (Hainan Island, China; Li et al., 2023), and sea-level rise (0.3–0.5 m by 2050) salinizes coastal farmland, reducing arable area by 10–15% (Seychelles; Okafor et al., 2022).

Biodiversity is critical to tropical island agriculture: pollinators (bees, butterflies) contribute to 70% of fruit and vegetable production (Rossi et al., 2022), and native trees in agroforestry systems prevent soil erosion and regulate microclimates (reducing drought impacts). However, current unsustainable agricultural practices—such as monoculture of cash crops (palm oil, sugarcane), excessive use of chemical pesticides, and overgrazing—have caused severe biodiversity loss: on Trinidad and Tobago, monoculture sugarcane plantations have reduced bird diversity by 50% compared to native forests (Okafor et al., 2023). At the same time, food security remains a pressing issue—30% of tropical island populations face moderate to severe food insecurity (UNDP, 2023), due to low crop yields, high dependence on food imports (60–80% of staple foods in small islands), and climate-induced crop failures.

Eco-agricultural practices, such as diversified agroforestry and pollinator-friendly farming, have shown potential to address this trade-off. For instance, on Hainan Island, diversified agroforestry (mixing rubber trees with bananas and legumes) has increased both native plant diversity (by 30%) and crop yields (by 20%) compared to rubber monocultures (Li et al., 2022). However, the adoption of these practices remains low (15–20% of farms), due to high initial costs, lack of technical knowledge, and limited market incentives for eco-friendly crops (Hernandez et al., 2023).

1.2 Research Gap

Existing studies on biodiversity and food security have mostly focused on continental regions or large islands (e.g., Madagascar), with limited attention to small tropical islands (area <10,000 km^2) characterized by extreme land scarcity and ecological fragility. Most research has also treated biodiversity conservation and food security as conflicting goals, failing to systematically identify and quantify their synergies (e.g., how pollinator conservation improves crop yields). Additionally, there is a lack of long-term (post-2020) data on climate change impacts on both biodiversity and food production in tropical island systems, and few studies have integrated community participation into solution design—critical for ensuring the sustainability of interventions in island communities with strong traditional livelihoods.

1.3 Research Objectives

To fill these gaps, this study aims to:

Assess the current status of biodiversity (plant, pollinator, soil macrofauna) and food security (yield, self-sufficiency rate, food access) in 6 tropical island regions (2021–2024).

Identify the key conflicts (e.g., land use competition) and synergies (e.g., pollinator services boosting yields) between biodiversity conservation and food production.

Evaluate the effectiveness of five eco-agricultural practices in enhancing both biodiversity and food security, under climate change scenarios.

Propose community-inclusive, policy-supported strategies to promote the adoption of synergistic practices in tropical island regions.

1.4 Scope and Significance

This study covers 6 tropical island regions across three ocean basins:

Pacific Ocean: Hainan Island (China), Fiji Islands

Indian Ocean: Seychelles, Mauritius

Atlantic Ocean: Trinidad and Tobago, Cape Verde

These regions represent diverse tropical island ecosystems (coral islands, volcanic islands) and agricultural systems (cash crop monocultures, traditional agroforestry, subsistence farming), as well as varying levels of economic development (high-income: Seychelles; middle-income: Hainan; low-income: Cape Verde).

The significance of this study lies in three aspects:

Scientific Value: It quantifies the synergies between biodiversity and food security in tropical island systems, filling the research gap in small island-specific studies.

Practical Value: It evaluates actionable eco-agricultural practices, providing technical guidance for farmers and policymakers.

Policy Value: It aligns with global agendas (UN SDGs, UN Framework Convention on Climate Change) and supports tropical island countries in developing national biodiversity-food security strategies.

2. Literature Review

2.1 Current Status of Biodiversity and Food Security in Tropical Islands

2.1.1 Biodiversity Loss in Tropical Island Agriculture

Tropical islands are hotspots of biodiversity loss, driven primarily by agricultural expansion. Deforestation for monoculture plantations (palm oil, sugarcane) has reduced native forest cover by 30–40% on many islands over the past 50 years (UNEP, 2023). For example, on Fiji Islands, 60% of native lowland forests have been converted to sugarcane plantations, leading to a 55% decline in endemic plant species (Hernandez et al., 2022).

Pollinator loss is another critical issue: chemical pesticides used in monocultures have reduced bee populations by 40–50% on Hainan Island (Li et al., 2023), and the loss of native flowering plants (due to land conversion) has reduced butterfly diversity by 35% on Trinidad and Tobago (Okafor et al., 2023). Soil biodiversity is also degraded—excessive use of chemical fertilizers reduces soil macrofauna (e.g., earthworms) by 25–30% (Rossi et al., 2022), impairing soil fertility and water retention.

Climate change exacerbates biodiversity loss: rising temperatures (1.0–1.5°C since 2000) have shifted the distribution of endemic plants to higher elevations (on Mauritius, 30% of mountain plant species have moved upslope by 100–200 m; Patel et al., 2022), and typhoons destroy 15–20% of native tree seedlings in agroforestry systems (Hainan Island; Li et al., 2023).

2.1.2 Food Security Challenges in Tropical Islands

Food security in tropical islands is threatened by three interrelated factors:

Low Yield Stability: Climate-induced extreme events (typhoons, droughts) reduce crop yields by 25–35% annually. On Cape Verde, droughts in 2022 reduced maize yields by 40%, leading to a 20% increase in food imports (FAO, 2023).

High Import Dependence: Small tropical islands import 60–80% of staple foods (rice, wheat) due to limited arable land. For example, the Seychelles imports 90% of its food, making it vulnerable to global food price fluctuations (World Bank, 2023).

Livelihood Vulnerability: 70% of rural households in low-income islands (e.g., Cape Verde) depend on subsistence farming—crop failures lead to immediate food insecurity and income loss (UNDP, 2022).

Monoculture cash crops (e.g., palm oil in Trinidad and Tobago) further undermine food security: they occupy 50–60% of arable land but contribute little to local food supply (most are exported), reducing the area available for staple crops (maize, beans; Okafor et al., 2022).

2.2 Synergies and Conflicts Between Biodiversity and Food Security

2.2.1 Synergies: Biodiversity Supports Food Production

Biodiversity provides critical ecosystem services for agriculture:

Pollination Services: Native pollinators (bees, birds) increase the yield of fruit and vegetable crops by 20–30%. On Hainan Island, farms with pollinator-friendly hedgerows have 25% higher mango yields than farms without hedgerows (Li et al., 2022).

Soil Fertility Regulation: Soil macrofauna (earthworms, termites) improve soil structure, increasing water infiltration by 20–25% and nutrient availability by 15–20%. In the Seychelles, organic farms with high earthworm abundance have 18% higher cassava yields than conventional farms (Patel et al., 2023).

Pest Control: Native predators (ladybugs, spiders) reduce pest populations by 30–40%, reducing the need for chemical pesticides. On Mauritius, intercropping sugarcane with native flowering plants increased pest predator abundance by 45%, reducing pesticide use by 30% and sugarcane yields by only 5% (Rossi et al., 2023).

2.2.2 Conflicts: Land and Resource Competition

The primary conflict between biodiversity and food security is land use:

Native Forest Conversion: Converting native forests to agricultural land (to increase food production) reduces biodiversity by 40–50%. On Fiji Islands, converting 100 km^2 of native forest to maize fields increased food production by 15% but caused a 45% loss of endemic bird species (Hernandez et al., 2023).

Input Competition: Resources (e.g., labor, fertilizers) allocated to biodiversity conservation (e.g., planting native trees) may reduce investment in food crops. In Cape Verde, farmers who allocate 20% of their land to conservation areas have 10–15% lower staple crop yields (UNDP, 2023).

Climate change intensifies these conflicts: to adapt to droughts, farmers often expand irrigation to food crops, reducing water availability for native wetlands (critical for biodiversity). On Trinidad and

Tobago, irrigation expansion for sugarcane has reduced wetland area by 20%, threatening 30% of wetland-dependent species (Okafor et al., 2022).

2.3 Eco-Agricultural Practices for Synergistic Development

2.3.1 Diversified Agroforestry

Diversified agroforestry combines food crops (e.g., bananas, beans) with native trees (e.g., mahogany, coconut) in a multi-layered system. It enhances biodiversity by providing habitat for native plants and animals: on Hainan Island, agroforestry systems with 5–8 native tree species support 70–80% of the native bird diversity found in primary forests (Li et al., 2022). For food security, the tree layer reduces typhoon damage (by 30–40%) and improves microclimates (lowering temperature by 2–3°C), increasing crop yield stability. In the Seychelles, coconut-banana agroforestry has 25% higher yield stability than banana monocultures during droughts (Patel et al., 2023).

However, adoption is limited by long-term tree growth (native trees take 3–5 years to mature) and lack of technical knowledge—only 15% of farmers in Cape Verde know how to design diversified agroforestry systems (Hernandez et al., 2023).

2.3.2 Pollinator-Friendly Hedgerows

Pollinator-friendly hedgerows are strips of native flowering plants (e.g., lantana, sunflower) planted along field edges. They increase pollinator abundance by 50–60% and diversity by 35–45% (Rossi et al., 2022). On Mauritius, mango farms with hedgerows have 25% higher yields and 15% better fruit quality (due to improved pollination) than farms without hedgerows. Hedgerows also reduce soil erosion by 20–25% (by acting as windbreaks) and provide additional income (farmers sell flowers or honey from hedgerows).

The main barrier is initial establishment cost: planting hedgerows costs 200–300 per hectare, which is 10–15% of smallholder farmers' annual income in low-income islands (FAO, 2022).

2.3.3 Rainwater Harvesting + Organic Farming

Rainwater harvesting (e.g., storage tanks, contour bunds) combined with organic farming (using compost, manure instead of chemicals) addresses both climate resilience (drought adaptation) and biodiversity conservation. Rainwater harvesting increases water availability by 40–50% during dry seasons, while organic farming increases soil biodiversity (earthworm abundance by 30–40%) and reduces pesticide-related pollinator loss (Rossi et al., 2023). On Cape Verde, this combination has increased maize yields by 20% and reduced soil erosion by 35% compared to conventional maize farming (Hernandez et al., 2023). Organic farming also improves food quality—on Hainan Island, organic vegetables have 30% higher vitamin C content than conventional vegetables, and sell at a 50% price premium in local markets (Li et al., 2022).

Challenges to adoption include limited access to organic inputs (e.g., compost, manure) in remote island regions—on Cape Verde, 40% of farmers report traveling 10+ km to purchase organic fertilizers (UNDP, 2023)—and the need for specialized knowledge in composting and organic pest management.

2.3.4 Intercropping of Staple Crops with Nitrogen-Fixing Plants

Intercropping staple crops (e.g., maize, cassava) with nitrogen-fixing plants (e.g., beans, peanuts) enhances soil fertility and biodiversity while maintaining or increasing food yields. Nitrogen-fixing plants improve soil nitrogen content by 20–30%, reducing the need for chemical fertilizers and benefiting soil macrofauna (earthworm abundance increases by 15–20%; Rossi et al., 2023). On Trinidad and Tobago, maize-bean intercropping has increased total crop productivity by 15% (compared to maize monoculture) and provided additional protein sources (beans) for local food security (Okafor et al., 2023).

This practice also supports biodiversity: the mixed crop canopy provides habitat for insect pollinators, increasing pollinator diversity by 25–30% compared to monocultures. However, adoption is limited by labor-intensive planting and harvesting—intercropping requires 20–25% more labor than monoculture, which is a barrier for smallholder farmers with limited family labor (FAO, 2022).

2.3.5 Community-Managed Conservation Areas

Community-managed conservation areas are small patches of native vegetation (5–10% of farmland) managed by local communities to protect biodiversity, while also providing ecosystem services for agriculture. These areas act as "biodiversity refuges" for native plants and animals—on the Seychelles, community conservation areas have maintained 90% of endemic plant species and increased pollinator abundance by 40% in surrounding farmland (Patel et al., 2023). They also reduce soil erosion by 30–35% (by stabilizing slopes) and regulate water flow, increasing irrigation water availability during dry seasons.

The success of this practice depends on strong community governance—on Mauritius, communities with formal management agreements (defining roles for farmers, local governments, and NGOs) have maintained conservation areas for 5+ years, while those without agreements have seen 20% of conservation areas converted to farmland (Rossi et al., 2022). Barriers include lack of community capacity (e.g., limited training in conservation management) and insufficient financial support for maintenance (e.g., weeding, tree planting).

2.4 Policy and Institutional Support for Synergistic Practices

Policy support is critical for promoting the adoption of eco-agricultural practices in tropical islands. Key policy measures include:

Input Subsidies: Subsidies for organic fertilizers, native tree seedlings, and rainwater harvesting equipment reduce initial costs. On Hainan Island, the government provides a 50% subsidy for organic fertilizers, increasing organic farming adoption by 30% (Li et al., 2023).

Technical Training: Extension services that provide hands-on training in practice design and management. In Trinidad and Tobago, farmer field schools (training 2,000 farmers annually) have increased the adoption of maize-bean intercropping by 25% (Okafor et al., 2022).

Market Incentives: Eco-labeling schemes and premium prices for biodiversity-friendly crops. The Seychelles' "Island Eco-Crop" label allows farmers to sell organic fruits at a 40% price premium in tourist markets, increasing farmer income by 20% (Patel et al., 2023).

Community Governance Support: Funding for community conservation committees and legal recognition of community-managed areas. On Mauritius, the government provides $10,000/year to community conservation committees for maintenance, reducing the conversion of conservation areas by 15% (Rossi et al., 2022).

However, policy gaps remain: 60% of tropical island countries lack national strategies that integrate biodiversity conservation and food security (UNEP, 2023), and only 30% of smallholder farmers have access to extension services (FAO, 2022). Additionally, policies often focus on individual practices (e.g., organic farming) rather than integrated systems (e.g., agroforestry + pollinator hedgerows), limiting their impact on both biodiversity and food security.

3. Methodology

3.1 Study Design

This study adopts a **mixed-methods, participatory research design** that integrates quantitative (field surveys, ecological modeling) and qualitative (interviews, focus groups) approaches, with active community participation in data collection and solution design. This design ensures that findings are both scientifically rigorous (supported by objective data) and contextually relevant (reflecting the needs and perspectives of island communities).

The study is structured in three phases:

Baseline Assessment (2021–2022): Collect data on biodiversity, food security, and current agricultural practices in 6 island regions.

Practice Evaluation (2022–2023): Test the five eco-agricultural practices on 300 farms (50 farms/region) and measure their impact on biodiversity and food security.

Strategy Development (2023–2024): Organize stakeholder workshops to co-design policy and community-based strategies for scaling up effective practices.

3.2 Study Regions and Farm Selection

The 6 study regions were selected based on three criteria: (1) representation of different tropical island ecosystems (coral islands: Seychelles, Cape Verde; volcanic islands: Hainan, Trinidad and Tobago; mixed ecosystems: Fiji, Mauritius); (2) diversity of agricultural systems (cash crop monocultures, traditional agroforestry, subsistence farming); and (3) varying levels of food insecurity (high: Cape Verde, Fiji; moderate: Hainan, Trinidad and Tobago; low: Seychelles, Mauritius).

For each region, 300 farms were selected using **stratified random sampling** to ensure representation of three farm types:

Monoculture Farms: Growing a single cash crop (e.g., palm oil, sugarcane) or staple crop (e.g., maize).

Traditional Agroforestry Farms: Growing a mix of crops and native trees (no formal biodiversity management).

Eco-Agricultural Farms: Adopting one or more of the five practices (selected to evaluate practice effectiveness).

Farm size ranged from 0.5–5 hectares (smallholder farms, which account for 80% of agricultural land in tropical islands; FAO, 2023), and all farms had been in operation for at least 3 years to ensure stable production and biodiversity data.

Table 1: Study Regions, Ecosystem Types, and Dominant Agricultural Systems (2021–2024)

Region	Ecosystem Type	Dominant Agricultural Systems	Key Crops	Food Insecurity Level (2023)
Hainan Island (China)	Volcanic	Rubber monoculture, traditional agroforestry	Rubber, bananas, mangoes	Moderate (25% of population)
Fiji Islands	Mixed (volcanic + coral)	Sugarcane monoculture, subsistence farming	Sugarcane, taro, cassava	High (35% of population)

Region	Ecosystem Type	Dominant Agricultural Systems	Key Crops	Food Insecurity Level (2023)
Seychelles	Coral	Coconut monoculture, tourism-integrated farming	Coconuts, tropical fruits, vegetables	Low (10% of population)
Mauritius	Mixed (volcanic + coral)	Sugarcane monoculture, organic farming	Sugarcane, tea, organic fruits	Low (12% of population)
Trinidad and Tobago	Volcanic	Sugarcane/palm oil monoculture, intercropping	Sugarcane, palm oil, maize, beans	Moderate (22% of population)
Cape Verde	Coral	Subsistence farming, maize monoculture	Maize, beans, potatoes	High (40% of population)

3.3 Data Collection

3.3.1 Quantitative Data

(1) Biodiversity Data:

Plant Diversity: Measured using quadrat sampling (10 m × 10 m quadrats, 5 quadrats/farm) to count native and exotic plant species, and calculate the Shannon-Wiener diversity index (H'). Data were collected twice/year (wet and dry seasons) to capture seasonal variation.

Pollinator Diversity: Used pan traps (yellow, blue, white) and observation surveys (30 minutes/farm, weekly for 3 months) to count bee, butterfly, and bird pollinators. Pollinator abundance and diversity (H') were calculated for each farm.

Soil Biodiversity: Collected soil samples (0–20 cm depth, 3 samples/farm) to count earthworms and macroinvertebrates (using the Berlese-Tullgren method). Soil organic matter content (Walkley-Black method) and nutrient levels (nitrogen, phosphorus, potassium) were also measured.

(2) Food Security Data:

a.**Yield Data**: Collected crop yield data (kg/ha) for staple and cash crops, with annual measurements for 3 years (2021–2023). Yield stability was calculated as the coefficient of variation (CV) of yields across years.

b.**Self-Sufficiency Rate**: Surveyed farmers to determine the percentage of food consumed that is produced on-farm (vs. purchased/imported).

c.**Food Access**: Collected data on household food expenditure (percentage of income spent on food) and frequency of food shortages (times/year).

(3) Climate and Environmental Data:

a.**Climate Data**: Sourced from regional meteorological stations and NASA's POWER database, including daily temperature, precipitation, and typhoon/drought records (2021–2023).

b.**Soil and Water Data**: Measured soil erosion (using sediment traps) and water availability (well water levels, rainfall runoff) for each farm.

3.3.2 Qualitative Data

Farmer Interviews: Conducted semi-structured interviews with 1,800 farmers (300/region) to explore: (1) perceptions of biodiversity loss and food insecurity; (2) barriers to adopting eco-agricultural practices; (3) needs for policy and technical support. Interviews lasted 60–90 minutes and were audiorecorded (with consent) for transcription.

Stakeholder Focus Groups: Organized 12 focus groups (2/region) with 8–10 participants each, including farmers, extension agents, policymakers, and NGO representatives. Focus groups discussed: (1) priority actions for balancing biodiversity and food security; (2) design of community-managed conservation areas; (3) market opportunities for eco-friendly crops.

Participatory Observations: Researchers spent 1–2 weeks/farm observing agricultural practices (e.g., planting, harvesting, pest management) to verify survey data and understand practical challenges in implementing eco-agricultural practices.

3.3.3 Ecological Modeling Data

Used the **InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model** to simulate the impact of eco-agricultural practices on two key ecosystem services: (1) pollination service (linking pollinator diversity to crop yields); (2) soil conservation (linking vegetation cover to soil erosion). Input data for the model included:

Land use maps (Sentinel-2 satellite images, 10 m resolution, 2021–2023).

Biodiversity data (plant and pollinator diversity from field surveys).

Climate data (precipitation, wind speed) from meteorological stations.

Soil data (texture, slope) from the Harmonized World Soil Database (HWSD).

3.4 Data Analysis

3.4.1 Quantitative Analysis

Descriptive Statistics: Summarized biodiversity (H' index, abundance) and food security (yield, self-sufficiency rate) indicators across farm types and regions using SPSS 26.0. Calculated mean values and standard deviations to compare baseline conditions (2021) and post-practice conditions (2023).

Inferential Statistics:

a.Used **analysis of variance (ANOVA)** to test for significant differences in biodiversity and food security indicators between farm types (monoculture vs. agroforestry vs. eco-agricultural). Post-hoc Tukey's HSD tests were used to identify pairwise differences.

b.Applied **regression analysis** (R 4.2.3) to explore the relationship between biodiversity indicators (e.g., pollinator diversity) and food security indicators (e.g., crop yield).

c.Used **t-tests** to compare yield stability (CV) before and after implementing eco-agricultural practices.

Model Validation: Calibrated and validated the InVEST model using field data (e.g., observed crop yields, soil erosion rates) from 2021 (calibration period) and 2022 (validation period). Model performance was evaluated using the coefficient of determination (R^2) and root mean square error (RMSE), with $R^2 > 0.7$ and RMSE < 10% indicating acceptable performance.

3.4.2 Qualitative Analysis

Thematic Analysis: Applied Braun & Clarke's (2006) six-step approach to analyze interview transcripts and focus group records: (1) familiarization with data; (2) generation of initial codes (e.g., "cost barriers," "technical knowledge gaps"); (3) grouping codes into themes (e.g., "adoption barriers," "policy needs"); (4) reviewing themes for consistency; (5) defining and naming themes; (6) writing up results.

Cross-Region Comparison: Compared themes across the 6 regions to identify common barriers (e.g., limited access to organic inputs) and context-specific challenges (e.g., typhoon impacts in Hainan vs. drought impacts in Cape Verde). Used a matrix to summarize key findings for each region.

3.4.3 Participatory Data Validation

To ensure the accuracy and relevance of findings, we organized **community validation workshops** (1/region) with 20–30 farmers and stakeholders. Participants reviewed draft results (e.g., biodiversity trends, practice effectiveness) and provided feedback to revise and refine analysis—for example, correcting misinterpretations of traditional agricultural practices and adding local knowledge about pollinator behavior.

4. Results

4.1 Baseline Status of Biodiversity and Food Security (2021)

4.1.1 Biodiversity Across Farm Types

Biodiversity indicators varied significantly between farm types, with monoculture farms having the lowest biodiversity and traditional agroforestry farms having the highest (Table 2).

Plant Diversity: The Shannon-Wiener index (H') for native plants was 0.8–1.2 in monoculture farms (e.g., palm oil plantations in Trinidad and Tobago), 1.8–2.2 in eco-agricultural farms (adopting one practice), and 2.5–2.8 in traditional agroforestry farms (e.g., mixed crop-tree systems in the Seychelles). Monoculture farms had 45–55% fewer native plant species than traditional agroforestry farms.

Pollinator Diversity: Pollinator H' was 0.6–0.9 in monoculture farms (due to pesticide use and lack of flowering plants), 1.5–1.8 in eco-agricultural farms, and 2.0–2.3 in traditional agroforestry farms. Bee abundance was 50–60% lower in monoculture farms than in traditional agroforestry farms.

Soil Biodiversity: Earthworm abundance was 10–15 individuals/m² in monoculture farms (due to chemical fertilizers), 25–30 individuals/m² in eco-agricultural farms, and 35–40 individuals/m² in traditional agroforestry farms. Soil organic matter content was 1.0–1.5% in monoculture farms, 2.0–2.5% in eco-agricultural farms, and 2.8–3.2% in traditional agroforestry farms.

Table 2: Baseline Biodiversity Indicators Across Farm Types (2021, Mean ± SD)

Farm Type	Native Plant H'	Pollinator H'	Earthworm Abundance (individuals/m²)	Soil Organic Matter (%)
Monoculture	1.0 ± 0.2	0.7 ± 0.1	12 ± 3	1.2 ± 0.2
Eco-Agricultural (1 practice)	2.0 ± 0.3	1.6 ± 0.2	28 ± 4	2.2 ± 0.3
Traditional Agroforestry	2.6 ± 0.3	2.1 ± 0.2	37 ± 5	3.0 ± 0.3

4.1.2 Food Security Across Farm Types

Food security indicators also varied by farm type, with trade-offs between yield level and stability:

Yield Level: Monoculture farms had the highest yields for cash crops (e.g., 8–10 tons/ha for sugarcane in Fiji) but lower yields for staple crops (e.g., 2–3 tons/ha for maize in Cape Verde) compared to eco-agricultural farms. Traditional agroforestry farms had moderate staple crop yields (3–4 tons/ha for cassava in the Seychelles) but low cash crop yields (1–2 tons/ha for rubber in Hainan).

Yield Stability: Monoculture farms had the lowest yield stability—sugarcane yields in Fiji had a coefficient of variation (CV) of 35–40% (due to typhoons and droughts), while eco-agricultural farms had a CV of 15–20% (e.g., maize-bean intercropping in Trinidad and Tobago). Traditional agroforestry farms had the highest stability (CV = 10–15%), as the mixed crop-tree system buffered climate impacts.

Self-Sufficiency Rate: Eco-agricultural farms had the highest self-sufficiency rate (60–70%, e.g., rainwater harvesting + organic farming in Cape Verde), as they focused on staple crop production. Monoculture farms had the lowest (20–30%), due to prioritizing cash crop exports over local food needs. Traditional agroforestry farms had a moderate rate (45–55%).

Table 3: Baseline Food Security Indicators Across Farm Types (2021, Mean ± SD)

Farm Type	Staple Crop Yield (tons/ha)	Cash Crop Yield (tons/ha)	Yield CV (%)	Self-Sufficiency Rate (%)	Food Expenditure (% of Income)
Monoculture	2.5 ± 0.5	9.0 ± 1.0	37 ± 4	25 ± 5	65 ± 8
Eco-Agricultural (1 practice)	3.8 ± 0.6	4.5 ± 0.8	18 ± 3	65 ± 7	40 ± 6
Traditional Agroforestry	3.5 ± 0.5	1.5 ± 0.4	12 ± 2	50 ± 6	45 ± 7

4.1.3 Climate Change Impacts (2021–2023)

Over the 3-year study period, climate change exacerbated both biodiversity loss and food insecurity:

Biodiversity Impacts: Typhoons in Hainan destroyed 15–20% of native trees in agroforestry systems, reducing plant diversity (H') by 0.3–0.5. Droughts in Cape Verde reduced flowering plant cover by 30%, leading to a 25% decline in pollinator abundance. Sea-level rise in the Seychelles salinized 10% of coastal farmland, killing 40% of soil macrofauna (earthworms, termites) in affected areas.

Food Security Impacts: Typhoons reduced sugarcane yields by 30–35% in Fiji (2022) and mango yields by 25–30% in Hainan (2023). Droughts in Cape Verde reduced maize yields by 40% (2022), increasing food imports by 20% and food expenditure to 70% of household income.

4.2 Effectiveness of Eco-Agricultural Practices (2022–2023)

After 2 years of implementation, all five practices significantly improved both biodiversity and food security, with varying effectiveness across regions (Table 4).

4.2.1 Diversified Agroforestry

Diversified agroforestry (mixing 5–8 native tree species with food crops) had the strongest overall impact on biodiversity:

Biodiversity Gains: Native plant H' increased by 0.8–1.2 (e.g., from 1.0 to 2.1 in Hainan's rubber-based systems), and bird diversity increased by 40–50% (due to tree canopy habitat). Pollinator abundance rose by 35–45% (flowering trees provided nectar sources).

Food Security Gains: The tree layer reduced typhoon damage by 30–40%, lowering yield CV by 10–15 (e.g., from 37% to 22% for sugarcane in Fiji). Staple crop yields increased by 15–20% (maize yields in Cape Verde rose from 2.5 to 3.0 tons/ha) due to improved microclimates (lower temperature, higher humidity).

Adoption rates were highest in the Seychelles (35%) and lowest in Cape Verde (15%), due to differences in tree seedling availability and technical training.

4.2.2 Pollinator-Friendly Hedgerows

Hedgerows (native flowering plants along field edges) had the most targeted impact on pollination services:

Biodiversity Gains: Pollinator H' increased by 0.6–0.9 (e.g., from 0.7 to 1.6 in Trinidad and Tobago's sugarcane farms), and bee species richness rose by 30–40%. Hedgerows also provided habitat for beneficial insects (ladybugs), reducing pest populations by 35–45%.

Food Security Gains: Fruit crop yields increased by 25–30% (mango yields in Hainan rose from 5.0 to 6.5 tons/ha) due to improved pollination. Vegetable yields (tomatoes, peppers) increased by 20–25% in Fiji and Mauritius.

The main limitation was initial cost (200–300/ha), but subsidies reduced this barrier—adoption rates reached 30% in Hainan (50% subsidy) vs. 12% in Cape Verde (no subsidy).

4.2.3 Rainwater Harvesting + Organic Farming

This combination was most effective in drought-prone regions (Cape Verde, Mauritius):

Biodiversity Gains: Organic farming increased soil organic matter by 0.5–0.8% (from 1.2 to 2.0% in Cape Verde), boosting earthworm abundance by 50–60% (from 12 to 18 individuals/m^2). Rainwater harvesting maintained flowering plant cover during droughts, preventing a 20–25% pollinator decline.

Food Security Gains: Water availability increased by 40–50% during dry seasons, reducing drought-induced yield losses by 30–35% (maize yields in Cape Verde fell by only 10% in 2023, vs. 40% in conventional farms). Organic crops sold at a 40–50% price premium, increasing farmer income by 25–30%.

Adoption was limited by organic input access—only 20% of farmers in remote Cape Verde villages could access compost, compared to 60% in Hainan.

4.2.4 Intercropping (Staple Crops + Nitrogen-Fixing Plants)

Intercropping (e.g., maize + beans, cassava + peanuts) was the most cost-effective practice for smallholders:

Biodiversity Gains: Mixed crop canopies increased insect diversity by 25–30%, and nitrogen-fixing plants improved soil nitrogen content by 20–30%, boosting soil macrofauna by 15–20%.

Food Security Gains: Total productivity (staple + nitrogen-fixing crops) increased by 15–20% (e.g., from 3.8 to 4.5 tons/ha in Trinidad and Tobago's maize-bean systems). Protein intake from beans increased by 30% for farming households, reducing malnutrition risk.

Labor intensity was a barrier—adoption rates were 25% in regions with family labor surplus (Fiji) vs. 10% in regions with labor shortages (Cape Verde).

4.2.5 Community-Managed Conservation Areas

Conservation areas (5–10% of farmland) acted as "biodiversity refuges" and provided ecosystem services:

Biodiversity Gains: Areas maintained 90–95% of endemic plant species (e.g., Seychelles' endemic palms) and increased pollinator abundance by 40% in surrounding farmland (via spillover effects). Soil erosion in conservation areas was 70–80% lower than in farmland, reducing sedimentation in nearby rivers.

Food Security Gains: Conservation areas regulated water flow, increasing irrigation water availability by 20–25% during dry seasons. In Mauritius, this reduced sugarcane yield losses by 15–20% during droughts.

Success depended on community governance—areas with formal management agreements had 80%

higher survival rates (5+ years) than unmanaged areas (30% survival).

Table 4: Average Impact of Eco-Agricultural Practices (2022–2023, % Change from Baseline)

Practice	Native Plant H' Increase (%)	Pollinator Abundance Increase (%)	Soil Macrofauna Increase (%)	Staple Crop Yield Increase (%)	Yield CV Reduction (%)	Self-Sufficiency Rate Increase (%)
Diversified Agroforestry	40–50	35–45	30–40	15–20	30–40	10–15
Pollinator-Friendly Hedgerows	15–20	50–60	10–15	25–30 (fruit crops)	15–20	8–12
Rainwater Harvesting + Organic Farming	20–25	25–30	50–60	20–25	40–50	15–20
Intercropping (Staple + Nitrogen-Fixing)	10–15	25–30	15–20	15–20 (total productivity)	20–25	5–10
Community-Managed Conservation Areas	50–60 (in areas)	40–50 (surrounding farms)	40–50 (surrounding farms)	10–15	25–30	5–8

4.3 Regional Case Studies

4.3.1 Case Study 1: Hainan Island (China) – Typhoon-Prone Volcanic Ecosystem

Hainan's main challenges were typhoon-induced crop losses and rubber monoculture-related biodiversity loss. The study implemented two key practices:

Diversified Agroforestry: Converted 50 rubber monoculture farms to rubber-banana-mahogany systems. After 2 years, native plant H' increased from 1.0 to 2.1, and typhoon damage to bananas reduced by 35% (yield CV fell from 32% to 18%). Mango intercropping added $600/ha to farmer income.

Pollinator-Friendly Hedgerows: Planted lantana and sunflower hedgerows on 50 mango farms. Pollinator abundance increased by 55%, and mango yields rose from 5.0 to 6.5 tons/ha. The government provided a 50% subsidy for hedgerow establishment, increasing adoption from 10% to 30%.

Key challenge: 25% of farmers reported difficulty pruning native trees (due to lack of training). The solution: organized 10 farmer field schools, training 500 farmers in tree management—pruning efficiency improved by 40%.

4.3.2 Case Study 2: Seychelles – Coral Island with Tourism Integration

The Seychelles faced sea-level rise impacts and low food self-sufficiency (60% imports). The study focused on:

Community-Managed Conservation Areas: Established 10 coastal conservation areas (5–10% of farmland) managed by local communities. These areas protected 90% of endemic coastal plants and reduced soil salinization by 30% (via mangrove buffers). Surrounding farms saw a 45% increase in pollinator abundance, boosting vegetable yields by 20%.

Tourism-Integrated Eco-Farming: Partnered with 30 hotels to purchase organic fruits/vegetables from eco-farms. The "Island Eco-Crop" label allowed farmers to sell at a 40% price premium, increasing income by 25%. Food self-sufficiency rose from 40% to 55%.

Key challenge: 30% of communities lacked governance experience. The solution: trained 200 community members in conservation management and legal agreement drafting—all 10 areas maintained stable vegetation cover (80%+) after 2 years.

4.3.3 Case Study 3: Cape Verde – Drought-Prone Coral Island

Cape Verde's main issues were drought-induced food insecurity (40% food insecurity) and limited organic input access. The study implemented:

Rainwater Harvesting + Organic Farming: Installed 50 rainwater storage tanks (10,000 L each) and distributed compost on 50 maize farms. Water availability during droughts increased by 50%, and maize yields rose from 2.5 to 3.8 tons/ha (drought losses reduced by 40%). Soil organic matter increased from 1.2% to 2.0%, boosting earthworm abundance by 60%.

Intercropping: Promoted maize-bean intercropping on 50 farms. Total productivity increased by 18% (maize: 3.8 tons/ha, beans: 1.2 tons/ha), and protein intake for farming households rose by 30%.

Key challenge: 40% of farmers had to travel 10+ km to buy compost. The solution: established 5 community compost centers (using agricultural waste), reducing compost transport costs by 50%—organic input access improved by 60%.

5. Discussion

5.1 Key Findings and Synergy Mechanisms

This study identifies three critical synergies between biodiversity conservation and food security in tropical island systems:

Habitat Provision Boosts Ecosystem Services: Diversified agroforestry and conservation areas provide habitat for pollinators and soil organisms, which in turn improve crop yields. For example, 1% increase in pollinator H' was associated with a 2–3% increase in fruit yields (regression analysis, R^2 = 0.72). This aligns with Rossi et al. (2023), who found similar pollination-yield links in Mediterranean agroecosystems.

Climate Resilience Benefits Both Goals: Practices like agroforestry (tree canopy) and rainwater harvesting reduce climate-induced losses for both crops and biodiversity. In Hainan, agroforestry reduced typhoon damage to crops by 35% and protected 20% of native tree species—breaking the "climate-biodiversity-food" negative feedback loop.

Market Incentives Align Interests: Eco-labels (e.g., Seychelles' "Island Eco-Crop") and tourism partnerships make biodiversity-friendly farming profitable. Farmers in the Seychelles earned 25% more from eco-crops, increasing their willingness to allocate land to conservation (5–10% of farmland).

The study also quantifies a key conflict resolution: converting 10% of monoculture land to biodiversity-friendly practices reduces cash crop yields by only 5–8% but increases staple crop yields by 15–20% and biodiversity by 40–50%. This contradicts the common narrative that conservation "reduces food production" (Hernandez et al., 2023).

5.2 Comparison with Existing Literature

Our results extend previous research in three ways:

Small Island Specificity: Most studies focus on large islands (e.g., Madagascar) or continents. We show that tropical small islands (area <10,000 km²) require tailored practices—e.g., community conservation areas for coastal salinization (Seychelles) vs. rainwater harvesting for droughts (Cape Verde)—due to extreme land scarcity and climate vulnerability.

Long-Term Climate Data: Post-2020 data reveals that climate change exacerbates biodiversity-food trade-offs 2–3 times faster in islands than in continents (e.g., 40% maize yield loss in Cape Verde's 2022 drought vs. 15% in continental West Africa; FAO, 2023). This highlights the urgency of island-specific adaptation.

Participatory Design: Unlike top-down studies, we co-designed practices with communities—e.g., Cape Verde's compost centers (based on farmer feedback about input access)—increasing adoption by 40% compared to externally imposed practices (Patel et al., 2023).

5.3 Implications for Practice and Policy

5.3.1 For Farmers and Extension Services

Adopt Practice Combinations: Combine practices based on local climate risks:

a.Typhoon-prone regions (Hainan, Fiji): Diversified agroforestry + pollinator hedgerows.

b.Drought-prone regions (Cape Verde, Mauritius): Rainwater harvesting + intercropping.

c.Coastal regions (S

Coastal regions (Seychelles, Cape Verde): Community-managed conservation areas (mangrove buffers) + rainwater harvesting.

Leverage Local Knowledge: Integrate traditional agroforestry practices (e.g., Seychelles' coconut-cassava systems) with modern eco-agricultural techniques. For example, Cape Verde's farmers used traditional composting methods (mixing crop waste with goat manure) to improve organic input quality—compost nutrient content increased by 15% compared to commercial compost.

Collaborate for Markets: Form farmer cooperatives to access eco-labeled markets. In Trinidad and Tobago, 20 maize-bean farmers formed a cooperative, securing a supply contract with a local supermarket chain—eco-friendly beans sold at a 30% price premium, increasing per-farm income by $400/year.

5.3.2 For Policymakers

Design Targeted Subsidies: Prioritize high-impact, high-cost practices with region-specific subsidies:

a.Typhoon-prone regions: 50% subsidy for diversified agroforestry (tree seedlings, pruning tools).

b.Drought-prone regions: 40% subsidy for rainwater harvesting tanks and organic compost.

c.Coastal regions: 60% subsidy for community conservation area establishment (mangrove saplings, fencing).

Hainan's 50% hedgerow subsidy increased adoption by 20%, demonstrating the effectiveness of targeted support.

Strengthen Technical Infrastructure: Establish regional "Eco-Agriculture Hubs" to provide:

a.Input supply (native tree seedlings, organic fertilizers) to reduce transport costs (e.g., Cape Verde's compost centers cut costs by 50%).

b.Training (farmer field schools, digital tutorials) on practice design and management—Hainan's tree pruning training improved efficiency by 40%.

c.Market linkages (eco-label certification, tourism partnerships)—Seychelles' tourism integration increased farmer income by 25%.

Integrate into National Policies: Develop national "Biodiversity-Food Security Strategies" that align with UN SDGs. For example, the Seychelles updated its 2024 Agricultural Policy to include community conservation areas as a key adaptation measure, allocating $2 million for hub establishment and training.

5.4 Limitations and Future Research

5.4.1 Limitations

Long-Term Sustainability: This study measures 2–3 year impacts of practices; long-term effects (5–10 years) on soil fertility, endemic species survival, and market stability require further monitoring. For example, diversified agroforestry's tree growth may compete with crops over time, potentially reducing yields.

Gender Equity: Only 30% of survey participants were women, and we did not analyze gender disparities in access to subsidies or training. In Cape Verde, women farmers reported 20% less access to extension services than men, suggesting potential equity gaps.

Model Uncertainty: The InVEST model's pollination service predictions (R^2 = 0.72) are acceptable but may underestimate impacts in data-sparse regions (e.g., remote villages in Fiji with limited yield monitoring).

5.4.2 Future Research Directions

Long-Term Monitoring: Establish permanent observation plots in 6 study regions to track soil organic matter, endemic plant populations, and crop yields over 10+ years. This will help assess practice sustainability and adjust management (e.g., tree pruning frequency) as needed.

Gender-Inclusive Interventions: Design targeted training and subsidy programs for women farmers (e.g., flexible training schedules to accommodate caregiving responsibilities) and evaluate their impact on adoption rates and household food security.

Digital Tools for Precision Management: Develop low-cost mobile apps (with offline functionality) to help farmers: (1) monitor soil moisture and pollinator activity; (2) access market prices for eco-friendly crops; (3) connect with extension agents. This builds on Thapa et al. (2023)'s work on digital agriculture in tropical regions.

Climate Projection Modeling: Use downscaled climate models to predict biodiversity-food security impacts under 1.5°C and 2°C warming scenarios. This will help identify high-risk regions (e.g., low-lying coastal farms in the Seychelles) and prioritize adaptation investments.

6. Conclusion

Tropical island eco-agricultural systems face unique challenges of land scarcity, ecological fragility, and climate vulnerability, which have historically created trade-offs between biodiversity conservation and food security. However, this study demonstrates that eco-agricultural practices—diversified agroforestry, pollinator-friendly hedgerows, rainwater harvesting + organic farming, intercropping, and community-managed conservation areas—can resolve these trade-offs by enhancing synergies: habitat provision boosts ecosystem services (pollination, soil fertility), climate resilience protects both crops and biodiversity, and market incentives align farmer livelihoods with conservation goals.

Across 6 tropical island regions, these practices increased native plant diversity by 10–60%, pollinator abundance by 25–60%, and staple crop yields by 10–30%, while reducing yield variability (CV) by 15–50%. Regional case studies highlight the critical role of targeted policies (subsidies, hubs) and community participation—Hainan's hedgerow subsidies increased adoption by 20%, and Cape Verde's compost centers improved organic input access by 60%.

As tropical islands face accelerating climate change, balancing biodiversity and food security is not only possible but essential for sustainable development. This study provides a roadmap for achieving this balance through integrated, context-specific interventions that empower farmers, guide policymakers, and support the achievement of UN SDGs 2 (Zero Hunger), 13 (Climate Action), and 15 (Life on Land). Future research and policy action should focus on long-term sustainability, gender equity, and digital innovation to ensure these synergies endure for generations.

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