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SEAGRASS USE AND LIVELIHOOD DEPENDENCE IN SMALL-SCALE FISHERIES: SOCIOECONOMIC IMPLICATIONS FOR COASTAL RESOURCE MANAGEMENT IN THE KEI ISLANDS, INDONESIA

PEMANFAATAN LAMUN DAN KETERGANTUNGAN MATA PENCAHARIAN DALAM PERIKANAN SKALA KECIL: IMPLIKASI SOSIAL-EKONOMI BAGI PENGELOLAAN SUMBER DAYA PESISIR DI KEPULAUAN KEI, INDONESIA

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ABSTRACT

Seagrass meadows support coastal livelihoods, but how habitat-use frequency reflects overall livelihood dependence remains insufficiently understood. We surveyed 200 fisheries-based individuals across coastal villages in the Kei Islands, Indonesia. Outcome-specific regression models examined associations between fishing strategy, seagrass-use frequency, livelihood contribution, catch quantity, gross catch value, environmental perceptions, and management support. Invertebrate/gleaning-only fishers had significantly lower odds of frequent seagrass use than finfish-only fishers (odds ratio = 0.013; 95% CI: 0.002–0.099), whereas mixed fishers showed no clear difference from finfish-only fishers. Fishing diversification showed no clear association with proportional livelihood contribution, nor did fishing strategy associate with catch quantity or gross catch value. Furthermore, associations of seagrass-use frequency and livelihood contribution with perceived environmental change, threat recognition, and management support were inconsistent across outcomes. Thus, pronounced differences in habitat-use frequency among fishing strategies do not reliably reflect other livelihood and management dimensions. Assessments of seagrass-associated fisheries should treat habitat use, livelihood contribution, fisheries outcomes, and management attitudes as complementary indicators rather than assuming a single measure represents the others.

Keywords: seagrass, coastal livelihood, fishing, Kei Islands.

ABSTRAK

Ekosistem padang lamun mendukung mata pencaharian masyarakat pesisir, namun frekuensi pemanfaatan habitat lamun masih belum sepenuhnya dipahami. Penelitian ini melibatkan 200 responden yang menjalankan kegiatan berbasis perikanan di desa-desa pesisir Kepulauan Kei, Indonesia. Model regresi digunakan untuk mengkaji hubungan antara strategi penangkapan, frekuensi pemanfaatan lamun, kontribusi terhadap mata pencaharian, jumlah hasil tangkapan, dan nilai kotor hasil tangkapan, serta hubungannya dengan persepsi lingkungan dan dukungan terhadap pengelolaan. Pada kelompok responden yang diklasifikasikan berdasarkan strategi penangkapan, nelayan yang hanya menangkap atau mengumpulkan biota invertebrata memiliki peluang relatif yang jauh lebih rendah untuk melaporkan frekuensi pemanfaatan lamun yang lebih tinggi dibandingkan nelayan yang hanya menangkap ikan bersirip (*rasio odds* = 0,013; IK 95%: 0,002–0,099). Tidak ditemukan perbedaan yang jelas antara nelayan dengan strategi penangkapan campuran dan nelayan yang hanya menangkap ikan bersirip. Hasil analisis tidak menunjukkan bukti statistik yang jelas mengenai hubungan antara diversifikasi penangkapan dan kontribusi proporsional terhadap mata pencaharian, maupun antara strategi penangkapan dan jumlah atau nilai kotor hasil tangkapan. Hubungan frekuensi pemanfaatan lamun dan kontribusi terhadap mata pencaharian dengan persepsi perubahan lingkungan, pengenalan ancaman, dan dukungan terhadap pengelolaan juga tidak menunjukkan pola yang konsisten pada seluruh *outcome*.

Kata kunci: lamun, pencaharian pesisir, perikanan, Kepulauan Kei.

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INTRODUCTION

Seagrass meadows are productive coastal ecosystems that support biodiversity, fisheries, food provision, and the livelihoods of coastal communities. Their contribution to fisheries occurs through several pathways, including the provision of nursery and feeding habitats, support of food webs extending into adjacent ecosystems, and direct fishing grounds for finfish and invertebrates (Nordlund et al., 2018; Unsworth et al., 2019). Seagrass-associated fishing is geographically widespread and is particularly important to small-scale fisheries, where shallow and accessible meadows can provide fishing opportunities requiring relatively low levels of capital, technology, and mobility (Jones et al., 2022). Consequently, the importance of seagrass extends beyond its ecological functions, where seagrass meadows form coupled social–ecological systems in which ecosystem condition, fishing practices, household livelihoods, and human well-being are closely connected (Cullen-Unsworth et al., 2014). These relationships are especially relevant in Indonesia, where seagrass meadows support fisheries and coastal livelihoods but remain exposed to pressures associated with coastal development, land-based disturbance, fishing activities, and other anthropogenic stressors (Unsworth et al., 2018). A national assessment subsequently characterized Indonesian seagrass ecosystems as being generally in moderate ecological condition, reinforcing the need for management that accounts not only for habitat status but also for the people who depend on seagrass-associated resources (Hernawan et al., 2021).

This study aimed to determine how fishing strategies are associated with seagrass use and the reported proportional contribution of seagrass-associated activities to livelihoods. Small-scale coastal communities in the Kei Islands were investigated, where fisheries and other marine-based activities are important components of local livelihoods and where customary systems of coastal resource management remain important. Previous research in the Kei Islands has demonstrated that fishers differ in the importance they assign to environmental, economic, social, and cultural objectives of community-based marine management, indicating that coastal resource users should not be treated as a socially homogeneous group (Hoshino et al., 2017).

Existing studies establish the importance of seagrass to small-scale fisheries but also indicate substantial heterogeneity in the people and activities supported by these ecosystems. At a global scale, fishing within seagrass meadows includes diverse gears, target species, fishing modes, and livelihood functions, ranging from mobile finfish fishing to intertidal collection of invertebrates (Nordlund et al., 2018). In tropical small-scale fisheries, seagrass grounds can generate substantial catches and monetary benefits and may provide relatively stable fishing opportunities compared with other coastal habitats (de la Torre-Castro et al., 2014). Intertidal gleaning illustrates a different pathway of seagrass use, where these fisheries often require simple equipment, target accessible invertebrate resources, and can be particularly important for household food supply and livelihoods (Furkon et al., 2020). Cross-country evidence from the Indo-Pacific further demonstrates that household income and adaptive capacity influence dependence on seagrass fisheries, showing that habitat use cannot be separated from socioeconomic circumstances (Jones et al., 2022). More

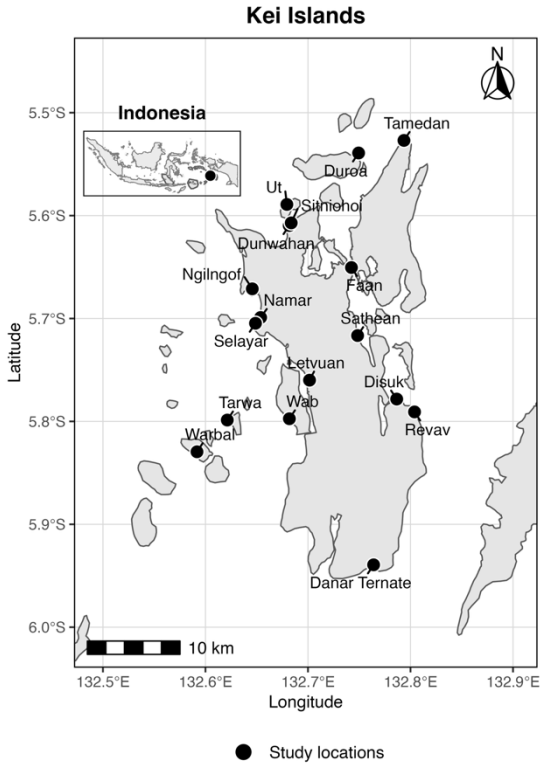
broadly, Indonesian small-scale fishing households operate within diverse livelihood portfolios and differ in assets, vulnerability, livelihood opportunities, and capacity to respond to environmental and economic change (Stacey et al., 2021).

Previous studies have examined different aspects of the relationships between seagrass ecosystems, small-scale fisheries, and coastal livelihoods. At the global scale, Nordlund et al. (2018) documented the diversity and widespread occurrence of seagrass-associated fishing activities, while Furkon et al. (2020) investigated invertebrate gleaning fisheries in Indonesia, including catch composition, catch per unit effort, and ecological drivers of gleaning productivity. At the household level, Jones et al. (2022) demonstrated that income and adaptive capacity were associated with dependence on seagrass fishing habitats, while Jones et al. (2026) provided further evidence linking exclusive reliance on seagrass fishing grounds with household poverty across Indo-Pacific coastal communities. Other studies have focused on fisheries production and economic benefits. For example, de la Torre-Castro et al. (2014) compared fishing effort, catch biomass, and monetary returns among seagrass, mangrove, and coral reef habitats, whereas Quiros et al. (2018) examined catch composition, market value, livelihood diversification, and social vulnerability among seagrass-fishing communities in the Philippines. Research on social perceptions has also demonstrated that occupation and socioeconomic characteristics influence seagrass resource utilization and awareness of ecosystem services and threats, as reported by Lukman et al. (2021) and Rifai et al. (2023b) in Indonesia.

RESEARCH METHODS

Study Area

The study was conducted in the Kei Islands, Maluku Province, eastern Indonesia, from May to August 2026, where coastal communities interact closely with shallow-water marine habitats, including seagrass meadows. Small-scale fisheries in the study area include finfish capture, invertebrate harvesting, and intertidal gleaning, as well as mixed fishing strategies that combine these activities. Survey respondents were represented across 17 coastal villages in the analytical dataset: Danar Ternate, Disuk, Duroa, Dunwahan, Faan, Letvuan, Namar, Ngilngof, Ut Island, Revav, Sathean, Selayar, Sitniohoi, Tamedan, Tarwa, Warbal, and Wab (Figure 1). Villages were retained in the statistical framework to account for spatially structured differences among communities, including differences in access to fishing grounds, livelihood opportunities, and local ecological conditions. Five seagrass species were identified in the study location, namely *Cymodocea* sp., *Syringodium isoetifolium, Thalassia hemprichii, Halodule* sp., and *Enhalus acoroides*.



Source: Authors' map, generated using R statistical software (2026)

Figure 1. Study Location

Study Design and Respondent Sampling

A two-stage purposive sampling approach was employed. First, a preliminary field assessment identified villages characterized by the presence of seagrass habitats and communities engaged in fisheries-related livelihoods. Second, respondents were purposively recruited from individuals directly undertaking fishing, gleaning, seaweed farming, or other marine-based livelihood activities, rather than household members reporting on their behalf. All interviews were conducted face-to-face using a structured questionnaire. Before each interview, the purpose of the study was explained to respondents, and verbal informed consent was obtained. Participation was voluntary, and interviews proceeded only after respondents indicated their willingness to participate. The complete survey comprised 200 respondents. Of these, 170 provided valid responses for seagrass-use frequency, 137 for the proportional contribution of seagrass-associated fishing to livelihoods, and 163 for catch quantity and gross catch value, before accounting for missing covariate information. Analyses were outcome-specific because not all respondents provided complete information for every variable. Consequently, final analytical sample sizes differed across statistical models according to the availability of valid outcome and covariate data.

Fishing-strategy Classification and Analytical Populations

Fishing strategies were classified according to respondents' reported extractive activities. Finfish-only fishers were defined as respondents reporting finfish capture without crab, sea cucumber, or shellfish collection. Invertebrate/gleaning-only fishers were those reporting at least one invertebrate collection activity without finfish capture. Mixed fishers were defined as respondents

who participated in both finfish capture and at least one invertebrate collection activity. Respondents who did not meet these capture-fishing definitions were classified as other/no capture fishery and were excluded from the primary fishing-strategy analyses. Seaweed-farming activity was considered in an expanded resource-use classification used for sensitivity analysis but did not determine the primary three-group fishing typology. The primary hypothesis tests were restricted to respondents reporting seagrass utilization and an eligible extractive fishing strategy. Additional inclusion criteria were applied according to the availability and validity of each outcome and its associated covariates. Consequently, the numbers of respondents included in the fitted models differed from the total survey sample and from the numbers providing valid outcome responses. Final analytical sample sizes were determined using complete observations for the variables included in each model.

Hypotheses and Analytical Framework

Four primary hypothesis groups were specified. H1 tested whether fishing strategy was associated with frequency of seagrass use. H2 tested whether diversified fishing was associated with the proportional contribution of seagrass-associated fishing. H3 tested whether fishing strategy was associated with (H3a) catch quantity and (H3b) gross economic value. H4 tested whether frequency of seagrass use and contribution/dependence were associated with (H4a) perceived catch decline, (H4b) perceived recent seagrass condition, (H4c) perceived threats, and (H4d) support for seagrass management.

Data preparation and statistical inference

Continuous covariates were standardized where appropriate so that coefficients represent effects per one standard deviation increase:

$$z_{\mathrm{i}} = (x_{\mathrm{i}} - \bar{x}) / s_{\mathrm{x}}, \quad (1)$$

where x_i is the observed value, $\bar{x}$ is the sample mean, and s_x is the sample standard deviation. Categorical predictors were represented by indicator variables with substantively defined reference categories.

All tests were two-sided and evaluated at $\alpha = 0.05$. Effect estimates are reported with 95% confidence intervals. Exponentiated coefficients are reported as odds ratios (ORs) for logistic and cumulative-logit models and as multiplicative response ratios for Gamma-log models. For related global tests in the H3 and H4 hypothesis families, false-discovery-rate (FDR) adjusted P values were additionally calculated. Interpretation considered effect magnitude, confidence-interval width, model diagnostics, sparse data, and consistency across sensitivity analyses rather than statistical significance alone.

H1: fishing strategy and frequency of seagrass use

The primary H1 analysis used a cumulative link mixed model with a logit link and a village random intercept because frequency of seagrass use was ordinal. For respondent i in village j, the model was:

$$log\{ P(Y_{\mathrm{ij}} > k) / P(Y_{\mathrm{ij}} \leq k) \} = \alpha_k + \beta_1 S_{1\mathrm{ij}} + \beta_2 S_{2\mathrm{ij}} + \gamma^{\mathrm{T}} X_{\mathrm{ij}} + u_{\mathrm{j}}, \quad (2)$$

$$u_j \sim N(0, \sigma^2{}_{\mathrm{vi/a}} g_{\mathrm{e}}) \quad (3)$$

where Y_{ij} denotes the ordered frequency response; α_k denotes category-specific thresholds; S_1 and S_2 represent the invertebrate/gleaning-only and mixed strategies relative to finfish-only fishing; and X contains household income, livelihood, work experience, sex, and household size.

$$Frequency \sim strategy + household\ income + livelihood + work\ experience + sex + household\ size + (1 \mid village) \quad (4)$$

An unadjusted Kruskal-Wallis test was used as a non-parametric comparison of observed frequency distributions. Adjusted pairwise contrasts among strategy categories were obtained using estimated marginal means with Tukey correction. Ordinal assumptions were evaluated using nominal-effect and scale-effect tests.

H2: fishing diversification and contribution

The H2 outcome was also ordinal and was initially analyzed using a cumulative link mixed model:

$$log\{\, P(D_{ij} > k) \,/\, P(D_{ij} \leq k) \,\} = \alpha_k + \beta_1 Diversified_{ij} + \gamma^{T} X_{ij} + u_j.$$

$$Contribution \sim diversification + household\ income + livelihood + work\ experience + sex + household\ size + (1 \mid village) \quad (5)$$

The primary mixed model exhibited a near-zero village variance and singular fit. Consequently, the primary point estimate was not used as stand-alone inferential evidence. Robustness was assessed using a collapsed three-level contribution outcome, alternative fishing-strategy coding, removal or alternative coding of household income, partial proportional-odds models, boat/fishing-experience specifications, and an unadjusted Fisher's exact test.

H3: fishing strategy, catch quantity, and gross economic value

Catch quantity and gross economic value were positive and right-skewed and were therefore modeled using Gamma generalized linear mixed models with log links:

$$Y_{ij} \sim Gamma(\mu_{ij}, \varphi), \quad (6)$$

$$log(\mu_{ij}) = \beta_0 + \beta_1 S_{1ij} + \beta_2 S_{2ij} + \gamma^{T} X_{ij} + u_j, \quad (7)$$

$$u_j \sim N(0, \sigma^2{}_{\text{vil/a}} g_{\text{e}}) \quad (8)$$

For H3a, Y was reported catch quantity; for H3b, Y was gross catch value. Primary covariates included work experience, livelihood, sex, and household size. Household income was examined in sensitivity analyses rather than included in the primary specification.

Catch ~ strategy + work experience + livelihood + sex + household size + (1 | village)

Gross value ~ strategy + work experience + livelihood + sex + household size + (1 | village).

Overall strategy effects were tested with likelihood-ratio tests comparing nested models with and without the strategy term. Adjusted response-scale means and Tukey-adjusted pairwise comparisons were calculated. Kruskal-Wallis tests provided unadjusted non-parametric comparisons.

H4: utilization, dependence, perceptions, and management support

H4a: perceived catch decline

Perceived catch decline was analyzed using mixed-effects binary logistic regression:

$$Y_{ij} \sim Bernoulli(p_{ij}),$$
$$logit(p_{ij}) = \beta_0 + \beta_1 Frequency_{ij} + \beta_2 Contribution_{ij} + \gamma^{T} X_{ij} + u_j.$$
$$Catch\ decline \sim frequency + contribution + strategy + work\ experience + sex + household\ size + (1 \mid village) \quad (9)$$

H4b: perceived recent seagrass condition

Recent condition was analyzed primarily with a cumulative link mixed model:

$$log\{ P(C_{ij} > k) / P(C_{ij} \leq k) \} = \alpha_k + \beta_1 Frequency_{ij} + \beta_2 Contribution_{ij} + \gamma^{T} X_{ij} + u_j \quad (10)$$

Sensitivity analyses retained the original four-category condition outcome and alternatively modeled worse versus not worse using binary logistic mixed regression. Nominal and scale tests were used to assess ordinal-model assumptions.

H4c: perceived threats

Threat responses were modeled at item level. Let Y_{ijm} indicate whether respondent i in village j endorsed threat item m:

$$Y_{ijm} \sim Bernoulli(p_{ijm}),$$
$$logit(p_{ijm}) = \beta_0 + \beta_1 Frequency_i + \beta_2 Contribution_i + \gamma^{T} X_i + \delta_m + r_i + u_j,$$
$$r_i \sim N(0, \sigma^2_{respon} d_{ent}),\ u_j \sim N(0, \sigma^2_{vil/a} g_e) \quad (11)$$

Threat-item identity was accounted for to capture differences in baseline endorsement among threat types. Alternative random-effects and respondent-level beta-binomial specifications were examined as sensitivity analyses.

H4d: support for management

Support for six management actions was also modeled as repeated binary item-level observations:

$$Y_{ijm} \sim Bernoulli(p_{ijm}),$$
$$logit(p_{ijm}) = \beta_0 + \beta_1 Frequency_i + \beta_2 Contribution_i + \gamma^{T} X_i + r_i + u_j + q_m,$$
$$r_i \sim N(0, \sigma^2_{respon} d_{ent}),\ u_j \sim N(0, \sigma^2_{vil/a} g_e),\ q_m \sim N(0, \sigma^2_{mana} g_{ement}) \quad (12)$$

Internal consistency of the six management-support items was evaluated using raw and standardized Cronbach's alpha; tetrachoric alpha was additionally calculated for the binary items. Nonlinear relationships were explored using polynomial contrasts for ordered frequency and contribution categories. Interactions between each exposure and management item were evaluated to assess heterogeneity among specific actions.

Statistical Modeling and Robustness Assessment

Primary model specifications, outcome definitions, explanatory variables, covariates, and random-effects structures are summarized in Robustness assessments that addressed alternative fishing-strategy classifications, missing household-income information, sparse ordinal categories, covariate specifications, and distributional assumptions. Proportional-odds assumptions were assessed using corresponding cumulative-link models with village fixed effects, including nominal-effect and scale-effect diagnostics. Simulation-based residual diagnostics were applied to applicable generalized linear mixed models, while convergence, random-effect stability, collinearity, and complete-case inclusion patterns were also examined. Global hypothesis tests were based on likelihood-ratio comparisons, with false-discovery-rate adjustment applied within the prespecified H3 and H4 hypothesis families. Statistical interpretation emphasized effect sizes, 95% confidence intervals, diagnostic findings, and consistency across sensitivity analyses rather than statistical significance alone.

Statistical Software

All statistical analyses were conducted in R 2026.01.1 Build 403 using packages appropriate for ordinal mixed models, generalized linear mixed models, estimated marginal means, robust inference, and simulation-based diagnostics.

RESULTS AND DISCUSSION

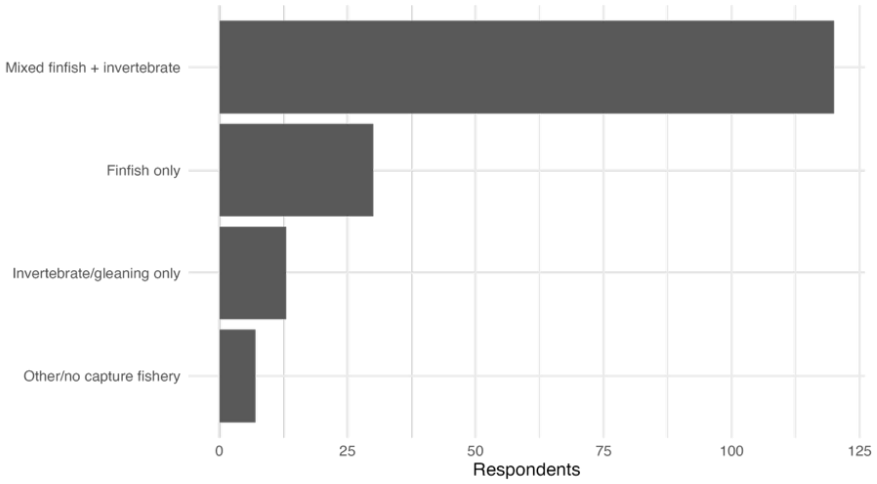
H1: Fishing Strategy Differentiated Seagrass-use Frequency

Fishing strategy showed a pronounced association with reported seagrass-use frequency. The cumulative-link mixed model (n = 130) indicated that invertebrate/gleaning-only fishers had substantially lower odds of reporting higher use-frequency categories than finfish-only fishers (OR = 0.013; 95% CI: 0.002–0.099; $p < 0.001$). Mixed fishers did not differ clearly from the finfish-only group (OR = 0.483; 95% CI: 0.181–1.293; $p = 0.148$). Tukey-adjusted pairwise comparisons further indicated differences between invertebrate/gleaning-only fishers and both finfish-only and mixed fishers (both $p < 0.001$), whereas the comparison between finfish-only and mixed fishers was not statistically significant (adjusted $p = 0.317$). In addition, the sensitivity analysis comparing diversified and specialized fishing strategies did not identify a clear association (OR = 1.137; $p = 0.774$). These findings indicate that the observed relationship was primarily attributable to the lower reported frequency of seagrass utilization among invertebrate/gleaning-only fishers, rather than a general effect of fishing diversification.

This result adds nuance to studies describing gleaning as an important seagrass-associated activity. Gleaning in shallow intertidal habitats can provide food and income using relatively simple and low-cost methods (Furkon et al., 2020; Pike et al., 2024; Stiepani, Jiddawi, et al., 2023; Tilley et al., 2021). Studies from Timor-Leste, Zanzibar, and the Philippines show that invertebrate gleaning can contribute substantially to household consumption, livelihoods, food security, and cultural practices (Pike et al., 2024; Stiepani, Jiddawi, et al., 2023; Stiepani, Sandig, et al., 2023; Tilley et al., 2021). However, gleaning is not restricted to seagrass. Fishers may move among reef flats,

unvegetated intertidal areas, rocky habitats, mangrove margins, and seagrass during the same tidal cycle, whereas some finfish gears may repeatedly target subtidal meadows, channels, or meadow edges (Herrera et al., 2022; Nordlund et al., 2018).

Fishing strategies were unevenly distributed among respondents. Mixed finfish–invertebrate fishing was the dominant strategy, followed by finfish-only and invertebrate/gleaning-only fishing, while relatively few respondents were classified as other/no capture fishery (Figure 2). Fishing strategy and frequency of seagrass use is shown in Table 1.



Source: Processed primary data (2026)

Figure 2. Distribution of Respondents Among Fishing-Strategy Categories. Mixed finfish–invertebrate fishing was the most common strategy, followed by finfish-only, invertebrate/gleaning-only, and other/no capture fishery.

Table 1. Fishing Strategy and Frequency of Seagrass Use

Fishing strategy comparison	Adjusted OR	95% CI	p-value	Interpretation
Invertebrate/gleaning only vs finfish only	0.013	0.002–0.099	<0.001	Strongly lower odds of more frequent seagrass use
Mixed finfish + invertebrate vs finfish only	0.483	0.181–1.293	0.148	No clear statistical evidence of a difference

Source: Processed primary data (2026)

H2: Diversification and Contribution

The original cumulative-link mixed model for reported proportional livelihood contribution exhibited a singular fit, with a near-zero village random-intercept variance (1.70×10^{-8}). Consequently, an alternative cumulative-link model without the village random intercept was fitted using the same 108 complete-case observations. This model provided no clear statistical evidence of an association between fishing diversification and reported proportional livelihood contribution (OR = 1.368; 95% CI: 0.522–3.585; p = 0.524; global likelihood-ratio test p = 0.522). The three-level contribution sensitivity analysis yielded a similar but imprecise estimate (OR = 1.377; 95% CI: 0.508–3.732; p = 0.530). Excluding household income from the adjustment set also produced an uncertain estimate (OR = 1.887; 95% CI: 0.678–5.253; p = 0.224). The H2 analysis provided no clear statistical evidence of an association between fishing-strategy diversification and reported proportional livelihood contribution.

Fishing diversification was not clearly associated with the proportional livelihood contribution of seagrass-associated activities. This result is consistent with evidence that dependence on coastal ecosystems is shaped by household circumstances as well as habitat use. Jones et al. (2022) showed that income, fishing assets, motorized boats, livelihood alternatives, and household characteristics contributed to seagrass-fishery dependence. Seagrass fisheries may also reduce dimensions of social vulnerability by providing accessible food and income, although these benefits vary among households and communities (Quiros et al., 2018). Fisheries livelihoods are shaped by assets, institutions, markets, household structure, access rights, mobility, and opportunities outside fishing (Warren & Steenbergen, 2021). The distinction between use and dependence is consequently important. Seagrass-associated fisheries may contribute through both subsistence and market pathways, meaning that monetary contribution alone can underestimate their importance (Wallner-Hahn et al., 2022). Data on fishing diversification and proportional dependence are shown in Table 2.

Table 2. Fishing Diversification and Proportional Dependence

Analysis	Comparison	Adjusted OR	95% CI	p-value
Four-level CLM (revised primary)	Diversified vs specialized	1.368	0.522–3.585	0.524
Three-level contribution sensitivity	Diversified vs specialized	1.377	0.508–3.732	0.530
No-household-income sensitivity	Diversified vs specialized	1.887	0.678–5.253	0.224
Three-strategy sensitivity	Invertebrate vs finfish	0.705	0.043–11.495	0.806
Three-strategy sensitivity	Mixed vs finfish	1.310	0.472–3.634	0.604

Source: Processed primary data (2026)

H3: fishing strategy, catch quantity, and gross economic value

Fishing strategy was not clearly associated with reported monthly catch quantity or gross catch value in the primary Gamma mixed models. The global likelihood-ratio tests yielded p = 0.497 for catch quantity and p = 0.431 for gross catch value, with FDR-adjusted p = 0.497 for both outcomes. However, the catch model exhibited a significant DHARMa residual-uniformity diagnostic (p = 0.009), despite the absence of corresponding dispersion (p = 0.442) or outlier (p = 0.264) signals. Additional residual examination indicated systematic deviations across fitted values and some fishing-strategy and village groups. An alternative Gamma model allowing dispersion to vary by fishing strategy did not resolve the residual-uniformity concern (p = 0.013) and had a slightly higher AIC than the primary model. Nevertheless, the estimated fishing-strategy response ratios remained broadly similar across specifications.

Structured coastal habitats including seagrass can support juvenile fish abundance and production (Lefcheck et al., 2019), and a global synthesis shows many positive relationships between seagrass habitat and commercially important species (Herrera et al., 2022). Low-volume catches of high-value species, for example, may generate similar gross values to larger catches of lower-value species. Gleaning catches may also be partly consumed rather than sold, so gross value does not fully represent their household contribution (Tilley et al., 2021; Wallner-Hahn et al., 2022). The survey also did not measure fishing effort, trip-level location, gear deployment, or habitat-specific

catch, so reported catch cannot be interpreted as catch per unit effort or direct seagrass productivity. Tropical small-scale fisheries operate across connected seascapes containing seagrass, coral reefs, mangroves, intertidal flats, and unvegetated habitats (de la Torre-Castro et al., 2014). Consequently, household catches may integrate production supported by several habitats. The broader value of seagrass therefore lies in ecological functions operating across species, habitats, seasons, and spatial scales rather than in a single household production metric (Nordlund et al., 2016; Unsworth et al., 2019, 2022). Data on fishing strategy and fisheries production are shown in Table 3.

Table 3. Fishing Strategy and Fisheries Production

Outcome	Fishing Strategy Comparison	Adjusted Response Ratio	95% CI	p-value	Global LRT p-value
Catch quantity (kg/month)	Invertebrate/gleaning-only vs finfish-only	1.242	0.755–2.044	0.393	0.497
	Mixed vs finfish-only	1.156	0.891–1.500	0.274	—
Gross catch value (IDR/month)	Invertebrate/gleaning-only vs finfish-only	1.215	0.719–2.054	0.467	0.431
	Mixed vs finfish-only	1.207	0.909–1.605	0.194	—

Source: Processed primary data (2026)

H4: Utilization/Dependence, Perceptions, and Management Support

The analyses of environmental perceptions and management support did not provide clear evidence of consistent associations with seagrass-use frequency or proportional livelihood contribution. For perceived catch decline, the adjusted odds ratios were 1.329 (95% CI: 0.676–2.613; p = 0.410) for use frequency and 0.701 (95% CI: 0.408–1.202; p = 0.197) for livelihood contribution. For perceived recent seagrass condition, the corresponding estimates were 0.676 (95% CI: 0.399–1.144; p = 0.145) and 1.282 (95% CI: 0.787–2.087; p = 0.318). Environmental threat recognition was not clearly associated with either use frequency (OR = 1.153; 95% CI: 0.939–1.417; p = 0.175) or livelihood contribution (OR = 0.887; 95% CI: 0.737–1.067; p = 0.205). Similarly, management support showed no clear association with use frequency (OR = 1.113; 95% CI: 0.713–1.737; p = 0.639) or livelihood contribution (OR = 1.000; 95% CI: 0.677–1.476; p = 1.000). These associations were secondary exploratory findings rather than primary tests of H4 and should be interpreted cautiously, particularly given the residual-model diagnostic limitations identified for the management-support model (Table 4). The H4 analyses did not identify consistent associations between reported seagrass-use frequency or proportional livelihood contribution and perceptions of environmental change, environmental threat recognition, or support for seagrass management. None of the eight primary H4 associations provided clear statistical evidence after correction for multiple testing. These findings suggest that the two measured indicators of habitat utilization and livelihood contribution did not consistently explain variation in the assessed perceptions and management attitudes within the analytical sample. However, they do not demonstrate that these relationships are absent.

Table 4. Seagrass-Use Frequency, Reported Livelihood Contribution, Environmental Perceptions, and Management Support

Outcome	Predictor	Adjusted OR	95% CI	p-value
H4a Catch decline	Use frequency	1.329	0.676–2.613	0.410
	Contribution/dependence	0.701	0.408–1.202	0.197
H4b Recent seagrass condition	Use frequency	0.676	0.399–1.144	0.145
	Contribution/dependence	1.282	0.787–2.087	0.318
H4c Threat endorsement	Use frequency	1.153	0.939–1.417	0.175
	Contribution/dependence	0.887	0.737–1.067	0.205
H4d Management support	Use frequency	1.113	0.713–1.737	0.639
	Contribution/dependence	0.999	0.677–1.476	0.999

Source: Processed primary data (2026)

The four hypothesis groups provided differing levels of evidence regarding human–seagrass relationships in the surveyed Kei Islands communities. H1 identified a pronounced association between fishing strategy and reported seagrass-use frequency, particularly among invertebrate/gleaning-only fishers. H2 provided inconclusive evidence concerning fishing-strategy diversification and proportional livelihood contribution, with interpretation constrained by sparse observations and the singular primary model. H3 did not provide clear statistical evidence of fishing-strategy differences in reported catch quantity or gross catch value, although uncertainty and catch-model diagnostic limitations warrant caution. H4 did not identify consistent associations between reported seagrass-use frequency or proportional livelihood contribution and environmental perceptions or management support, while exploratory secondary associations suggested variation across socioeconomic and fishing-strategy groups.

Neither seagrass-use frequency nor proportional livelihood dependence consistently predicted reported catch decline, recent seagrass condition, or recognition of environmental threats. In the Philippines, awareness of seagrass ecosystem services and perceived threats differed among communities and between rural and urban settings (Quevedo et al., 2020, 2023). In Indonesia, community awareness of seagrass ecosystem services likewise varied (Rifai et al., 2023a). Local ecological knowledge can nevertheless provide valuable evidence of long-term ecosystem change. Jones et al. (2022) showed that local knowledge could identify changes in seagrass social–ecological systems, while Newmaster et al. (2011) documented detailed community knowledge of seagrass resources, uses, species, and environmental change. This distinction is particularly relevant in Indonesia, where seagrass ecosystems experience multiple anthropogenic pressures and vary considerably in ecological condition (Hernawan et al., 2021; Unsworth et al., 2018).

CONCLUSION AND SUGGESTION

Conclusion

Seagrass meadows support diverse small-scale fishing strategies in the Kei Islands, Indonesia, but the relationships between resource users and seagrass ecosystems extend beyond habitat-use frequency. Invertebrate/gleaning-only fishers had substantially lower odds of reporting more frequent seagrass use than finfish-only fishers, whereas mixed fishers did not differ clearly

from the finfish-only group. The analyses provided no clear statistical evidence of associations between fishing diversification and proportional livelihood contribution or between fishing strategy and reported catch quantity or gross catch value. Similarly, seagrass-use frequency and reported livelihood contribution were not consistently associated with perceptions of environmental change, threat recognition, or support for seagrass management. These findings highlight heterogeneity in habitat utilization and indicate that seagrass-use frequency, livelihood contribution, fisheries outcomes, and management attitudes capture conceptually distinct dimensions of human–seagrass relationships. Although the findings do not establish statistical independence among these dimensions, they underscore the importance of assessing them separately rather than assuming that habitat-use frequency alone adequately represents socioeconomic dependence or management preferences within the studied communities.

Suggestion

Seagrass management in the Kei Islands should adopt a multidimensional approach that recognizes differences among fishing strategies and livelihood circumstances. Resource-user assessments should consider not only the frequency of seagrass habitat utilization but also the proportional contribution of seagrass-associated activities to livelihoods, fisheries production, and socioeconomic characteristics when identifying groups potentially affected by conservation or management interventions. In particular, management planning should assess habitat-use frequency and reported livelihood contribution separately, rather than assuming that frequent habitat utilization necessarily indicates greater economic dependence. Combining these indicators may help identify differences in resource-use patterns and livelihood circumstances relevant to conservation planning. Future research should employ longitudinal and comparative approaches across coastal communities, incorporating household economic conditions, fishing effort, habitat characteristics, and environmental change to evaluate more directly how seagrass utilization relates to livelihood contribution, fisheries outcomes, and support for conservation.

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