Mapping and Scale Effects in Coastal Ecosystem Service Interactions: A Case Study of Ludao, Taiwan

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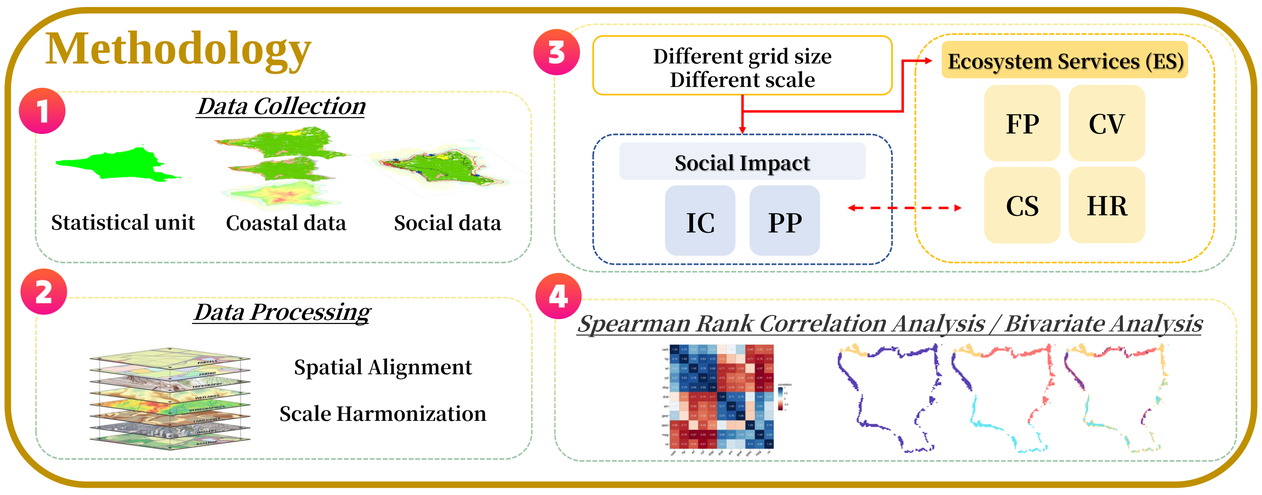
Abstract

Coastal ecosystems provide critical services that sustain biodiversity, support livelihoods, and enhance human well-being. However, research on ecosystem services in small island coastal areas remains limited, leaving gaps in understanding spatial heterogeneity and cross-scale interactions. This study takes Ludao as a case study and employs multi-scale spatial analysis across different spatial units. The results show that village-level units capture broad interaction patterns but may overstate correlations; basic statistical units reveal heterogeneity within overall trends; and 50-meter grids identify local trade-offs around ports and tourist hotspots. Spatially, fish provisioning is concentrated along the southwest coast, cultural and social pressures cluster around settlements and ports, and regulating services align with ecologically vulnerable areas. These findings highlight the importance of multi-scale comparisons for advancing sustainable coastal governance on small islands.

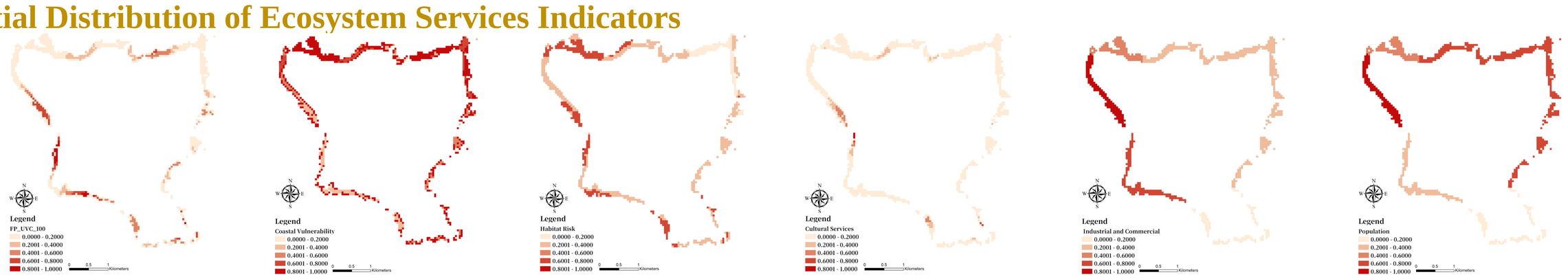
Introduction

Small islands often rely on fisheries, tourism, and cultural activities to sustain local development, yet they face growing challenges from coastal vulnerability, habitat degradation, and concentrated human pressures. To address these issues, this study developed an indicator framework encompassing provisioning, regulating, cultural, and social pressure services. By applying multi-scale spatial analysis, the research examines the spatial distribution of ecosystem service indicators, identifies hotspots and inter-indicator differences, and emphasizes the influence of scale effects on sustainable coastal governance and island planning.

Methodology

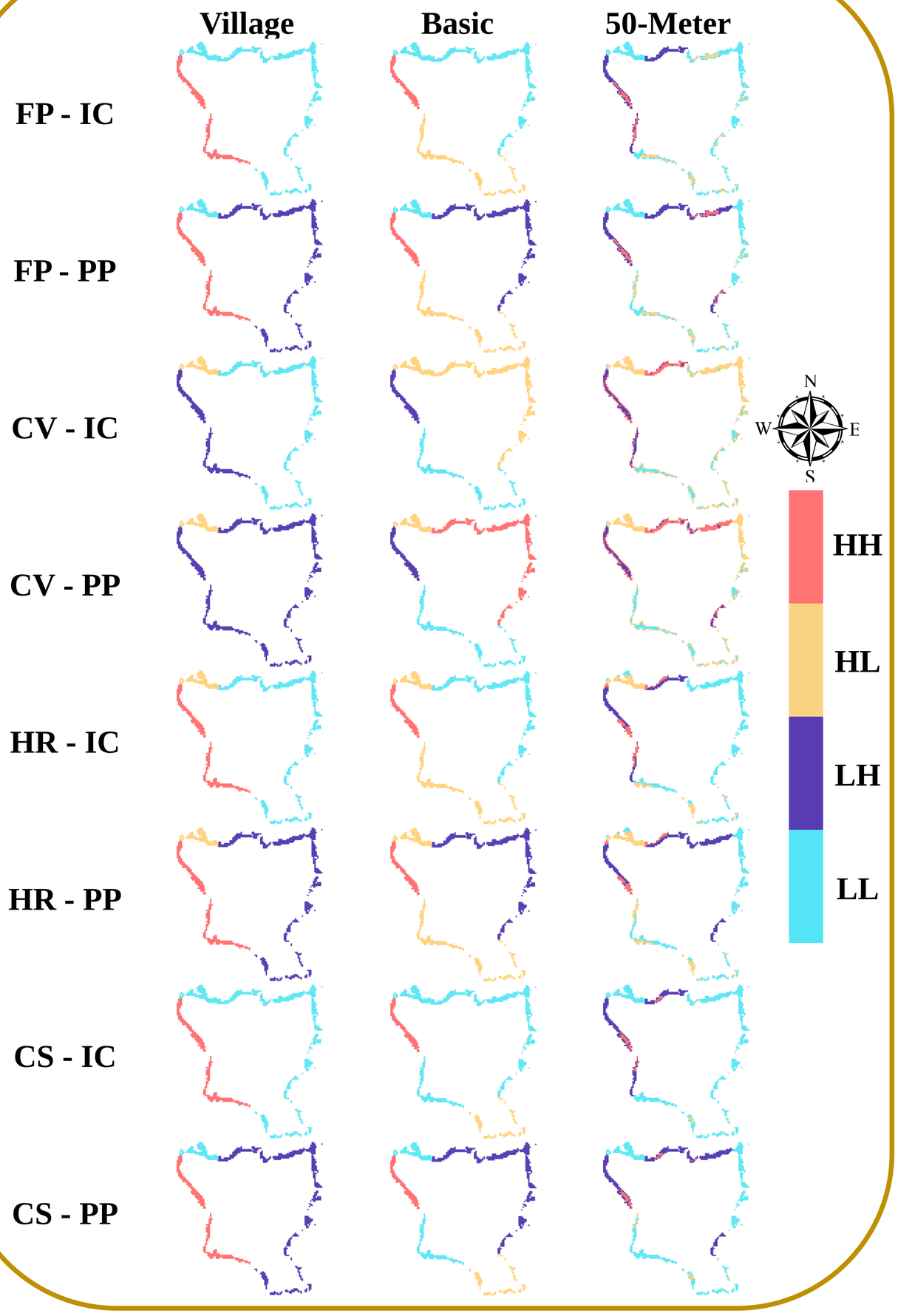


Spatial Distribution of Ecosystem Services Indicators



Fish Provisioning, FP | Coastal Vulnerability, CS | Fish Provisioning, HR | Cultural Services, CS | Industrial & Commercial, IC | Population, PP

Bivariate Analysis of Indicator Combinations



Spearman Rank Correlation Analysis

	Village	Basic	50-meter
FP-CV	-0.5704	-0.7719	-0.5265
FP-HR	0.3245	0.2286	-0.2567
FP-CS	1.0000	0.6947	0.2606
FP-IC	0.6904	0.4591	-0.4969
FP-PP	1.0000	-0.0187	-0.3620
CV-HR	0.1051	-0.0938	0.3744
CV-CS	-0.5704	-0.4666	-0.3675
CV-IC	-0.2608	-0.0713	0.2291
CV-PP	-0.5704	0.4065	0.2734
HR-CS	0.3245	0.7128	-0.1793
HR-IC	0.8999	0.3136	0.1958
HR-PP	0.3245	-0.4824	-0.0829
CS-IC	0.6904	0.5327	-0.2909
CS-PP	1.0000	-0.0536	-0.3557
IC-PP	0.6904	0.4137	0.2320

-1.0000 0.0000 1.0000

1. Indicator Correlation:
A clear trade-off exists between social pressure factors and provisioning and regulating services (e.g., fish provisioning, coastal vulnerability, and habitat risk), indicating that ecosystem services are particularly vulnerable in densely populated or industrially concentrated areas.

2. Scale effects :
village units may amplify or oversimplify relationships, while smaller statistical units reduce overall correlation strength.

Conclusions & Future Work

1. This study demonstrates that ecosystem services on small islands exhibit both synergies (e.g., provisioning and cultural) and trade-offs (e.g., social pressure versus ecological functions), reflecting complex human–nature interactions.

2. Scale strongly shapes interpretation: village-level units capture broad patterns, statistical units reveal regional heterogeneity, and fine-resolution grids highlight localized hotspots of conflict and pressure.

3. By integrating multi-scale spatial analysis, the study advances understanding of ecosystem service heterogeneity on small islands and provides insights for balancing macro-level planning with micro-level management.

4. These findings contribute to sustainable coastal governance by offering a framework that links spatial analysis to practical applications in fisheries, tourism, and adaptive planning. Future work should expand temporal data and integrate broader ecological and socio-economic indicators.