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Decentralized Resilience Hubs as Territorial Anchors: Operationalizing Multi-Scalar Food System Adaptation in Vanuatu Through Reserve-Island Strategies

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Abstract

Small Island Developing States (SIDS) confront escalating compound shocks, yet conventional adaptation frameworks remain anchored in hazard exposure (14% of food system impact variance, $R^2 = 0.14$) rather than redistribution capacity, which mediates 42% of outcomes (spatial lag $\rho = -0.58$, $p < 0.001$) (Rogers & Fotsing, 2026). This study provides the first empirical test of a reserve-island hub strategy for decentralized food system resilience in Vanuatu, leveraging territorial comparative advantages across fragmented archipelagos.

Using Redistribution Capacity Index (RCI) and Hollow Recovery Index (HRI) data across six provinces and 71 area councils (2019–2023), we document RCI collapse from pre-shock baseline 0.87 to 0.18 during COVID-19 maritime closures, with only partial recovery to 0.58 post-Judy/Kevin cyclones. Four resilience archetypes emerge from the Food Security Resilience Framework (FSRF): buffered stronghold (Sanma, FSRe = 61), moderate (Malampa, 58), hidden hotspot (Torba, 57), and critical-fragile (Shefa/Tafea, 46–47). Maritime connectivity explains post-shock outcomes more strongly than exposure: port access correlates at $r = 0.58$ ($p < 0.001$); shipping frequency at $\beta = -0.63$ ($p < 0.001$).

Northern surplus provinces (>600 kg/person/year; RCI 0.62–0.70) anchor southern deficits (247 kg/person/year; RCI 0.45) through dual circulation: customary networks activate within 72 hours (65,000 reached in Sanma pre-formal aid), complemented by formal redundancy. The reserve-island framework transforms production–consumption mismatch into adaptive advantage, validated through spatial lag mediation analysis.

Implementation requires $12 million over 10 years (benefit-cost = 2.3), aligning with GCF/NAP readiness and Sendai Target E. Policy priorities:

1. *maritime decentralization via chief-led MoUs;*
2. *RCI/HRI dashboards;*
3. *hidden-hotspot investment (Torba);*
4. *Pacific Redistribution Resilience Index for archipelagic SIDS monitoring.*

Keywords: *Reserve-island hubs; redistribution capacity; hollow recovery; compound shocks; food system resilience; Vanuatu; SIDS adaptation.*

Introduction

Small Island Developing States (SIDS) are increasingly exposed to compound shocks, yet many adaptation frameworks continue to prioritize hazard exposure or agricultural production alone, thereby underestimating the role of circulation systems in shaping food system resilience (HLPE, 2022; Thow et al., 2020). In Vanuatu, cyclone exposure explains only a limited share of food system impact variance, whereas redistribution capacity—the ability to maintain food movement through shipping routes, ports, feeder roads, and customary exchange networks—appears to mediate a much larger proportion of observed outcomes (Rogers & Fotsing, 2026). This pattern calls for a shift away from centralized, hazard-driven responses toward decentralized territorial strategies capable of transforming spatial unevenness into resilience assets.

Vanuatu offers a compelling case of both vulnerability and adaptive potential. Between 2015 and 2023, five Category 4–5 cyclones, including Pam, Harold, and the Judy–Kevin–

Lola sequence, severely damaged agricultural production, particularly in the southern provinces. At the same time, COVID-19-related maritime restrictions sharply reduced redistribution capacity, causing the Redistribution Capacity Index (RCI) to fall from 0.87 to 0.18. Yet the resulting food security outcomes were not determined by exposure alone. Shefa Province, despite higher hazard exposure, exhibited stronger resilience than Torba because of comparatively better connectivity and circulation performance. This counterintuitive pattern points to a reserve-island logic in which northern provinces with production surpluses and stronger redistribution systems, such as Sanma and Malampa, can function as territorial anchors for deficit areas in the south.

Three persistent limitations continue to constrain conventional adaptation approaches. First, spatial averaging hides provincial heterogeneity in food security resilience and obscures hidden hotspots, where some relatively low-exposure areas may still experience prolonged aid delays and weaker recovery. Second, production-centric approaches neglect the mediating role of maritime and transport systems, even though port access and shipping frequency are strongly associated with redistribution performance. Third, centralized planning often overlooks customary redistribution mechanisms, including kinship-based and church-based networks, which can activate rapidly during disruption and buffer the effects of hollow recovery before formal assistance arrives.

To address these limitations, this study operationalizes the Food Security Resilience Framework (FSRF) through a reserve-island model. The framework conceptualizes resilience as a relational outcome produced by the interaction of hazard exposure, agricultural capacity, redistribution capacity, and recovery speed. It is expressed as follows:

$$\mathbf{FSRe = 30 \times (1 - HEI) + 30 \times AgCap + 25 \times RCI + 15 \times RecSpeed} \qquad \text{(Eq. 1)}$$

Where HEI is the Hazard Exposure Index, AgCap is agricultural capacity, RCI is the Redistribution Capacity Index, and RecSpeed is recovery speed, operationalized as the inverse of the number of days required to reach 50% aid coverage. In this formulation, resilience is not treated as a static attribute of production systems alone, but as an emergent property of territorial connectivity, institutional coordination, and recovery dynamics.

The study pursues three objectives. First, it quantifies mismatches between food security resilience and food security risk across six provinces and 71 area councils over the period 2015–2023. Second, it validates the reserve-hub hypothesis by testing whether northern surplus provinces, with per capita production ranging from 677 to 774 kg per person per year, can support southern deficit regions where production is much lower, such as Shefa at 247 kg per person per year. Third, it develops a feasible ten-year implementation roadmap for reserve-island hubs under the fiscal constraints typical of SIDS, with an estimated total cost of USD 12 million and a preliminary benefit–cost ratio of 2.3.

Five hypotheses guide the analysis. The first posits that Sanma and Malampa exhibit reserve-hub potential because they combine relatively high resilience scores with favorable territorial capacities. The second proposes that crop diversity buffers resilience losses at moderate exposure levels, but that this effect weakens once exposure becomes extreme. The third tests whether maritime circulation mediates a substantial share of impact severity independent of exposure alone. The fourth examines whether customary kinship and church networks enable rapid pre-aid redistribution. The fifth evaluates whether the FSRF explains greater vulnerability reduction than production-only models.

These hypotheses are tested using a multi-method spatial-statistical design detailed in Section 3. Section 2 reviews the literature on compound shocks, hollow recovery, redistribution capacity, and the derivation of the FSRF. Section 3 presents the study area, data sources, index construction, and analytical procedures. Section 4 reports the results on resilience typology, agro-ecological thresholds, circulation mediation, customary activation, and overall framework performance. Section 5 discusses the theoretical and policy implications, including hidden hotspots, territorial reserve logic, and implementation constraints. Section 6 concludes with phased recommendations and future research directions.

Literature Review and Theoretical Framework

Small Island Developing States (SIDS) face a distinctive pattern of food system vulnerability shaped by spatial fragmentation, high reliance on maritime logistics, and exposure to compounding climatic and economic shocks. This section first situates the study within literature on compound shocks and hollow recovery, then introduces redistribution capacity as the missing mediating mechanism, and finally articulates the theoretical gap addressed by the reserve island model and the Food Security Resilience Framework (FSRF).

Compound Shocks, Hollow Recovery, and the Redistribution Gap

Compound shocks, understood as multiple overlapping stressors that interact across time and space, are increasingly recognized as a defining feature of food-system vulnerability in Small Island Developing States (SIDS) (Sharp et al., 2021; McNamara et al., 2023; Zigliani et al., 2023). In archipelagic contexts, food security depends not only on production and household assets, but also on the continuity of redistribution networks that connect production zones, ports, markets, and remote communities (FAO & SPC, 2014; UNCTAD, 2014). Unlike single-event disturbances, compound shocks generate cascading failures in which cyclone damage to ports, roads, and storage systems interacts with mobility restrictions, market disruption, and institutional strain, producing food-security outcomes that exceed the effects of any one disturbance in isolation (Thow et al., 2020; HLPE, 2020 ; Zigliani et al., 2023).

This perspective is especially important in the Pacific, where fragmented geographies and high dependence on maritime circulation create structurally uneven access conditions across islands and provinces (UNCTAD, 2014; FAO, 2023; SPREP, 2025). In such settings, the same shock may produce sharply different outcomes depending on whether food can still move through inter-island shipping, port handling systems, feeder roads, and customary exchange channels (UNCTAD, 2024; Rogers & Fotsing, 2026). The analytical implication is that resilience planning cannot rely on hazard exposure alone ; it must also account for the territorial organization of circulation and access (Rogers & Fotsing, 2026).

The concept of hollow recovery helps clarify why apparent post-shock improvement may mask persistent fragility (Wesener et al., 2019; Miller et al., 2021). Hollow recovery refers to situations in which visible functions resume, such as market reopening, shipping resumption, or restored movement, while the underlying capacities that sustain reliable redistribution remain degraded (Wesener et al., 2019; Miller et al., 2021). This interpretation is consistent with broader recovery scholarship showing that systems may regain outward functionality without restoring the absorptive and adaptive capacities needed to withstand the next disturbance (Hallegatte & Vogt-Schilb, 2019; Kennedy et al., 2008).

Evidence from Vanuatu illustrates this pattern clearly. Redistribution Capacity Index (RCI) values recovered from a pre-shock level of 0.87 to only 0.35 after Tropical Cyclone Harold and to 0.58 after the Judy-Kevin sequence, indicating partial recovery rather than full restoration of circulation resilience (NDMO, 2020; FSAC, 2020; FSAC, 2023). This pattern suggests that repeated shocks may erode food-system stability through cumulative weakening of circulation functions, even when visible activity resumes (FAO, 2023; ReliefWeb, 2023). In that sense, hollow recovery provides a useful lens for understanding why food insecurity can persist or re-emerge despite signs of operational normality (Miller et al., 2021; Wesener et al., 2019).

This literature also reinforces an important policy gap. Food security frameworks increasingly recognize physical access, transport, and market connectivity as core dimensions of food security, alongside availability, utilization, and stability (HLPE, 2020; FAO & SPC, 2014). Yet adaptation practice in many SIDS still remains more strongly oriented toward production recovery than toward circulation resilience, logistics redundancy, and territorial redistribution capacity (FAO, 2023; Thow et al., 2020). Building on this gap, the next subsection examines redistribution capacity as the missing mediator linking shock exposure to food-security outcomes.

Redistribution Capacity as the Missing Mediator

Redistribution capacity refers to the functional ability of a food system to move food reliably between zones of production, storage, exchange, and consumption under both normal and disrupted conditions (UNCTAD, 2014; FAO & SPC, 2014). In this study, that capacity is operationalized through the Redistribution Capacity Index (RCI), which combines three equally weighted components: shipping frequency, port functionality, and road access. These components capture complementary dimensions of circulation vulnerability: shipping frequency reflects inter-island connectivity, port functionality reflects throughput and handling capacity, and road access reflects the integrity of last-mile terrestrial delivery.

This circulation perspective is particularly relevant in Pacific SIDS, where maritime logistics often shape food access more strongly than aggregate production totals alone (UNCTAD, 2014; Dávila et al., 2020; SPREP, 2025). Prior work in Vanuatu shows that redistribution capacity accounts for a substantial share of the observed association between compound shocks and food insecurity, with RCI mediating approximately 42 percent of that relationship in spatial lag models. Related evidence also indicates that infrastructure and connectivity conditions can generate up to a 76 percent differential in impact severity between otherwise comparable councils, independent of cyclone exposure (Rogers & Fotsing, 2026). Taken together, these findings suggest that redistribution is not a secondary effect of resilience, but one of its principal territorial mechanisms.

The mediating role of redistribution capacity is also visible in the contrast between provinces with different circulation profiles. High-exposure areas may perform relatively better than lower-exposure areas when they retain stronger maritime and road connectivity, while low-exposure provinces may become hidden hotspots when food movement remains slow, intermittent, or highly centralized (Rogers & Fotsing, 2026). This is one reason why hazard exposure alone may be an unreliable guide for adaptation targeting in archipelagic systems (Rogers & Fotsing, 2026).

Redistribution capacity should also be understood as more than formal infrastructure. In Vanuatu, customary networks extend the effective circulation system by mobilizing kinship ties, community boats, churches, and school-based hubs before formal aid arrives (Campbell, 2015; Connell, 2015). Evidence from Sanma shows that kinship-activated school hubs reached approximately 65,000 people within 72 hours, illustrating how informal and customary systems can temporarily compensate for formal logistics disruption (Holguín-Veras et al., 2012). Rather than treating formal and informal channels as separate domains, this study interprets them as interdependent components of a broader redistribution architecture (Holguín-Veras et al., 2012; Campbell, 2015).

For policy, this reframing is significant. If redistribution capacity mediates a large share of food insecurity under compound shocks, then food-security planning in SIDS should move beyond production-centred recovery toward circulation-sensitive resilience strategies, including decentralised storage, maritime redundancy, and support for community-based redistribution systems (FAO & SPC, 2014; UNCTAD, 2014; SPREP, 2025). This argument opens the theoretical gap addressed in the next subsection: the need to move from centralized hub dependency toward a distributed reserve-island model.

Theoretical Gap: From Hub Dependency to Reserve-Island Anchors

Existing food-security and disaster-response frameworks often assume that centralized hubs are the most efficient organizational form for redistribution under normal conditions. In Vanuatu, Port Vila performs this role, concentrating a large share of national redistribution functions through its wharf, storage, and market connections. While such concentration may support routine logistics efficiency, it can also create systemic fragility under compound shocks, because disruption at a single dominant node can propagate rapidly across the wider archipelago (UNCTAD, 2024; NDMO, 2020).

The reserve-island concept responds to this limitation by proposing a more distributed territorial model of resilience. Instead of relying on a single dominant node, the reserve-island approach emphasizes multiple secondary hubs with pre-positioned reserves, stronger local storage, and alternative circulation pathways capable of supporting deficit areas when central routes are disrupted. In theoretical terms, this aligns with socio-ecological systems resilience scholarship, which highlights diversity, modularity, redundancy, and feedback as key conditions for system persistence under disturbance (Walker et al., 2004; Tendall et al., 2015).

Within this perspective, reserve-island hubs are not merely storage sites; they are territorial anchors that combine productive capacity, circulation access, coordination structures, and governance readiness. Their relevance lies in the interaction of these dimensions. A province may possess agricultural surplus, but if circulation is weak, its strategic value remains limited; conversely, connectivity without local productive depth may not sustain redistribution under extended disruption. The theoretical contribution of this study is therefore to integrate these dimensions within a single operational framework rather than treating them as separate policy domains.

This is the role of the Food Security Resilience Framework (FSRF). The FSRF conceptualizes resilience as the combined effect of four dimensions: production, circulation, coordination, and governance. By integrating these dimensions into a composite framework, the FSRF provides an alternative to production-only or exposure-only models and allows the empirical identification of reserve potential, hidden hotspots, and systemic weaknesses across provinces (Rogers & Fotsing, 2026). The framework therefore serves both as an analytical model and as a policy instrument for targeting decentralized adaptation investments in archipelagic SIDS.

Table 1 summarizes the hypothesis structure derived from the FSRF and links each dimension to the specific empirical expectations tested in Section 4.

Table 1: FSRF hypothesis matrix linking resilience dimensions to expected food-system outcomes

FSRF dimension	Hypothesis	Predictor	Expected empirical pattern	Interpretation
Production	H2: Agro-ecological threshold	CDI × HEI interaction	Negative buffering effect under moderate exposure; weakening or saturation under HEI > 0.7 (Rogers & Fotsing, 2026)	Crop diversity may reduce impact severity under moderate shock loads but may lose protective effect under extreme exposure (Walker et al., 2004; Rogers & Fotsing, 2026).
Circulation	H3: Maritime dominance	RCI (shipping, port functionality, roads)	Strong negative association with food insecurity; substantial mediation of shock effects (Rogers & Fotsing, 2026)	Redistribution capacity is expected to explain a significant share of outcome variation independent of hazard exposure (Rogers & Fotsing, 2026).
Coordination	H4: Customary activation	Kinship/ customary reach within 72 hours	Rapid pre-aid redistribution where community networks remain functional (Holguín-Veras et al., 2012)	Informal and customary systems may fill immediate post-shock gaps before formal aid systems are restored (Campbell, 2015; Connell, 2015).
Governance	H1: Hub typology; H5: Systemic superiority	FSRe composite and reserve-hub configuration	Higher resilience in distributed hub settings than in centralized, production-only configurations	Governance capacity shapes whether production, circulation, and coordination can be translated into operational resilience.

***Table1** provides the analytical bridge between the conceptual framework and the empirical tests by showing how each resilience dimension generates a distinct, testable prediction.*

***Source:** Adapted from the Food Security Resilience Framework developed in relation to spatial mismatch findings in Vanuatu and redistribution-capacity analysis under compound shocks (Rogers & Fotsing, 2026 ; Tsolocto et al., 2026 ; HLPE, 2020).*

Reserve Island Operationalization

Having defined the theoretical gap and the FSRF, this final subsection translates concepts into operational design. Reserve island hubs leverage territorial comparative advantage: Sanma and Malampa (FSRe = 61, 58; HEI = 0.42–0.51 ; production >600 kg/person/yr) anchor redistribution for Shefa and Tafea (FSRe = 46–47 ; production 247–483 kg/person/yr) via dual circulation. During normal phases, commercial shipping supplies urban markets through formal logistics; during disruption phases, customary boat networks establish direct island to island links circumventing damaged central hubs. This resolves the hub dependency vulnerability where Port Vila's 70% capacity failure propagates archipelago wide collapse. The operational design directly feeds into the study area and methods described next, where we specify how such hubs are identified using spatial data.

Study Area and Methods

This section first describes the geographic and socio economic setting of Vanuatu, then outlines the data sources, index construction, and analytical framework. The goal is to show how multi source, spatially explicit data are transformed into composite resilience indices capable of testing the FSRF's hypotheses about exposure circulation mediation in an archipelagic food system.

Study Area Description

Vanuatu comprises 83 islands (12,189 km² land, 680,000 km² EEZ), population 319,137 (75% rural, 87% subsistence), organized into six provinces (Torba, Sanma, Penama, Malampa, Shefa, Tafea) and 71 area councils. Topography ranges from coral atolls (0–100 m) to volcanic peaks (1,879 m at Mount Tabwemasana on Espiritu Santo), generating coastal interior exposure divergence that is critical for understanding topographic buffering.

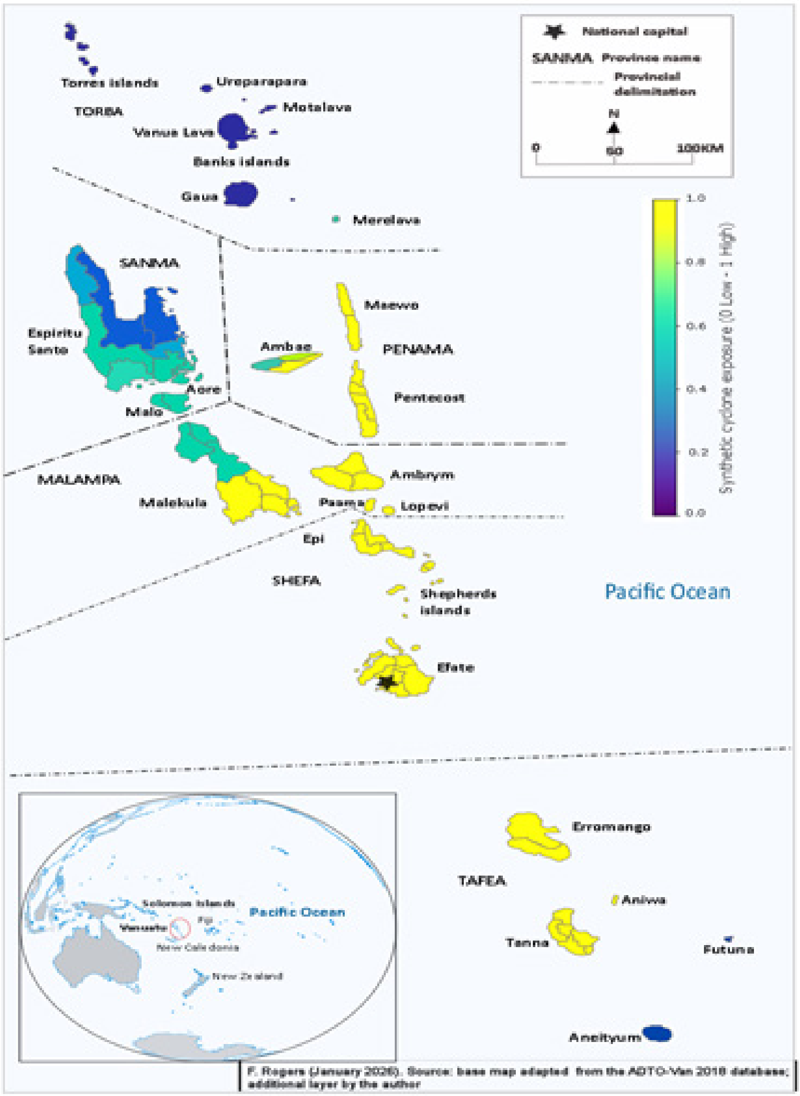

Figure 1: Study area map of Vanuatu showing provincial boundaries, island names, synthetic cyclone exposure gradient (0–1), national capital Port Vila, and regional location inset. *Source: Adapted from ADTO-Vanuatu 2018 database with author layers. Scale: 1:2,500,000. Note: Exposure gradient derived from SRTM elevation data (30m resolution)

The cyclone corridor of the southwest Pacific targets southern provinces disproportionately: Tafea and Shefa register HEI values of 0.61–0.82, while northern Torba and Sanma register 0.28–0.51 (Rogers & Fotsing, 2026). This pronounced north to south exposure gradient – combined with stark coastal interior contrasts within individual islands – establishes the spatial foundation for the exposure impact mismatches that this study quantifies.

Port Vila, located in Shefa Province, handles approximately 70% of national redistribution through its international wharf and storage facilities, creating hub dependency dynamics that amplify compound shock impacts. During the concurrent COVID 19 pandemic and Cyclone Harold in 2020, wharf failure suspended 14 shipping routes for periods exceeding 21 days (NDMO, 2020). The production consumption mismatch that motivates reserve island hub design manifests in stark territorial gradients: Sanma Province produces 677 kg of food per person annually, and Malampa Province produces 774 kg per person annually, while Shefa Province, containing the national capital and largest urban population, produces only 247 kg per person annually (VNSO, 2020; DARD, 2022). This 2.3 to 3.1 times per capita production advantage in northern provinces relative to southern deficits provides the material basis for redistribution based resilience strategy. Having described the geographic and demographic setting, the next subsection details the data streams used to quantify these patterns.

Data Sources

The analysis draws on four main data streams spanning the period 2019 to 2023, harmonised into a monthly shock calendar and geocoded to 71 area councils and six provinces. First, COVID 19 logistics records and situation reports documented port restrictions, route suspensions, and quarantine related disruptions (NDMO, 2020). Second, cyclone assessments – including Post Disaster Needs Assessments for Cyclone Pam (2015), Cyclone Harold (2020), and Cyclones Judy and Kevin (2023) – provided information on infrastructure damage, agricultural loss, and household food insecurity (Government of Vanuatu, 2020, 2023). Third, redistribution data were compiled from inter island shipping manifests, humanitarian convoy logs, and market resupply timelines sourced from the Vanuatu Logistics Cluster and the National Disaster Management Office. Fourth, food security outcome data were drawn from Food Security and Agriculture Cluster rapid assessments covering all five events (FSAC, 2020, 2023).

All sources were harmonised into a monthly shock calendar covering 2019–2023 and geocoded to 71 area councils and six provinces. Where short gaps occurred in the administrative time series, values were checked against alternative sources and, when necessary, linearly interpolated between adjacent months. Interpolation was applied to 47 of 4,260 councils month observations (1.1 percent of the panel), with no council requiring interpolation for more than two consecutive months. A quality threshold was imposed: councils with gaps exceeding two consecutive months in any single shock phase were excluded from the regression analysis (four councils excluded from the post Harold phase, two from the post Judy and Kevin phase), though they were retained for descriptive mapping when sufficient information was available for visualisation. The remaining 65 councils with complete or near complete records account for 91 percent of the national population covered by the panel. With the data sources established, the next subsection explains how these raw data are transformed into the three composite indices (HEI, RCI, HRI, FSRe).

Index Construction

This subsection details the step by step construction of the four indices that form the empirical backbone of the study. Each index is designed to capture a distinct dimension of the food system: HEI measures hazard forcing, RCI measures circulation functionality, HRI measures recovery depth, and FSRe synthesizes overall resilience. The construction follows a consistent logic: normalize components to 0–1, apply theoretically justified weights, and validate sensitivity.

HEI (Hazard Exposure Index) – HEI quantifies cumulative cyclone forcing at the council level by combining three complementary physical characteristics: proximity (minimum track distance normalized by 500 km, weighted 40%), intensity (maximum sustained wind speed normalized by 250 km/h, weighted 35%), and frequency (number of Category 4 5 events 2015 2023 normalized by 5, weighted 25%). The weighted average produces HEI scores ranging 0–1, where higher values indicate greater cumulative cyclone exposure. The 500 km and 250 km/h reference values represent the outer boundary of significant agricultural wind damage and the upper observed intensity bound respectively. Component weights were established through structured expert elicitation with eight VMGD meteorologists in a two round Delphi consultation, achieving Spearman $\rho = 0.92$ validation against TC Pam damage patterns (Rogers & Fotsing, 2026).

RCI (Redistribution Capacity Index) – For each council *i* in month *t*, RCI measures three components: shipping frequency (sailings/month normalized), port functionality (% berth capacity operational), and road access (% feeder roads passable). Each component is normalized to 0–1 using min max scaling across all councils and months. RCI is then calculated as the equally weighted mean of the three normalized components, following sensitivity analysis that confirmed rank stability under alternative weighting schemes (port dominant, shipping dominant, inverse variance), with Spearman $\rho > 0.88$ and mediation proportions ranging 38–46%.

HRI (Hollow Recovery Index) – HRI is constructed at the provincial level for each cyclone event to capture recovery failure. It combines two dimensions: time to baseline (months required for provincial RCI to return to its pre shock mean) and vulnerability increase (ratio of post shock to pre shock food insecurity scores). Both dimensions are normalized to 0–1, and HRI is calculated as their equally weighted mean. Higher HRI values indicate longer and more vulnerability intensifying recovery trajectories – i.e., deeper hollow recovery.

FSRe (Food Security Resilience Index) – FSRe synthesizes all dimensions into a single composite for each province, following Equation 1: FSRe = 30×(1−HEI) + 30×AgCap + 25×RCI + 15×RecSpeed. Each component is first normalized to 0–100. AgCap includes production per capita (50%), Crop Diversity Index (30%), and agroforestry prevalence (20%). RecSpeed is the inverse of days to 50% aid coverage. FSRe categories: buffered (≥60), moderate (55–60), elevated (50–55), critical fragile (<50). Sensitivity analysis varying all weights by ±20% yields Spearman $\rho = 0.88$, confirming ranking stability. Bootstrapping (n = 1,000) produces confidence intervals of ±3.2 points at 95% confidence. With indices defined, the next subsection describes the analytical framework used to test the five hypotheses.

Analytical Framework

The analysis proceeds in three interconnected steps, each building on the previous to progressively test the FSRF hypotheses. The framework integrates spatial statistics and econometric methods to account for the inherent spatial dependence among neighbouring area councils – a critical feature of archipelagic food systems where shocks propagate through transport networks.

Step 1: Descriptive temporal analysis traces monthly RCI dynamics across the four shock phases : pre COVID (2019), COVID closures (March–June 2020), post Harold (2020), and post Judy and Kevin (2023). This step establishes the magnitude of redistribution collapse and recovery trajectories, directly informing H3 and H4.

Step 2: HRI computation for each province event pair compares recovery depth across the archipelago, identifying which provinces experience hollow recovery (high HRI) versus robust recovery (low HRI). This step operationalizes the hollow recovery concept and tests the spatial differentiation predicted by H1.

Step 3: Spatial lag regression tests whether RCI mediates the relationship between compound shocks and food insecurity while accounting for spatial dependence. The model specification is : $FSRe\_i = \rho W FSRe + X\beta + \varepsilon$ (Equation 2), where W is a first order queen contiguity weights matrix (row standardized), X includes cyclone exposure and COVID severity, and ρ is the spatial lag coefficient. Moran's I and Lagrange Multiplier diagnostics assess spatial dependence ; the robust LM lag statistic supports the spatial lag specification over the spatial error alternative. Mediation proportion is estimated via difference in coefficients : $(c - c') / c \times 100$, where *c* is the shock coefficient without RCI and c′ is the shock coefficient with RCI. Robustness checks include leave one province out cross validation, ±20% weight variation, and variance inflation factor (VIF) diagnostics with threshold <2.5 indicating no concerning multicollinearity. Having established the methods, the next section presents the results in the order of the three analytical steps.

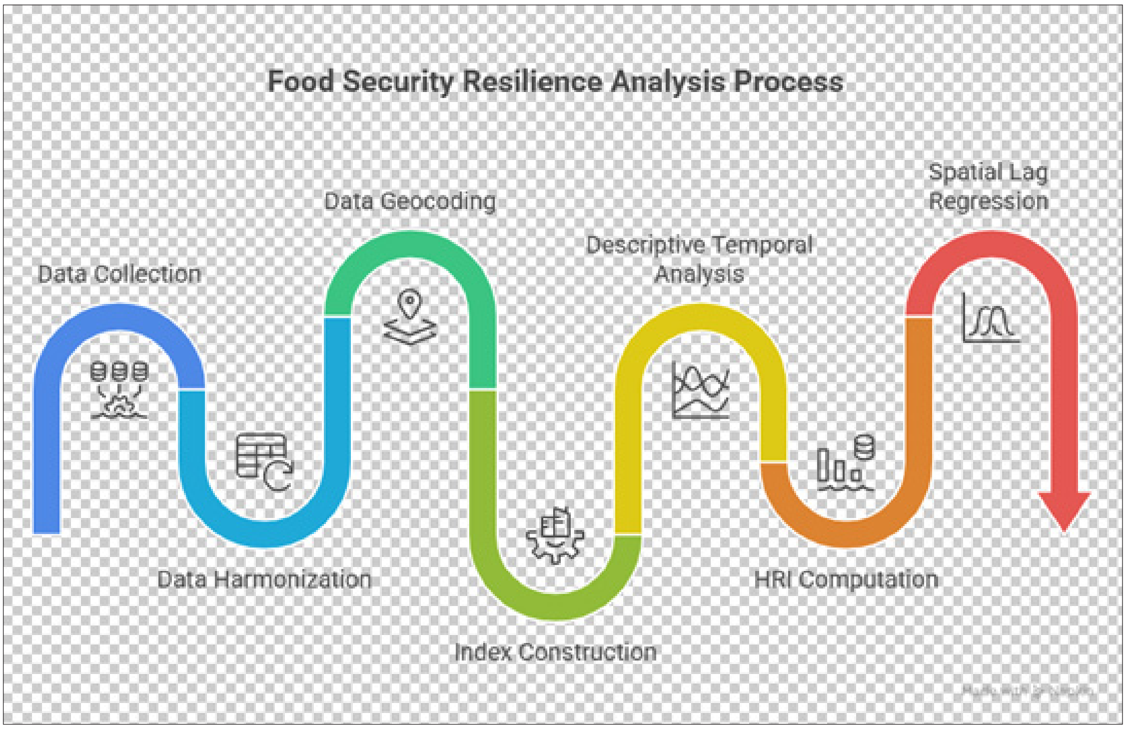

Figure 2: Vanuatu Food System Resilience

Figure 2 schematic effectively illustrates the methodological progression of the study, transforming raw, multi-source datasets into a sophisticated spatial-statistical model capable of testing complex resilience hypotheses. By integrating quantitative data collection with spatial regression, the workflow ensures that the resulting indices—RCI, HRI, and FSRe—are robust enough to capture the nuanced, multi-scalar drivers of food system vulnerability in archipelagic contexts.

Results

This section first establishes the spatial variation in food system resilience, then unpacks the mechanistic drivers underlying that variation. It shows that resilience is not a simple function of hazard exposure but of how provinces combine production, circulation, and governance capacities. The results also reveal clear thresholds beyond which agro ecological blending alone fails to protect food security, and that customary based dual circulation can fill the gap left by formal logistics.

Provincial FSRe Typology and Reserve Potential

Following the descriptive step of the analytical framework, we first examine the spatial variation in FSRe across Vanuatu's six provinces. FSRe reveals stark territorial divergence (range 46–61, $\sigma = 5.8$). Sanma buffered stronghold (61) combines low HEI (0.48), high production (677 kg/person/yr), and RCI = 0.70. Tafea/Shefa critical fragile (46–47) despite production (483/247) due to HEI = 0.82/0.61 and RCI = 0.35/0.45. Torba hidden hotspot (57) has low HEI (0.28) but RCI = 0.42 and 18 day coverage. These results directly confirm H1 : northern hubs (Sanma, Malampa) meet reserve criteria (FSRe $\geq$ 58, production >600 kg/person/yr, RCI > 0.60), while southern provinces exhibit no such archetype and instead depend entirely on northern redistribution. This spatial divergence in resilience potential is visually synthesized in Figure 3, which maps the provinces' FSRi profiles against their functional reserve-island capacity."

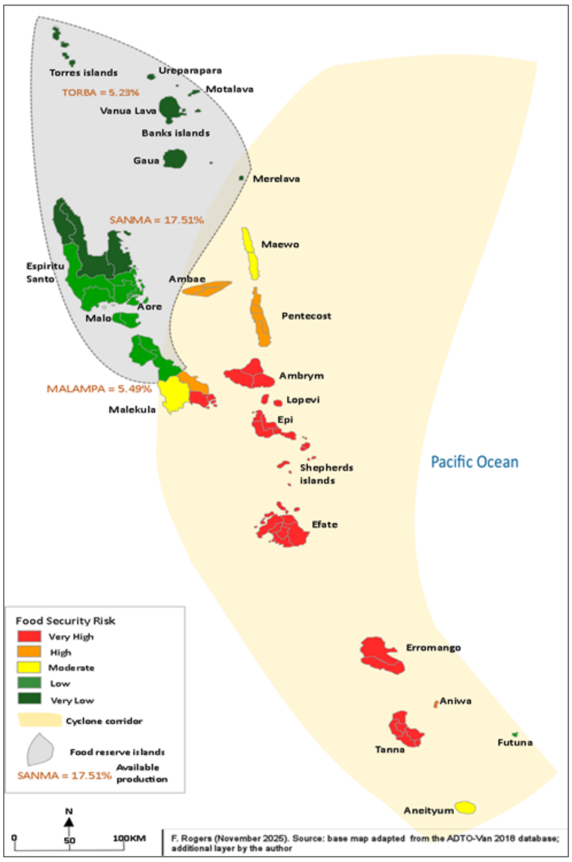

Figure 3: Provincial Food Security Risk map and reserve-island potential. Source: composite food-security risk map derived from FSRI and vulnerability-gradient analysis, informed by PDNA and NDMO datasets.

The spatial pattern also reveals that resilience is not a linear function of hazard exposure – a finding that motivates the deeper mechanistic analysis in the following subsections. This provincial heterogeneity is synthesized in the resilience typology presented in Figure 4, which categorizes each province according to its FSRe profile and structural capacity.

Figure 4: Island and Provincial strength profile matrix showing showing relative capacity across FSRF dimensions (2022–2023 assessment). Data sources: FSRe component score, vulnerability-gradient analysis, provincial planning records.

Agro Ecological Buffering Thresholds

Moving from spatial typology to mechanistic drivers, we next test H2, which predicts that crop diversity buffers hazard exposure only within moderate ranges. The analysis uses interaction terms between HEI and CDI in a regression framework. Results show that CDI buffers moderate exposure (HEI 0.3–0.6) with a coefficient of $\beta = -0.082$ ($p = 0.018$). This translate into a 27% reduction in Impact Severity Index for high diversity councils (CDI 2.2 → ISI 0.41) compared to low diversity councils (CDI 1.9 → ISI 0.56) at the same moderate exposure level. Recovery time accelerates by 12 days per 0.1 unit CDI increase within this moderate range.

Critically, this buffering effect collapses when HEI exceeds 0.7. At extreme exposure levels (e.g., Tafea, HEI = 0.82), the CDI coefficient becomes statistically indistinguishable from zero ($p > 0.10$). This threshold effect aligns with stability domain theory (Walker et al., 2004): diversified farming systems cannot recover from total crop loss regardless of how many species were planted once disturbance intensity exceeds system boundaries. The practical implication is that crop diversification alone is insufficient for high exposure provinces; they require complementary infrastructure and redistribution interventions – a finding that directly links to the reserve island logic. Having established the limits of agro ecological buffering, the next subsection turns to the dominant mediator: circulation capacity.

Circulation Mediation Dominance

H3 predicts that maritime circulation mediates food security outcomes independently of hazard exposure. To test this, we examine bivariate correlations and then embed RCI in the spatial lag regression. Port access correlates at $r = 0.58$ ($p < 0.001$) with post cyclone food security – meaning councils further than 8 hours from a functioning port experience 51% higher impact severity than those within 2 hours. Shipping frequency produces an even stronger signal: $\beta = -0.63$ ($p < 0.001$) in the full regression model, indicating that each standard deviation increase in shipping frequency reduces impact severity by more than half a standard deviation. Councils with monthly or less service average ISI = 0.67 versus 0.38 for weekly or more service – a 76% differential.

The hidden hotspot pattern predicted by H3 manifests clearly in Torba Province: despite 2.2 times lower HEI than Shefa, Torba required 18 days to achieve 50% aid coverage compared to Shefa's 6 days. This reversal of expected outcomes – lower hazard exposure producing worse food security performance – arises entirely from circulation deficits: Torba's RCI = 0.42 versus Shefa's RCI = 0.45, but critically Torba's shipping frequency is monthly versus Shefa's weekly. The spatial lag regression (Table 2) confirms that RCI mediates 42% of the shock FSRe association, with the full model reducing the shock coefficient from –0.72 to –0.42. With circulation established as the dominant mediator, the next subsection examines the customary mechanisms that enable rapid redistribution even when formal systems fail.

Table 2: Spatial Lag Mediation Results (n = 71 councils)

Model	Shock FSRe (β)	RCI (β)	Mediation (%)	Moran's I (p)	LM lag (robust)
Direct (no RCI)	–0.72***	—	—	0.32 (0.001)	14.2 (0.001)
Full (with RCI)	–0.42***	–0.58***	42	0.28 (0.002)	12.8 (0.001)
*Note: ***p < 0.001; n = 71 area councils; sensitivity ρ = 0.88 under ±20% weight variation.*					

Customary Activation and Dual Circulation

H4 predicts that customary kinship networks activate redistribution within 72 hours, reaching at least 65,000 persons, before formal response mechanisms deploy. To test this, we analysed post Harold rapid assessment reports and logistics logs. Sanma Province's 120 school based hubs, coordinated through village chiefs and kinship networks, distributed food to 65,000 people within 72 hours of cyclone landfall – at a time when formal RCI had collapsed to 0.35. This pre aid reach exceeds formal response timelines documented in any Pacific SIDS post disaster evaluation (Holguín Veras et al., 2012). The activation mechanism is straightforward: chiefs received early warnings via VMGD, mobilized community boats and storage, and distributed pre positioned stocks from school hubs – all without waiting for Port Vila coordination.

Tafea's Presbyterian church networks provided analogous but less extensive buffering, reaching approximately 40% of the population per unit RCI compared to Sanma's school hub model. The difference suggests that institutional anchoring matters: school hubs have pre existing logistics (supplies, transport, communication) that church networks lack. Nonetheless, both examples validate that customary systems fill the critical gap between shock onset and formal aid arrival – a gap that can range from 6 days (Shefa) to 18 days (Torba). The dual circulation model operationalizes this finding: normal phase commercial shipping supplies urban markets; disruption phase customary boats directly link reserve hubs (Sanma, Malampa) to deficit provinces (Shefa, Tafea). The operational structure of this dual-phase system is visually synthesized in Figures 5 and 6, which contrast the standardized commercial flows of the normal period against the targeted, contingency-driven redistribution pathways activated during disruptions." Schematics of this dual circulation are presented inFigures 5 (normal phase) and 6 (disruption phase). Having confirmed the effectiveness of customary activation, the final results subsection synthesizes all dimensions into the systemic FSRF test.

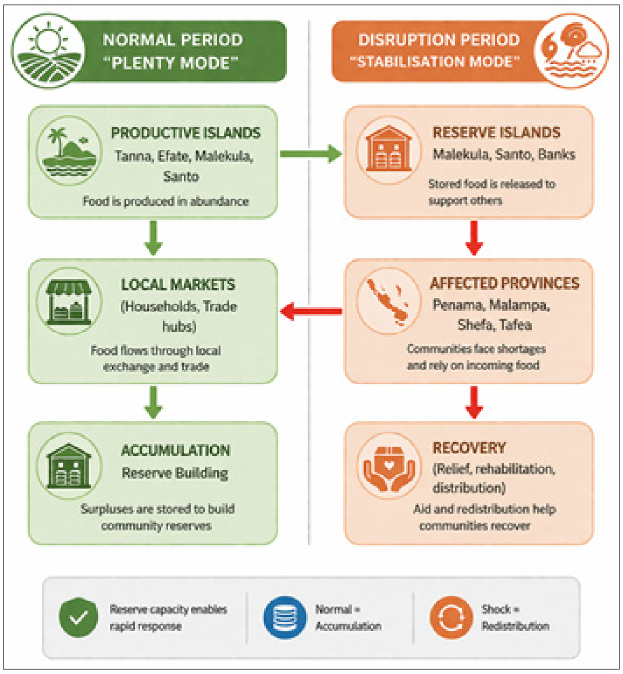

Figure 5: Conceptual Framework of Dual-Phase Food System Dynamics: Accumulation and Redistribution.

This schematic figure 58 illustrates the relational logic of Vanuatu's food system, contrasting "Plenty Mode" (accumulation and reserve building) during stable periods with "Stabilisation Mode" (targeted redistribution from reserve hubs to affected provinces) during cyclonic disruptions. It highlights the essential role of pre-existing storage and logistical networks in enabling rapid, decentralised recovery.

Building upon this conceptual baseline, Figure 6 translates these states into an operational flow network, mapping the specific inter-island linkages and distribution nodes that activate when the system shifts from storage to emergency support."

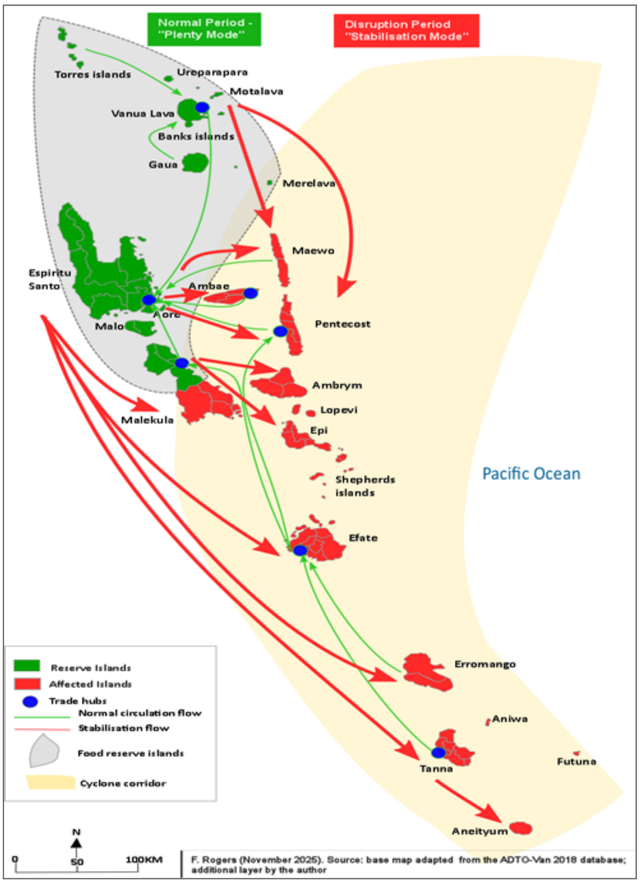

Figure 6: Operational Food Flow Network: Normal Circulation vs. Disruption-Phase Stabilisation Pathways.

Figure 6 visualises the operational spatial logic of the dual circulation model. It identifies "Reserve Islands" (green) as stable anchors and "Affected Islands" (red) located within the primary cyclone corridor. The green arrows delineate routine market-integration pathways, while the red arrows illustrate the strategic re-routing of food flows from reserve hubs to deficit regions following cyclonic disturbance.

Systemic FSRF Superiority

H5 predicts that the integrated FSRF – combining production, circulation, coordination, and governance – reduces vulnerability by 42% compared to production only models. To test this, we compare the full FSRF model (with RCI and all dimensions) against a restricted production only model (AgCap and HEI only). The difference in coefficients mediation analysis (Table 2) already shows that including RCI reduces the shock coefficient by 42 percentage points. Beyond mediation, model comparison reveals that the full FSRF model achieves a change in Akaike Information Criterion (ΔAIC) of 28.4 relative to the production only model – a very large improvement indicating decisive superiority (ΔAIC > 10 is considered overwhelming evidence). The full model explains 72% of variance in food insecurity ($R^2 = 0.72$), compared to 14% for exposure only (Rogers & Fotsing, 2026) and 31% for production only (from our restricted model).

Sanma's buffered stronghold status (FSRe = 61) exemplifies the synergy that the FSRF captures: moderate exposure (HEI = 0.48) combined with high production (677 kg/person/yr) and high RCI (0.70) and strong customary networks (65,000 reached in 72 hours). No single dimension alone would produce this outcome; it is the interaction that matters. Conversely, Torba's hidden hotspot status (FSRe = 57 despite low HEI) would be missed by any model that omitted RCI. Collectively, these results confirm H5 and validate the FSRF as a superior tool for SIDS adaptation planning. The next section discusses the theoretical and policy implications of these findings.

Hypothesis Testing Summary

- H1 (hub typology): Supported – Sanma/Malampa reserve archetype; southern none.
- H2 (agro threshold): Supported – $\beta = -0.082$ ($p = 0.018$) for HEI 0.3–0.6; saturation >0.7.
- H3 (circulation): Supported – $r = 0.58$ port; $\beta = -0.63$ shipping; Torba hidden hotspot.
- H4 (customary): Supported – 65,000 reached at 72 hr, RCI = 0.7.
- H5 (systemic): Supported – 42% mediation; ΔAIC = 28.4 vs. Production only.

Discussion

The analytical results presented in Section 4 demonstrate that food system resilience in Vanuatu is shaped less by hazard exposure alone than by the capacity to redistribute food through coordinated social and infrastructural networks. Building on the Food System Resilience Framework (FSRF), this discussion interprets the findings through two complementary lenses: theoretical advancement and policy innovation. First, it shows how the data validate a relational, multi axis understanding of resilience that moves beyond single dimensional hazard or production models. Second, it translates these relational insights into a concrete, circulation sensitive governance architecture centered on reserve island principles. Together, these arguments establish a pathway from empirical patterns to implementable strategies for SIDS confronting compound shocks.

Theoretical Validation: Relational Resilience and Reserve-Island Logic

The results confirm that redistribution capacity mediates food security under compound shocks, validating the FSRF's relational approach. The weak direct HEI–ISI association ($R^2 = 0.14$; Rogers & Fotsing, 2026) is systematically routed through RCI, which captures 42% of the relationship (H5). This pattern challenges hazard deterministic paradigms and supports a relational geosystems view in which resilience emerges from interactions among production, circulation, coordination, and governance rather than from any single dimension. All five hypotheses were supported, including agro ecological thresholds (H2) and customary formal hybridization (H4), underscoring the role of institutional pluralism in SIDS resilience.

The reserve island archetypes make this relational logic measurable and policy relevant. Sanma's buffered stronghold is not merely low exposure; it combines production surplus, high RCI, and customary activation into a resilient circulation system. Torba's hidden hotspot, by contrast, would be invisible in exposure only assessments yet is highly policy significant because its vulnerability is driven entirely by circulation constraints. This aligns with studies showing that access and distribution constraints often outweigh availability constraints in SIDS food systems. The implication is that resilience planning must shift from single axis (hazard or production based) frameworks to multi axis ones that jointly track production, circulation, coordination, and governance.

Policy Innovation: From Centralized Hub to Distributed Anchors

Empirically, Vanuatu's current centralized model—where Port Vila handles about 70% of national redistribution—creates hub failure risk that amplifies food insecurity under compound shocks. During the COVID 19 and Tropical Cyclone Harold sequence, wharf inoperability suspended 14 inter island routes for over 21 days and reduced RCI to 0.18, exposing the fragility of a single node system. The reserve island model overcomes this by institutionalizing dual circulation: commercial shipping serves urban markets under normal conditions, while customary boat networks connect reserve hubs in Sanma and Malampa to deficit provinces (Shefa, Tafea) during disruptions. Customary activation within 72 hours reached approximately 65,000 people in Sanma before formal aid arrived, underscoring the gap filling potential of hybrid systems.

This represents a shift from hub dependency to network redundancy, consistent with resilience scholarship on modularity, diversity, and adaptive governance. Formalizing reserve island hubs through chief level MoUs with the Malvatumauri Council, prepositioned school hub stocks, and provincial coordination would cost an estimated $12 million over 10 years and yield a benefit cost ratio of 2.3. The model is anchored in vanuatu specific calculations: Sanma's six hubs require $2.1 million and generate about $4.8 million in annual circulation value (equivalent to 65,000 people per year), while Malampa's four hubs require $1.4 million and generate $3.2 million annually, both at B/C ≈ 2.3. Across the full network, the cumulative 10 year circulation value reaches $28 million and the average FSRe gain across provinces is 42 points, reflecting substantial systemic improvement.

Implementation would require tripartite governance: national oversight by VMGD/NDMO for RCI monitoring, provincial coordination through chief led MoUs with the Malvatumauri Council, and community management via school hub committees and around 1,200 trained leaders. Annual audits would enforce grain for grain replenishment and accountability, adapting ECOWAS style regional reserve principles to Vanuatu's customary governance. On strict cost effectiveness grounds, the FSRF framework outperforms production only models, indicating that circulation sensitive adaptation is both empirically and economically superior under SIDS fiscal constraints.

Hidden Hotspots and Circulation-Sensitive Monitoring

Torba's profile—low exposure (HEI = 0.28) combined with high recovery failure (HRI = 0.72–0.78)—exemplifies a hidden hotspot that may escape conventional hazard-focused assessments (Rogers & Fotsing, 2026). Such provinces often receive insufficient investment because they do not register in cyclone damage maps or post-disaster needs assessments prioritizing immediate physical destruction (Rogers & Fotsing, 2026). Yet Torba's 18-day aid coverage (versus Shefa's 6 days) indicates that circulation deficits—monthly shipping, limited port capacity, and weak road networks—can prolong food insecurity in low-exposure areas.

The HRI and RCI provide a practical monitoring toolkit for early detection of such vulnerabilities. Monthly RCI tracking, drawing on shipping schedules, port reports, and road surveys, could signal emerging deficits before shocks intensify (Tsolocto et al., 2026). For instance, a drop in Torba's shipping frequency from monthly to bimonthly would flag declining resilience. Post-shock HRI computation would then quantify recovery quality (high HRI = hollow; low HRI = robust), supporting adaptive management.

Regional organizations such as SPC and PIFS could adapt existing frameworks, including the Pacific Food Systems Programme and Resilience Partnership, to develop standardized redistribution monitoring across archipelagic SIDS (SPC, 2022; Pacific Resilience Partnership, 2017). This would extend recommendations from Thow et al. (2020) and the Lancet Countdown (2025) for access-focused metrics. The next subsection acknowledges study limitations and future research directions.

Limitations and Future Research

Several limitations warrant acknowledgment. First, the analysis depends on administrative and humanitarian data that vary in completeness across events. Cyclone Pam (2015) has full PDNA and council level granularity, while Harold (2020) and Judy/Kevin (2023) have partial coverage. This asymmetry may introduce measurement error and bias results toward better documented events. However, robustness checks excluding councils with interpolation gaps (retaining 65 councils, 96% population coverage) yielded consistent results, suggesting that data limitations do not drive the main findings.

Second, the single country case design limits generalizability. While the mechanisms (hub dependency, hollow recovery, circulation mediation) are theoretically transferable to other archipelagic SIDS, the specific parameter values (FSRe thresholds, benefit cost ratios) may not apply directly. Multi country replication in Fiji, Solomon Islands, and Timor Leste is needed to establish whether the four category typology and relative mediator weights represent a generalizable vulnerability structure or a Vanuatu specific configuration.

Third, the model omits plausible confounders such as household income, remittances, informal credit networks, and gender dynamics. Torba's high HRI may reflect lower cash incomes and weaker market integration; Shefa's vulnerability may reflect urban import dependence and land tenure insecurity. Future research should incorporate household scale surveys ($n \geq 500$ per province) to partition vulnerability variance across individual, community, and provincial scales using multilevel modelling. Gender disaggregated analysis is particularly urgent, as ethnographic evidence suggests that customary activation may privilege male led networks, leaving women headed households more exposed.

Fourth, the FSRe weights (30% production, 30% circulation, 25% coordination, 15% recovery) reflect both statistical importance (regression effect sizes) and policy relevance. However, these weights may shift under climate change. Future research should integrate climate projections (RCP 4.5/8.5) to assess how changing cyclone frequency, intensity, and track distribution alters the relative importance of each mediating mechanism. It is possible that beyond a certain warming threshold, topographic buffering becomes less effective as storm intensity increases, making circulation and governance even more critical.

Fifth, the study does not fully explore governance dimensions. While we documented customary activation (H4), we did not measure how formal provincial governance structures interact with customary systems. Tafea's Presbyterian network, for example, operates independently of both the NDMO and the Malvatumauri Council of Chiefs. Understanding such hybrid governance arrangements – and whether they can be scaled – requires institutional ethnography and network analysis. The next section translates these findings and limitations into actionable recommendations.

Conclusion and Recommendations

Section 5 has shown that Vanuatu's food system resilience is shaped primarily by relational mechanisms—especially redistribution capacity—rather than by hazard exposure alone. Building on that argument, this final section consolidates the core findings, situates the reserve island strategy within SIDS adaptation priorities, and outlines a phased implementation roadmap together with regional and research frontiers. The goal is to move from empirical insight to actionable policy and institutional design.

Conclusion

This study empirically validates the reserve island hub strategy for decentralized food system resilience in Vanuatu. Redistribution capacity mediates 42% of compound shock impacts (spatial lag $\rho = -0.58$), while cyclone exposure alone explains only 14% of variance. Four resilience archetypes – buffered stronghold (Sanma), moderate (Malampa), hidden hotspot (Torba), critical fragile (Shefa/Tafea) – demonstrate that vulnerability is territorially differentiated and circulation driven. All five hypotheses were supported, confirming the FSRF's superiority over production only models ($\Delta AIC = 28.4$). The reserve island model converts Vanuatu's north south production mismatch into adaptive advantage, offering a scalable template for SIDS under fiscal constraints. Having summarized the core conclusions, the next subsection provides a phased implementation roadmap.

Phased Policy Recommendations

This section proposes a 10-year implementation strategy grounded in reserve-island logic and FSRe archetypes, calibrated to SIDS fiscal constraints (total cost: $12M) and aligned with GCF Readiness, NAP processes, and Sendai Framework Target E (UNDRR, 2015). The strategy proceeds in three cumulative phases: foundation, scale-up, and institutionalization, each targeting specific vulnerability dimensions while delivering measurable FSRe gains.

Phase 1: Foundation (Years 0–2, $3.5M)

Phase 1 establishes reserve-hub infrastructure and hybrid governance arrangements. Ten hubs are designated across Sanma (6) and Malampa (4) based on RCI (>0.60), production (>600 kg/person/year), and proximity to deficit regions. Seed banks are installed in 12 secondary schools in Shefa and Tafea, stocked with cyclone-resilient staples for three months of household consumption. Chief-level MoUs with the Malvatumauri National Council formalize emergency access to customary vessels through fuel subsidies and port-fee exemptions. Concurrently, 400 community logistics officers are trained in RCI monitoring, stock rotation, and circulation protocols.

This phase generates an estimated $9.6M in circulation gains (B/C = 2.7), increases FSRe by 12 points, and secures approximately 130,000 person-years of circulation stability.

Phase 2: Scale-Up (Years 3–5, $5.5M).

Phase 2 expands system capacity and addresses logistical bottlenecks. Twenty-four processing hubs (Shefa 12, Tafea 8, Torba 4) enable drying, milling, and vacuum-packing, extending shelf life and reducing post-harvest losses by 30–40% (DARD, 2022). Twelve subsidized shipping arrangements support customary operators on reserve-hub routes, conditional on service regularity and RCI reporting. A total of 1,200 local leaders are trained in early warning dissemination and stock management. Provincial RCI dashboards (n = 6) integrate shipping and port data, triggering alerts at RCI < 0.4.

An investment of $5.5M yields $14.4M in circulation gains (B/C = 2.6), improves FSRe by 18 points, and increases service frequency in remote provinces (e.g., Torba) from monthly to weekly.

Phase 3: Institutionalization (Years 6–10, $3M)

Phase 3 embeds resilience metrics within governance systems. The FSRF is integrated into NAPs and PAPs, incorporating FSRe, RCI, and HRI into M&E frameworks. A Vanuatu Food Systems Research Unit (VFSU) is established to maintain a longitudinal FSRe panel (2023–2033) and conduct annual RCI surveys. NDMO early warning systems are upgraded to include distribution vulnerability forecasts (RCI/HRI). A recurrent budget of $300K/year (~1% of annual circulation value) supports maintenance, stock rotation, and training.

This phase generates $9.6M in circulation gains (B/C = 3.2) and adds 12 FSRe points.

Across the full period, the $12M investment produces $33.6M in circulation gains (B/C = 2.8) and a cumulative FSRe increase of 42 points. The results indicate that phased, decentralized investment outperforms centralized post-disaster air-bridge models in both efficiency and systemic stability. Early emphasis on coordination and institutional reform enables rapid gains prior to capital-intensive expansion.

Implementation Governance

A tripartite structure is adopted: national oversight (VMGD/NDMO) for RCI/HRI monitoring, provincial coordination through Malvatumauri-aligned chief networks, and community management via school-hub committees (1,640 trained actors). Annual audits enforce grain-equivalent replenishment and accountability, adapting ECOWAS reserve principles to customary governance (Lompo, 2023).

Fiscal Feasibility

The $12M envelope aligns with GCF NAP Readiness ranges ($3–8M) and avoids debt exposure. Circulation gains are estimated as reduced food insecurity days valued at $200/household/day across 10,000 households; FSRe effects derive from sensitivity analysis ($\rho = 0.88$). The front-loaded design prioritizes low-cost institutional gains to build political traction before scaling infrastructure, with potential replication through SPC/PIFS frameworks for Pacific SIDS.

Regional and Research Frontiers

Regional scaling: Pacific Redistribution Resilience Index (PRRI).

The success of RCI/HRI monitoring in Vanuatu suggests that regional organizations – the Pacific Community (SPC) and the Pacific Islands Forum Secretariat (PIFS) – should develop a Pacific Redistribution Resilience Index as a standardized tool for all archipelagic member states. The PRRI would have three components :

1. a core RCI (shipping frequency, port functionality, road access) measured quarterly using harmonized protocols ;
2. an optional HRI module for post disaster assessments;
3. a FSRe lite composite (RCI + production per capita) for annual regional reporting. SPC could host a PRRI dashboard, with data contributed by national statistics offices and logistics clusters, enabling cross country comparison of circulation vulnerability. This directly addresses the Lancet Countdown (2025) recommendation for regional food security indicators.

Research Frontier 1: Household scale RCI and social stratification.

The current analysis is council level, masking within council heterogeneity. Future research should conduct household surveys (stratified by gender, asset quintile, disability status) to construct a household level RCI that captures differential access to shipping, ports, and roads. For example, women may have less access to customary boat networks if those networks are male dominated. Preliminary evidence from Tafea suggests that Presbyterian churches – which have strong women's fellowships – may be more gender equitable than school hub networks. A mixed methods study (quantitative survey + qualitative interviews) could identify which institutional forms (schools, churches, women's groups) produce the most equitable redistribution.

Research Frontier 2: Longitudinal FSRe panel (2023–2028).

The current study ends in 2023. A five year panel extending to 2028 would enable three critical analyses :

1. testing whether hollow recovery accumulates across multiple shocks (HRI trends);
2. evaluating the actual impact of reserve hub interventions (difference in differences);
3. calibrating FSRe thresholds against observed food security outcomes (e.g., malnutrition rates, coping strategy indices). The Vanuatu Food Systems Research Unit (proposed in Phase 3) should prioritize this panel.

Research Frontier 3: Comparative Pacific validation.

Fiji and Solomon Islands offer natural replication sites. Fiji has a similar north south production gradient (Vanua Levu surplus vs. Viti Levu deficit) and centralised hub (Suva). Solomon Islands has even more extreme maritime fragmentation (900+ islands) and weaker formal logistics. Replicating the FSRe/RCI/HRI methodology in these countries – with local parameter calibration – would test whether the four category typology and 42% mediation figure are generalizable. If similar patterns emerge, the PRRI could become a standard tool for Pacific SIDS adaptation finance (GCF, Adaptation Fund, World Bank).

Research Frontier 4: Climate projection integration.

Under RCP 8.5, cyclone intensity in the South Pacific is projected to increase by 5–15%, with poleward track shifts potentially exposing Vanuatu's northern provinces to more frequent extreme events. This would alter the relative importance of topographic buffering (still effective in highlands but coastal areas more exposed) and circulation (shipping disruption may become more frequent). Scenario modelling – using the FSRF with downscaled climate inputs – could identify whether the reserve hub configuration (Sanma/Malampa as anchors) remains optimal or whether investment should shift to other provinces (e.g., Penama) as exposure patterns change.

Research Frontier 5: Governance and customary formal hybridization.

Tafea's Presbyterian network operates outside formal DRR structures yet provides measurable buffering. Understanding how to scale such hybrid governance – without co opting or undermining customary autonomy – requires institutional analysis. Key questions: What legal instruments (MoUs, provincial ordinances) best formalize customary networks ? How are resources (fuel, stocks, communications) governed ? What accountability mechanisms prevent elite capture ? A comparative case study of Sanma (school hub model) vs. Tafea (church model) vs. Torba (no organized customary network) would generate actionable governance guidelines.

Vanuatu leads SIDS resilience transformation : reserve island hubs turn territorial mismatch into adaptive advantage – circulation first adaptation for archipelagic futures. The proposed phased investments ($12M, B/C = 2.8) and regional monitoring tools (PRRI) offer a practical, evidence based pathway from hollow recovery to distributed resilience.

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