Identifying synergies between ecological and nutritional resilience of smallholder agroecosystems

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Overview

Background

- Smallholder agroecosystems produce one-third of the world's food with limited resources and institutional support, making them vulnerable to nutritional insecurity and environmental degradation.
- Given that smallholder farmers rely on household production to meet their nutritional needs, management of soil fertility, biodiversity, and other ecological characteristics of agroecosystems directly affects smallholders' capacity to produce sufficient crop nutrients for their diets.

Study purpose

- We lack explicit frameworks linking ecological and nutritional functions of agroecosystems, as well as research exploring farmers' adaptive capacity and agency in mediating these functions, and ultimately, agroecosystem resilience (Figure 1).
- To address these gaps, we developed an indicator framework to evaluate the complementary roles of ecological and nutritional functions of agroecosystems for smallholder resilience (at right).

Main findings

- Using case study data from 60 farms in eastern Guatemala, we found that ecological and nutritional indicators were significantly related (Kendall's tau = 0.58, z = 5.7, $p < 0.0001$), suggesting that farm management practices increased agroecosystem functions related to both SDG 2 (food and nutritional security) and SDG 15 (ecosystem functioning) in our sample.
- We found that farmers using ecological adaptation strategies such as cover cropping and agroforestry had significantly higher levels of agroecosystem functioning and resilience than farmers who were coping with shocks by working off-farm or renting land from plantations.
- Our findings demonstrate the importance of linking ecological and nutritional functions of agroecosystems through diversified management practices to leverage their synergies.

Conceptual Model

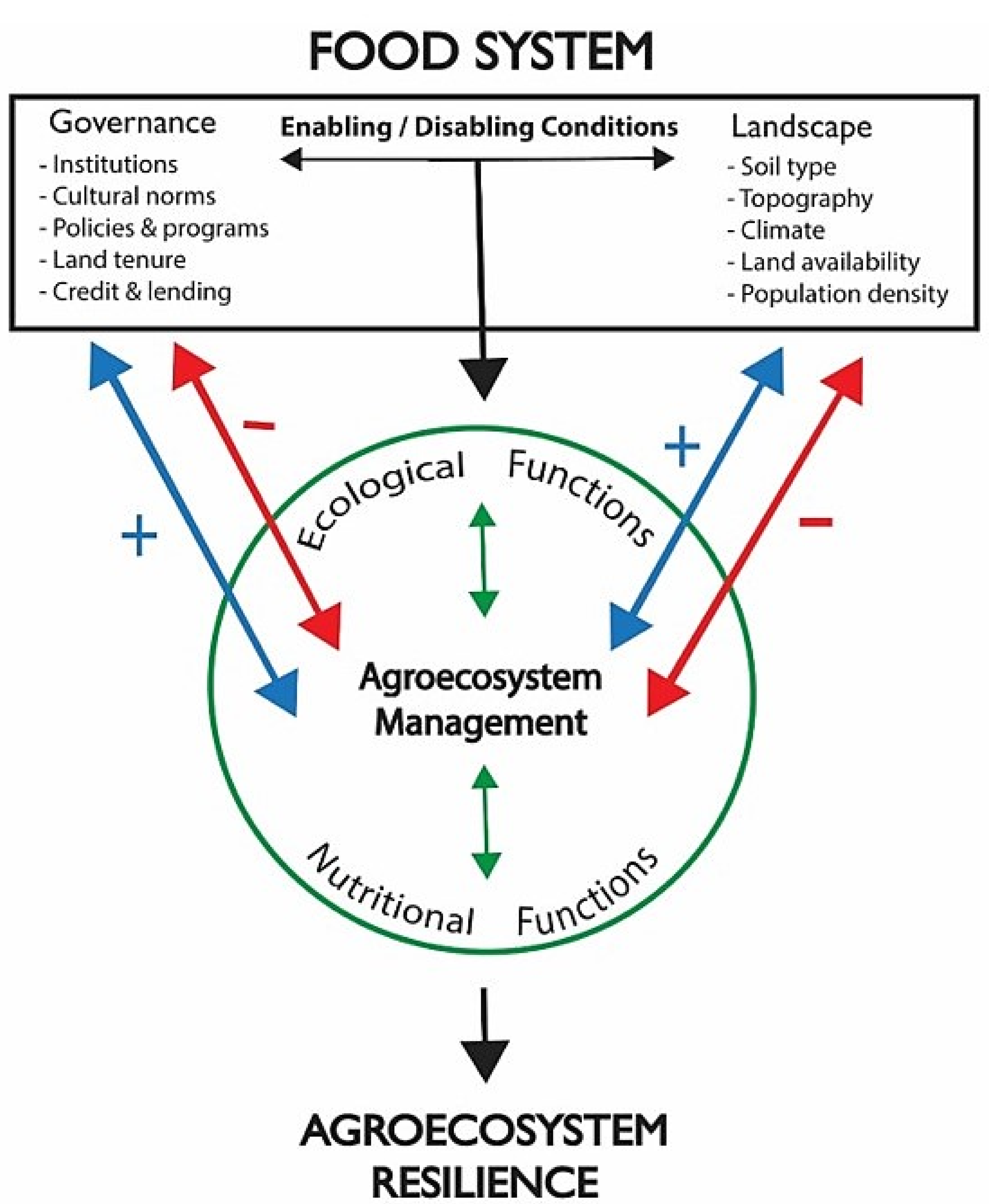

Figure 1. Conceptual diagram of interactions between agroecosystem functioning and resilience. Farm management affects ecological and nutritional functions, which in turn drive changes in agroecosystem resilience. Green arrows inside the circle represent the interactions between ecological and nutritional functions, which are mediated by agroecosystem management practices and the adaptive capacity of farmers. Farm-level management decisions are embedded within food systems and associated governance and landscape conditions, which can trigger positive (+) or negative (-) feedbacks in agroecosystems.

Indicator Framework

Table 1. Indicator framework for ecological and nutritional functions of agroecosystems. Indicators were adapted from prior frameworks (refs. 2-4). Indicators correspond with FAO dimensions of food and nutritional security (ref. 4), as indicated in parentheses below each indicator name. The *Stability* dimension is nested within each indicator pair.

Indicator Pair	Indicator Type	Indicator	Agroecosystem Function
1 Productivity (*Availability*)	Ecological (E)	Total crop production per area	Produce crops over time and under variable environmental conditions
	Nutritional (N)	Staple food availability	Supply sufficient quantities of staple crops to meet household caloric needs
2 Diversity (*Access*)	Ecological	Crop diversity	Fill distinct ecological niches and contribute to long-term productivity by varying crop species over time and in space
	Nutritional	Access to a diversified diet	Provide access to diverse food crops, potentially impacting diet quality
3 Quality (*Utilization*)	Ecological	Beneficial species interactions	Facilitate crops' nutrient uptake, growth, and reproduction through beneficial interactions within and between trophic levels
	Nutritional	Edible crop quality	Increase crop nutrient content and elicit phytochemical responses through facilitative species interactions, improving crop nutritional quality for human diets
4 Functional Diversity (*Utilization*)	Ecological	Functional diversity and redundancy	Enable a functional safety net by planting crops with diverse ecological functional traits and levels of associated non-crop species diversity
	Nutritional	Nutritional functional diversity	Fulfill nutritional needs for household diets by growing crop species that provide complementary and diverse nutrients

Table 2. Results of multiple correspondence analysis between individual pairs of ecological and nutritional indicators, representing tradeoffs or synergies, across all farms (n=60) in a case study in eastern Guatemala. All indicators showed significant positive (indicators 3 and 4) or negative (indicator 1) within-pair relationships at a 95% confidence interval. See ref. 1 for a visual representation of the analysis. Case study metrics (measures of the broader indicators) were derived from interview data except edible crop quality, which was measured by analyzing maize grain samples for protein concentration.

Indicator	Case Study Ecological Metric	Case Study Nutritional Metric	McNemar's $\chi 2$	df	p-value	Synergy or tradeoff?
1 Productivity	Crop yield over time	Deficit/surplus maize yield	26.73	3	6.70×10^{-6}	**tradeoff:** negative ecological; positive nutritional
2 Diversity	Agrobiodiversity	(data not available for case study)	--	--	--	--
3 Quality	Multi-cropping	Maize protein concentration	25.67	3	1.1×10^{-5}	**synergy**
4 Functional Diversity	Ecological crop functional diversity	Nutritional crop functional diversity	N/A (Fisher's Exact)	3	2.2×10^{-16}	**synergy**

References & Funding

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Case Study Results

- **Aim:** Use case study data from 11 villages in eastern Guatemala to identify how interactions between ecological and nutritional indicators in our framework can affect trends in agroecosystem functioning and resilience.
- **Findings:** Adaptive management practices tended to produce synergistic ecological and nutritional relationships, whereas coping and market-oriented strategies prioritized basic nutritional functions while undermining ecological ones (Figure 2).
- Existence of ecological and nutritional synergies highlights smallholders' capacity for resilience in degraded environments (Table 2, 3).

Table 3. Matrix showing relationships across all ecological and nutritional indicators for 60 farms in the Guatemalan case study. Relationships between paired indicators are shown in bold; all were significantly related. The strongest relationship was between the Functional Diversity indicators, 4E and 4N. Non-paired indicators had positive relationships (synergies), with the exception of the negative relationship (tradeoff) between ecological Productivity (1E) and Quality (3E) indicators.

	1E	3E	4E	1N	3N	4N
1E	NA	Tradeoff	No relationship	**Tradeoff**	(-) Synergy	No relationship
3E	Tradeoff	NA	(+) Synergy	No relationship	**(+) Synergy**	(+) Synergy
4E	No relationship	(+) Synergy	NA	No relationship	No relationship	**(+/-) Synergy**
1N	**Tradeoff**	No relationship	No relationship	NA	(+) Synergy	No relationship
3N	(-) Synergy	**(+) Synergy**	No relationship	(+) Synergy	NA	No relationship
4N	No relationship	(+) Synergy	**(+/-) Synergy**	No relationship	No relationship	NA

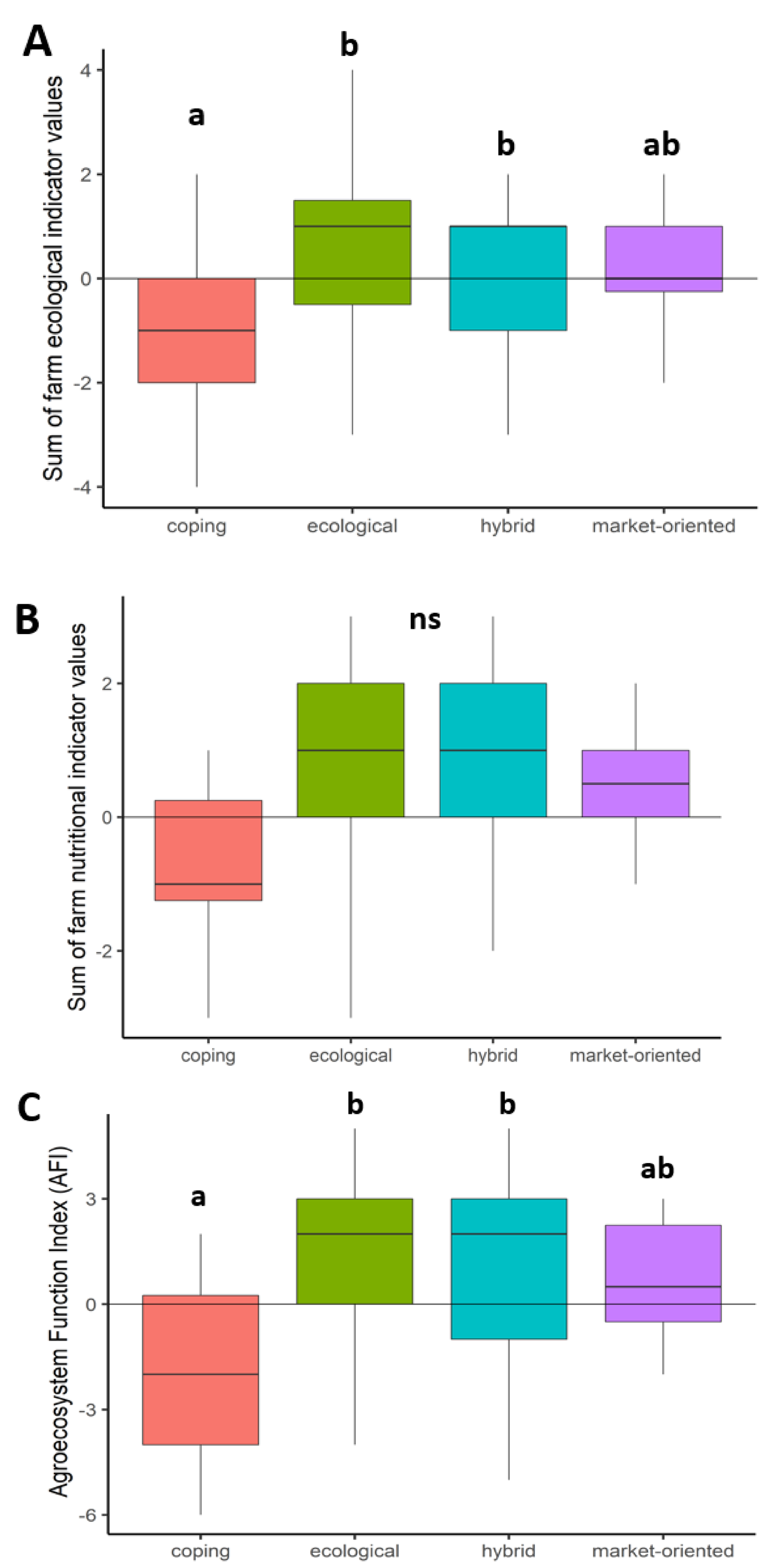

Figure 2. Coping and adaptation strategies in smallholder agroecosystems in eastern Guatemala. Farmer strategies to cope or adapt to shocks are shown in relation to the ecological (**4A**), nutritional (**4B**), and overall sums of indicators represented by the Agroecosystem Function Index (AFI) (**4C**). Primary adaptation strategies were ecological, market-oriented, or a hybrid approach using both ecological and market-oriented practices. Coping strategies included renting land, off-farm work on plantations, and increasing pesticide use. Ecological strategies included incorporating agroforestry techniques, use of leguminous cover crops, and integrating multiple crop diversification practices. Market-oriented strategies included increasing crop sales, growing hybrid maize varieties, and higher fertilizer and pesticide application rates. Different letters indicate significant differences by household coping or adaptation strategy ($p<0.05$; Tukey's HSD). "ns" indicates no significant model effects. Village was included as a random effect in all models.

Conclusions

- To foster resilient agroecosystems, we must meet the dual goals of bolstering ecological functions while producing sufficient high-quality food to ensure food security and nutrition.
- Our framework establishes that smallholder farmers can adopt management strategies in line with both ecological and nutritional goals.
- This adaptable indicator framework can help identify best practices that lead to ecological and nutritional synergies in diverse agroecosystems contexts and could aid decision-makers in targeting supportive resources to the most vulnerable households.