

Spatiotemporal determinants of seasonal gleaning

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Abstract

1. Many coastal communities depend on ecosystems for goods and services that contribute to human well-being. As long-standing interactions between people and nature are modified by global environmental change, dynamic and diversified livelihood strategies that enable seasonal adaptation will be critical for vulnerable coastal communities. However, the success of such strategies depends on a range of poorly understood influences.
2. Gleaning, the hand-based collection of marine organisms from littoral habitats, provides an interesting case study of dynamic change in social-ecological interactions. It is an important coastal livelihood strategy, yet seasonal gleaning dynamics have not been empirically explored in contemporary communities. We examined seasonal gleaning in eight coastal communities on Atauro Island, Timor-Leste, using household surveys and satellite-derived maps of shallow-water benthic habitats. Our analysis explored the factors affecting household decisions to glean in each season, the relationship between gleaning and seafood consumption, and seasonal gleaning pressure on near-shore coastal resources.
3. Dynamic marine harvesting strategies differed among households and gleaning activity was seasonally heterogeneous. Not all gleaning households gleaned during the season characterised by rough sea conditions despite rough season gleaning being associated with greater seafood consumption stability among seasons. Households also gleaned less regularly, and catches were smaller, in the rough season.
4. Differences in seasonal participation in gleaning were explained mostly by type and extent of shallow habitat proximate to a community. In the calm season, household gleaning was positively related to the total area of shallow habitat, and in the rough season the percentage of hard-bottom shallow habitat was also an important predictor of gleaning activity.
5. Our findings illustrate how changes in the biophysical environment mediate human–nature interactions at fine scales through time and space. Consequently, this research highlights the importance of context-specific perspectives for understanding drivers and dynamics in fishing pressure on littoral ecosystems, access to

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ecosystem benefits and limits to adaptation. Factors influencing when livelihood activities are feasible and desirable are important for evaluating the social impacts of climate change, particularly in the context of rural communities in the Global South.

KEYWORDS

coastal, coral reef, ecosystem services, food security, livelihoods, small-scale fisheries, social-ecological system

1 | INTRODUCTION

Understanding how coastal communities interact with and depend on local ecosystems is key to sustainably managing coastal social-ecological systems in a rapidly changing world. Coastal communities in the Global South, and particularly in Small Island States and rural areas, are some of the most vulnerable to climate change (Bindoff et al., 2019; Wong et al., 2014) because their livelihoods often depend directly on fragile marine resources and climate impacts pose major risks of food insecurity and poverty (Cinner et al., 2012; Cruz-Trinidad et al., 2014). Coastal ecosystem structures, processes and functions support a diversity of provisioning (e.g. fishery resources), regulating (e.g. wave attenuation) and cultural (e.g. seascape aesthetics) ecosystem services, which provide multiple material (e.g. food) and non-material (e.g. leisure opportunities) benefits to people (Barbier et al., 2011). Through human–nature interactions of ecosystem use and management, people realise and influence benefits from ecosystems (Spangenberg et al., 2014), including in coastal zones. These interactions also have impacts on coastal ecosystems; for example, fishing can modify the biophysical structure and function of coastal ecosystems through the removal of resources and changes in the structure of harvested populations, altering habitats and changing trophic interactions (Mangi & Roberts, 2006).

An important but poorly understood human–nature interaction in coastal areas is gleaning. Gleaning is a low-technology, multi-species and typically female-dominated small-scale fishery subsector that involves the manual collection of marine organisms from shallow-water and intertidal (hereafter 'littoral') habitats (Branch et al., 2002; Chapman, 1987). Gleaning is often part of diversified fishing strategies, complementing other fishing methods, predominantly as source of subsistence (Clark et al., 2002). Gleaners usually travel by foot and use their hands or hand-held tools (knives or metal sticks) to pry and stab target species that include molluscs, crustaceans and fish (Kleiber et al., 2014). Despite being a widespread livelihood activity in the Pacific (Kronen & Vunisea, 2007) and other coastal regions of the Global South (Fröcklin et al., 2014), gleaning is a data-limited sector, historically overlooked in fisheries and livelihoods research and underrepresented in our understanding of how people interact with coastal ecosystems (Harper et al., 2013; Kleiber et al., 2014). A rise in gender-sensitive fisheries research has increased the visibility of gleaning and particularly its importance for household food security (e.g. Tilley et al., 2020). The value of gleaning in the lives

of coastal communities extends beyond subsistence; for instance, gleaning also provides opportunity for socialising, knowledge sharing and enjoying nature (Grantham et al., 2020). However, gleaning can negatively affect coastal ecosystems and cause long-term ecosystem changes through direct pressure on target species' populations (Aswani et al., 2014; Keough et al., 1993) and damage of habitats from the use of destructive methods (e.g. trampling or overturning corals; Andréfouët et al., 2013). The management of gleaning fisheries is therefore crucial for sustaining human well-being and coastal ecosystems. However, gleaning fisheries and the use of littoral habitats are often most important for women, and tend to be underrepresented in coastal management as a result of gender blind spots (de la Torre-Castro et al., 2017). More empirical work is needed on gleaning as an interaction between coastal communities and the littoral zone.

Interactions between people and coastal environments, including fishing and gleaning, are not only a means to material gain but they also represent relationships to nature that are valued in themselves and contribute to quality of life. For example, through indigenous perspectives that recognise an interconnected web between all animate life and inanimate things, fisheries represent a set of responsibilities and relationships with other people and the environment (McMillan & Prosper, 2016). These relational values are defined as the '*[P]references, principles, virtues about/based on meaning-saturated relationships*' (Chan et al., 2018) and encompass a diversity of tangible and intangible values, rooted in human–nature interactions (unlike intrinsic values) and are distinct from instrumental values by being non-substitutable (Himes & Muraca, 2018). The importance of relational values is gaining traction in research frontiers that seek to better attend to the social dimensions of ecosystem services (Chan & Satterfield, 2020). A key development on the concept of ecosystem services is the proposed Nature's Contributions to People (NCP) framework, which includes cultural context as a crosscutting factor in recognition that worldviews underpin how human–nature interactions are perceived and valued (Díaz et al., 2018; Pascual et al., 2017). Stock-flow metaphors, such as framing the ocean as a service provider, oversimplify and misrepresent how people connect with coastal ecosystems and fail to capture multiple, interdependent and overlapping values (Klain et al., 2014). Indeed, the inseparability of material and non-material benefits of nature to people has been demonstrated in studies that show people highly value relational aspects associated with the subsistence benefits of fishing (Klain et al., 2014). Understanding how processes of change in coastal areas

will affect nature's contributions to people, such as those associated with gleaning, therefore requires not only evaluating how the delivery of benefits from ecosystems will be affected but also the implications for how people interact with nature because the relationships these interactions pertain to are valued in themselves.

In particular, there is a need to build a better understanding of how gleaning interactions are influenced by combined social, physical and weather conditions. Experimental methods suggest that weather, tidal conditions, habitat type, and the age and gender of gleaners affect gleaning returns (De Vynck et al., 2016). Other studies have looked at temporal trends in harvests from the littoral zone, for instance to monitor fishery rehabilitation success (Calvo-Ugarteburu et al., 2017) and seasonal trends in harvests have been found to differ with the availability of catch groups, which can vary between sites at fine spatial scales (Gina-Whewell, 1992; Kyle et al., 1997). Archaeological studies of shell middens provide insight into the seasonality of gleaning amongst early humans; seasonal trends in shellfish collection varied between locations and time periods, which has been attributed to differences in the availability and accessibility of shellfish and the availability of other foods (Burchell et al., 2013; Loftus et al., 2019). In some societies, shellfish are believed to have been targeted as a supplementary source of nutrition during lean seasons (Prendergast et al., 2016), while in others shellfish may have been harvested opportunistically in good weather (Loftus et al., 2019). However, little research has empirically explored seasonal dynamics and drivers of gleaning in contemporary communities and, particularly in the context of a changing climate, there is a pressing need to understand how access to gleaning areas and seasonal weather conditions influence how people interact with littoral ecosystems.

This study contributes to addressing some of these gaps by examining seasonal household gleaning dynamics using data collected from households living on Atauro Island, Timor-Leste, as a detailed case study. We focused on the following questions: (a) How does gleaning, as part of household marine harvesting strategies, vary seasonally? (b) What is the relationship between gleaning and seasonal variability in seafood consumption? (c) What determines the decision to glean in different seasons? Our results present a fine-grained perspective of how people interact with littoral habitats through seasonal gleaning and offer insights into dynamic and context-specific human–nature relationships.

2 | METHODS

2.1 | Research ethics and permits

Permission to conduct research on Atauro Island was granted by the Ministry of Fisheries and Agriculture, Timor-Leste. Prior to implementing the research, the lead author met with the *Xefi aldeia* (community leader) of each study community to discuss the research objectives and approaches and obtain permission to carry out household surveys. Survey participants were read a description of the research and gave signed consent; if consent was not given the survey did not proceed. The research presented in this study was

carried out according to Human Ethics requirements from James Cook University, Australia (approval number H7626).

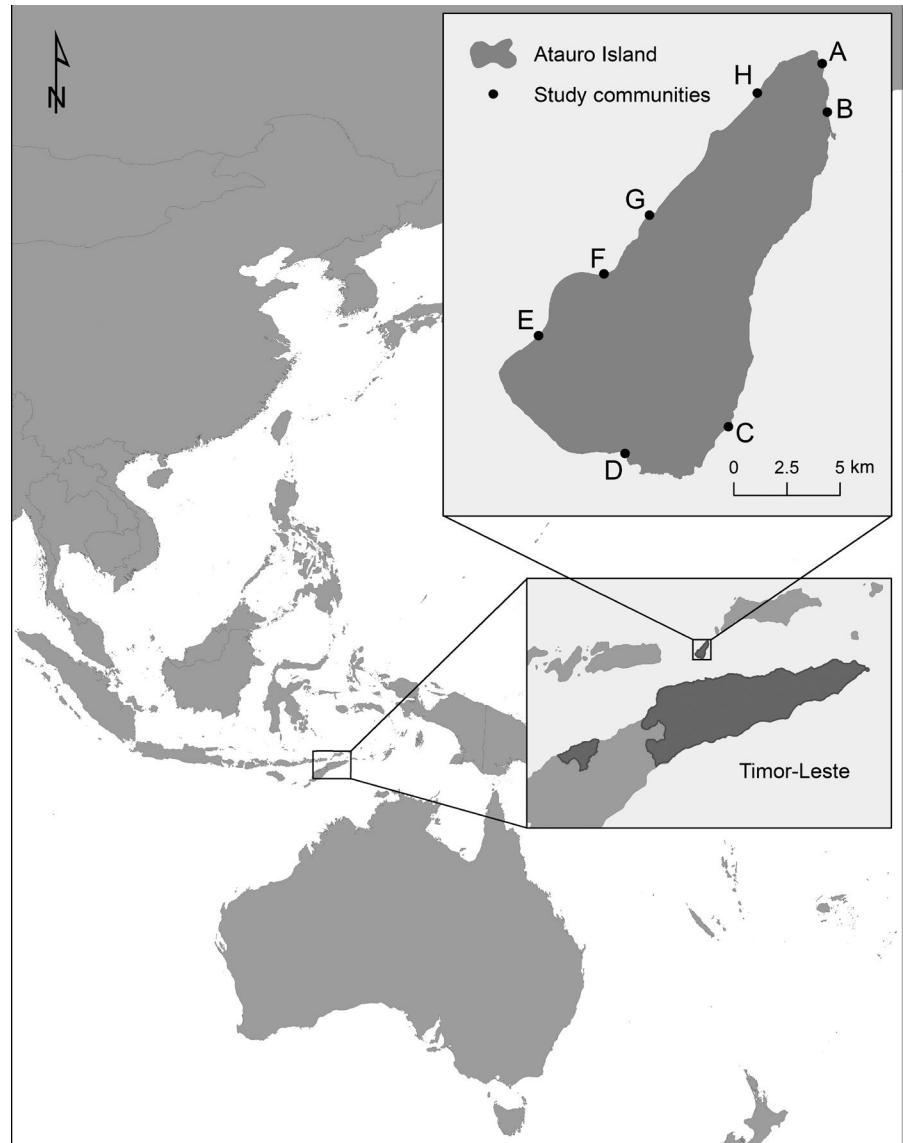
2.2 | Study site

Research was undertaken on Atauro Island, Timor-Leste (Figure 1). Sustainably managing coastal resources is a major challenge in Timor-Leste as the country faces pressing issues of poverty and food insecurity. Average seafood consumption in Timor-Leste is low for a small-island nation due to the low-technology and small-scale nature of the fishing sector and poor transport and storage infrastructure, but as the country continues to develop, demand for seafood and pressure on coastal resources are projected to rise (Mills et al., 2013). Increased availability and access to seafood have the potential to improve food and nutrition security and provide an important source of income for coastal communities (Farmery et al., 2020). However, limited data in Timor-Leste's fisheries sector, particularly the blind spot surrounding gleaning, are a barrier to sustainable and equitable management (Tilley et al., 2020). The coral reefs of Timor-Leste are located at the heart of the Coral Triangle and support one of the world's highest species richness of coral reef fishes (PIFSC, 2017b). Without careful management to reconcile livelihood demands with ecosystem sustainability, development of Timor-Leste's fisheries sector risks undermining the country's rich marine ecosystems.

Atauro Island is located 25 km north of the capital, Dili, and is Timor-Leste's only populated islet. It is home to a population of over 9,200 people (0.8% of Timor-Leste's total population) and comprises five administrative sub-districts, containing 23 communities (GDS, 2015). Livelihoods on Atauro Island are predominantly diversified and subsistence focussed, with the most common activities being crop farming, livestock rearing and fishing (Mills et al., 2017). Livelihoods are more fishery dependent on Atauro Island than other parts of Timor-Leste and every Saturday the island hosts the country's largest regular fish market (Mills et al., 2013). Fishing has been linked to food and income security on Atauro Island and measures of poverty indicate well-being is greater in coastal communities than upland communities (Mills et al., 2017). The beaches and reefs of Atauro Island also support a small, but growing, tourism industry and have become the focus of a national conservation programme centred around establishing a network of marine protected areas (Conservation International, 2020).

The type and extent of littoral habitats surrounding Atauro Island vary geographically. Sandy beaches stretch along most of the north-eastern coast, backed by small patches of mangroves and fringed by coral reefs and seagrass beds, with large sandy flats covered in coral rubble and rocks exposed at low tide. The southern coast of Atauro Island is characterised by steep cliffs, pebbly beaches and large rocky boulders. Along the western coast, mixed pebble-sand beaches meet a narrow fringing reef that drops off abruptly and, in many places, reef flats are exposed at low tide. The maximum tidal range on Atauro Island is 1.5–2.0 m (UNDP & MAF, 2018). Gleaning takes place in the littoral zone, with gleaning predominantly focused on intertidal habitats exposed at low tide, but gleaners also collect organisms from

FIGURE 1 Map of Atauro Island, Timor-Leste, showing the location of the eight study communities: Akrema (A), Urua'ana (B), Makili (C), Berau (D), Maquer (E), Atecrú (F), Adara (G) and Vatu'u (H)



shallow water, sometimes wading up to waist deep. Gleaning is carried out in all littoral habitat types surrounding Atauro Island; this includes collecting various organisms found among coral rubble and rocks in the large sandy tidal flats, pools and rock crevices in exposed coral reef flats at low tide, and the splash zone on rocky boulders.

2.3 | Data

Our analyses are based on household socioeconomic data and spatial information about the littoral habitats surrounding Atauro Island.

2.3.1 | Household data

Household data were collected as part of a seasonal livelihoods and food security survey. Questions relevant to this study addressed basic indicators of household socio-demographics and recall of typical

marine harvesting activities and seafood consumption for two fishing seasons. In the survey, marine harvesting activities were categorised as gleaning or fishing, in line with how activities are distinguished locally. In Tetum (one official language of Timor-Leste), gleaning (using hand/hand-held tools to gather marine organisms from the littoral zone) is referred to as 'collecting' (*meti*) while all other fishing methods (including the use of nets, traps and line based fishing from the shore or boats) are classified as fishing (*peska*). Sea conditions were used to define fishing seasons (calm season and rough season) because during preliminary activities fishers identified sea conditions as the main determinant of intra-annual fishing cycles on Atauro Island and because months are not a commonly used measure of time in the study communities. According to fishing households, the main rough season on Atauro Island is associated with the western monsoon (typically January–March), during which strong westerly winds create large swell particularly on the western and southern coasts and around the northern tip of the island but also to a lesser extent on the eastern coast. Strong easterly winds during the eastern monsoon (typically

July–August) creates rough sea conditions on the eastern coast and variable sea conditions around the rest of the island, with August also being considered a rough month by most communities.

The survey was translated into Tetum and digitised using the KoBoToolbox software (Harvard Humanitarian Initiative, n.d.). Questions used to collect data analysed in this survey are presented in English in Appendix 1. The survey was implemented by the lead researcher and facilitators in eight communities (Figure 1). Communities were selected for being coastal and to capture a range of geographical orientations on Atauro Island. Households were opportunistically sampled using a door-to-door approach over a period of 3 days in each community.

2.3.2 | Spatial habitat data

To quantify differences in the littoral zone (representing potential gleaning habitats) around the island, we used an existing map of coastal habitats sourced from the Pacific Islands Fisheries Science Center of the U.S. National Oceanic and Atmospheric Administration (NOAA) (PIFSC, 2017a). The map classifies coastal areas according to benthic habitat type based on variants in the spectral signature using high-resolution WorldView-2 satellite imagery (PIFSC, 2017b). Using ArcGIS Desktop 10 software package (ESRI, 2019), we calculated the area of hard-bottom shallow habitat (habitat class 'hard shallow') and other shallow habitat (grouped habitat classes of 'soft shallow', 'seagrass' and 'mangroves') within a 2-km radius of each community (Appendices 2.1 and 2.2). Although not all areas classified as 'shallow' are necessarily accessible to gleaners, shallow habitat reflects differences in the extent and type of littoral zone proximate to each community and therefore provides a useful proxy for comparing relative differences in potential gleaning areas. The 2-km radius buffer zone was chosen based on conversations with gleaners on typical distances travelled.

2.4 | Analysis

Analyses were carried out using R statistical software (R Core Team, 2018). Generalised linear mixed models were fitted using the `LME4` package (Bates et al., 2014), with the exception of negative binomial distributions, which were fitted using the `glm.nb` function from the `MASS` package (Venables & Ripley, 2002). Residual diagnostics were checked using the `DHARMA` package (Hartig, 2020). Pairwise comparisons of estimated marginal means (EMM) were done using the `EMMEANS` package (Lenth, 2019) with post-hoc Tukey method. All results were reported using a 95% confidence interval (p value ≤ 0.05) for statistical significance and degrees of freedom were calculated using Kenward–Roger approximation.

2.4.1 | Dynamic marine harvesting

Dynamic marine harvesting strategies and gleaning seasonality were analysed using data on household participation in fishing and gleaning

during the rough and calm seasons. Marine harvesting strategies were categorised as *Glean*, *Fish*, *Glean & Fish* or *None*, according to whether any household member fished/gleaned during each season. Household gleaning seasonality was defined as *Year round* (marine harvesting strategy includes gleaning during rough and calm seasons), *Rough only* (marine harvesting strategy only includes gleaning in the rough season), *Calm only* (marine harvesting strategy only includes gleaning in the calm season) or *Never* (gleaning not included in marine harvesting strategy).

2.4.2 | Seafood consumption stability and seasonal gleaning

To assess the relationship between seasonal gleaning and stability in household seafood consumption between the rough and calm seasons, we developed a measure of *Consumption stability*. For each household in each season, the mean number of days per week that a household ate any of four categories of seafood (fresh fish, dried fish, shells and other) was calculated. Mean days in the rough season were then divided by mean days in the calm season to give rough-season seafood consumption as a proportion of calm-season consumption; thus, consumption stability values closer to one represent greater stability. To understand how seasonal gleaning might influence household consumption stability, while controlling for seasonal fishing, we used a linear mixed effect regression model, represented as:

$$Stab \sim Gs + (1|Fs) + (1|C),$$

where *Stab* is consumption stability and *Gs* and *Fs* are seasonal participation (i.e. year round, rough only, calm only, never) in gleaning and fishing, respectively. Seasonal fishing was included as a random effect to control for differences in seasonal seafood consumption likely associated with fishing. *C* is community and was included as a random effect to account for the nested sample design.

2.4.3 | Determinants of gleaning

Factors affecting gleaning in the rough and calm seasons were fitted using a binomial distribution. Whether a household gleaned (*G*) was regressed against a cross-level interaction between season (*S*) and relevant spatial habitat, socio-demographic and livelihood factors (Table 1) to understand how seasons and geographical location might influence gleaning activity. The model is represented as:

$$G \sim S: (Ar * Hd + A + W + B + L + F) + (1|id/C).$$

The cross-level interaction between season and other factors was chosen because of the specific focus of this research on factors influencing seasonal gleaning. An interaction between the two spatial habitat factors Area (*Ar*) and Hard (*Hd*) was also included to capture the combined effect of spatial attributes on seasonal gleaning. Household (*id*) and community (*C*) were included as random factors

TABLE 1 Description of the spatial and socioeconomic factors and rationale for their inclusion in the models

Symbol	Name	Description	Type	Rationale
Ar	Area	Area (ha) of shallow habitat (includes hard-bottomed and other shallow habitat), proximate to community (within a 2-km radius)	Continuous	Gleaning takes place in the littoral zone, therefore as a proxy for potential total gleaning area, larger shallow area proximate to the community is expected to be positively related to gleaning
Hd	Hard	Proportion of proximate shallow habitat area that is hard-bottomed	Proportion	Hard-bottom shallow habitats on Atauro Island mostly represent near-shore coral reefs. Tidal reef flats are an important gleaning area (Chapman, 1987; Teh et al., 2013; Whittingham et al., 2003) and thus, the proportion of hard-bottom shallow area is expected to be positively related to gleaning
A	Adults	Proportion of household members aged 18–60 years	Proportion	Human capital, including labour capacity, determines a household's ability to do things and therefore their livelihood strategies (Scoones, 1998). The proportion of adult household members, as the primary labour force, could be positively related to gleaning if labour enables gleaning or negatively related to gleaning if gleaning is an activity of last resort for households that are unable to do other activities
W	Women	The number of female (youth, adult and elderly) household members	Discrete	Gleaning in rural areas is typically a female-dominated activity (Branch et al., 2002; Chapman, 1987) and so it is expected that households containing more females would be more likely to glean
B	Brick	Whether the household lives in a completed brick house	Binary	As a low-input fishery, gleaning may be an important livelihood strategy for poorer households. House material can provide a good indicator of wealth in contexts where income is highly variable (Chasekwa et al., 2018); on Atauro Island, because building a brick house is a key aspiration and main use of income, with houses often being built incrementally over many years. Non-brick houses are typically constructed from a combination of sheet metal, palm fronds and bamboo
L	Livelihoods	The number of livelihood activities ^a a household participates in	Discrete	Livelihood diversification is an important strategy for reducing seasonal variability in food and income (Ellis, 2000). Households with more diverse livelihoods may be less dependent on gleaning due to available alternative sources of food and income
F	Fishing	Whether the household fishes	Binary	As a source of seafood, gleaning may be less important for households that also fish

^aCalculated as the sum of crop farming, livestock rearing, fishing (fishing/gleaning/fish processing/fish trade), seaweed farming, tourism, transportation, salary, casual labour and kiosk (run small shop).

to reflect the nested sample design and to account for any community-level effects on gleaning that may not be captured by factors included.

Due to uncertainty surrounding the accuracy of spatial habitat data proximate to community H (i.e. a small portion of the north-western habitat map was manually adjusted by NOAA to correct a possible error in the automated classification process of the satellite image), and to check the robustness of our results, we tested a model excluding community H (*Model A*) and one including all communities (*Model B*). To further validate our findings on habitat, we tested a simplified model including only the cross interaction between season and spatial habitat factors (*Model C*) and excluding data from community H:

$$G \sim S: (Ar * Hd) + (1|id/C).$$

Throughout the results, we report the conditional goodness of fit (i.e. including the random component) and provide coefficients as log-odds

based on scaled and centred data, that is, effect sizes are measured holding other factors constant at their mean.

2.4.4 | Community gleaning trends

To characterise seasonal gleaning across the study communities, we used descriptive statistics to summarise household gleaning trips and catches. Household gleaning seasonality was categorised as *Year round*, *Calm only*, *Rough only* or *Never*, and the regularity of gleaning trips in each season was categorised as *Daily*, *Multi-weekly*, *Weekly* or *Occasionally* (less than once per week). Gleaning catch quantities were recorded according to the typical basket level of catch collected on a typical gleaning trip, categories included *Low* (1/4), *Mid* (1/2), *High* (3/4) and *Full*. Catch groups were broadly categorised as *Shells* (includes a diversity of molluscs), *Tiny fish* (schools of juvenile fish trapped at low tide), *Octopus*, *Fish* (reef fish trapped in pools and rock crevices), *Crab*, *Eel* and *Other*. In each season, the

importance of each catch group to households was categorised as *Main catch* (primary group collected by gleaners), *Caught* (collected as secondary catch group) and *Not caught* (not collected by gleaners).

3 | RESULTS

3.1 | Sample summary

In total, 131 households were surveyed, of which three were ultimately excluded because their livelihood strategies did not involve marine harvesting. Surveyed households were distributed evenly across study communities (Table 2). The final sample represented 661 individuals, with a mean household size of 5.25 and an average of 34% of household members being dependents (<11 or >60 years). All surveyed households participated in at least two different livelihood activities, all households farmed crops and this was the most important activity for 64% of households, all but one household kept

livestock, and fishing was the most important livelihood activity for 33% of households.

3.2 | Seasonal household gleaning and fishing

Gleaning was part of dynamic and heterogeneous household marine harvesting strategies (Figure 2). More households gleaned in the calm season, but the relative importance of gleaning was greater in the rough season when it was the only marine harvesting strategy for many households. In the calm season, all households did some form of marine harvesting; a majority did both gleaning and fishing or only fished, and very few only gleaned. Comparatively, in the rough season, a third of households did no marine harvesting, the number of households that fished, either solely or in combination with gleaning, dropped, and the number that only gleaned increased and this was the most common strategy. Dynamic marine harvesting strategies shape different seasonal trends in gleaning. Households that

TABLE 2 Number of households surveyed in each community

Code	A	B	C	D	E	F	G	H	Total
Village	Akrema	Urua'ana	Makili	Berau	Maquer	Atecru	Adara	Vatu'u	
Households	16	15	15	15	15	16	18	18	128

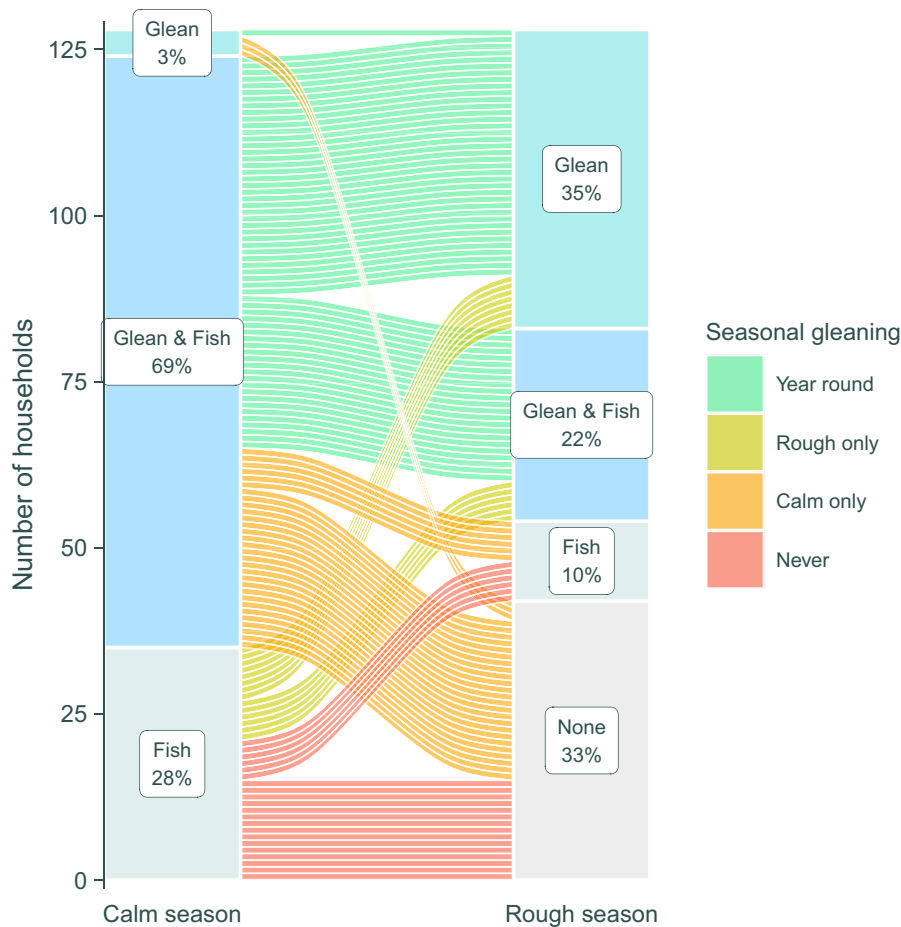


FIGURE 2 Alluvial plot illustrating household seasonal movement between marine harvesting strategies and associated gleaning seasonality. Connecting lines represent individual households

gleaned year round either maintained gleaning and fishing ($n = 23$) or gleaning only ($n = 1$) in both seasons, or specialised from gleaning and fishing in the calm season to only gleaning in the rough season ($n = 36$). Households for whom gleaning was only a rough-season activity fished in the calm season, and either switched to gleaning only ($n = 8$) or diversified to gleaning and fishing ($n = 6$) in the rough season. Households for whom gleaning was only a calm-season activity, either fished and gleaned ($n = 24$) or only gleaned ($n = 3$) in the calm season and then stopped marine harvesting ($n = 21$) or switched to fishing only ($n = 6$) in the rough season. Households that never gleaned, fished in the calm season and either continued to do so ($n = 6$) or stopped all marine harvesting ($n = 15$) in the rough season.

3.3 | Seafood consumption stability

Stability in seafood consumption between the rough and calm seasons was significantly related to seasonal gleaning ($R^2 = 0.33$). Paired comparisons show that, taking account of seasonal fishing, gleaning during the rough season matters for seasonal seafood consumption (Figure 3; Appendix 3). Consumption stability was similar among households that gleaned year round and only in the rough season,

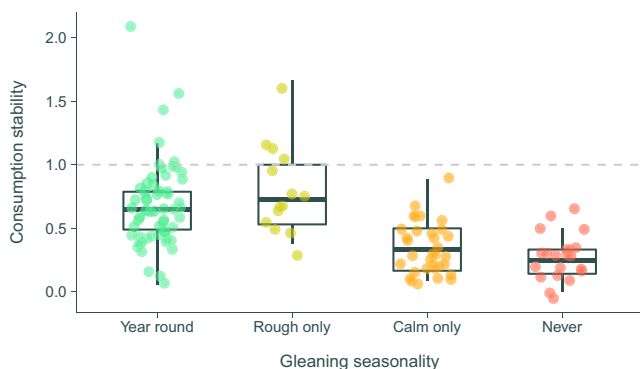


FIGURE 3 Boxplot of household seafood consumption stability according to gleaning seasonality. Dashed line represents stable consumption

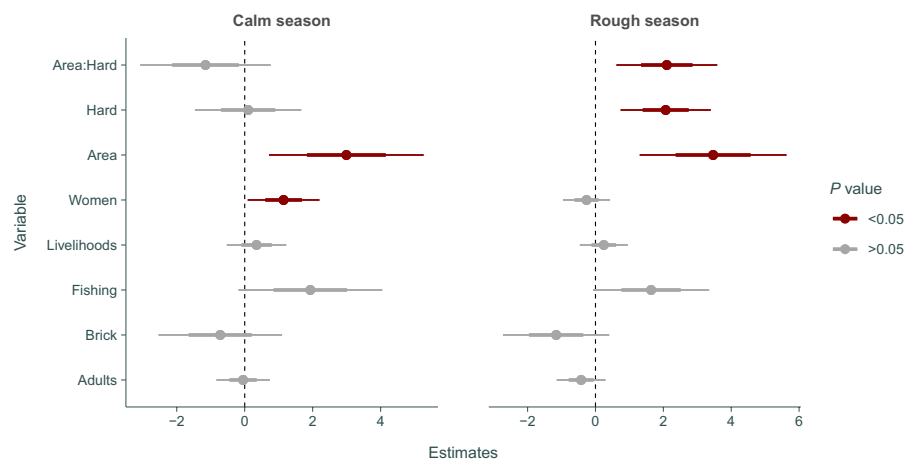
and similar amongst those who only gleaned in the calm season and those who never gleaned. Consumption was significantly more stable between seasons for households that gleaned in the rough season (*Rough only* and *Year round*) than for those who did not (*Calm only* and *Never*; *Calm only/Rough only*, $t = -3.49$, $df = 64$, $p = 0.004$; *Calm only/Year round* $t = -4.36$, $df = 109$, $p < 0.001$; *Never/Rough only* $t = -3.77$, $df = 54$, $p = 0.002$; *Never/Year round* $t = -4.37$, $df = 71$, $p < 0.001$).

3.4 | Determinants of gleaning

For the analysis of determinants of seasonal household gleaning, we excluded community H due to shortcomings in available spatial habitat data for this community. Comparing models, we found no qualitative difference between excluding (*Model A* $R^2 = 0.85$) or including (*Model B* $R^2 = 0.73$) community H, except that *Fishing* was a statistically significant driver of gleaning in the rough season in *Model B* but not *Model A* (Appendix 4). In the remainder of the paper, we focus on *Model A* only. The marginal effects of *Model A* are summarised in Figure 4 and further details are available in Appendix 4.

Seasonal household gleaning was explained mostly by spatial habitat factors (Figure 4). The odds of gleaning in the calm season were significantly and positively related to area of shallow habitat within a 2-km radius of the community (*Area* log-OR = 2.99, $p = 0.01$) and to a lesser extent the number of women in a household (*Women* log-OR = 1.14, $p = 0.034$). The odds of gleaning in the rough season were also significantly and positively related to shallow habitat area (*Area* log-OR = 3.47, $p = 0.002$) and, with slightly smaller marginal impacts, the proportion of shallow area that was hard bottomed (*Hard* log-OR = 2.07, $p = 0.002$) or the interaction between shallow area and hard-bottom coverage (*Area:Hard* log-OR = 2.10, $p = 0.002$). In both seasons, the odds of gleaning were greater for households who fished than for those who did not; however, the relationship between seasonal fishing and gleaning was not statistically significant (*Fishing* calm season log-OR = 1.93, $p = 0.074$; rough season log-OR = 1.64, $p = 0.061$). When only season and spatial habitat

FIGURE 4 Forest plot for factors effecting gleaning in the calm season and rough season, showing p values, estimate coefficients, standard errors (thick line) and 95% confidence intervals (thin line) for Model A



factors were included in the model (*Model C*, $R^2 = 0.67$), the relationship between habitat and seasonal gleaning held (Appendix 4).

The relationship between shallow habitat and gleaning is evident in the geographical distribution of community-level trends in seasonal gleaning on Atauro Island (Figure 5). Gleaning was highly seasonal on the north-eastern coast of Atauro Island (communities A, B) where all households gleaned in the calm season but many stopped during the rough season. The gently sloping, sandy littoral zone that characterises this coastline provides the largest area of shallow benthic habitat, but

only a small proportion is hard bottomed. Gleaners in these communities described it as being difficult to find seafood in the rough season because the sea gets 'dirty' as the wind and swell lead to increased turbidity and suspended solids from the soft shallow habitat. In the southern part of the island (communities C, D and E), gleaning was less common in general and also decreased in the rough season. The steep rocky coastline in this part of the island provides only a very narrow fringe of littoral habitat that is highly exposed to rough sea conditions. On the western coast (communities F and G), gleaning was widespread among households and relatively stable between seasons. The littoral zone in this area is characterised by tidal reef flats that are moderate in size and dominated by hard-bottom habitat. While in community (H) at the north-western tip of the island, gleaning increased notably in the rough season. The data suggest the shallow habitat proximate to community H was almost entirely hard-bottom shallow habitat; however, this community was not included in the model due to the limitations surrounding habitat mapping errors that mean other shallow habitat types could be more common in this area. Anecdotal evidence from informal discussions suggest that limited gleaning in the calm season by households in community H is due to time scarcity and abundant seafood associated with a highly productive fusilier (*Caesionidae* family) fishery targeted by gillnets in the calm season.

3.5 | Community gleaning trends

Gleaning trends among study communities illustrate differences in seasonal gleaning trips and catches (Figure 6). Seasonal gleaning strategies among households match the geographical trends in the number of households that glean in each season; notably, the number of households that never gleaned was highest in communities in the south (C, D and E) while the number of households who only gleaned in the rough season was highest in community H on the north-western tip (Figure 6a). Seasonal shifts in the regularity of gleaning trips amongst gleaning households also varied among communities (Figure 6b). In general, trips tended to be less regular in the rough season and the number of households that gleaned daily or multiple times a week decreased notably in the rough season in communities A (calm $n = 7$, rough $n = 2$) and B (calm $n = 11$, rough $n = 2$). Comparatively, gleaning in community H was more regular in the rough season and the number of households that gleaned multi-weekly or daily increased from none in the calm season to seven in the rough season. Typical catch quantities were greater in the calm season when more households reported high or full baskets in all communities (Figure 6c) and, in communities F and G for example, no households reported low basket levels in the calm season compared with six and five households, respectively, in the rough season. Shelled molluscs were the most widespread catch group (Figure 6d). A majority of gleaning households reported collecting shells in the calm season (88%) and the rough season (71%), and shells were commonly reported as the main catch group of gleaners, especially in the rough season. Fish and octopus were the most seasonally variable catch groups; for example, in community G, in the calm season fish and octopus were caught by 13 and 14 households,

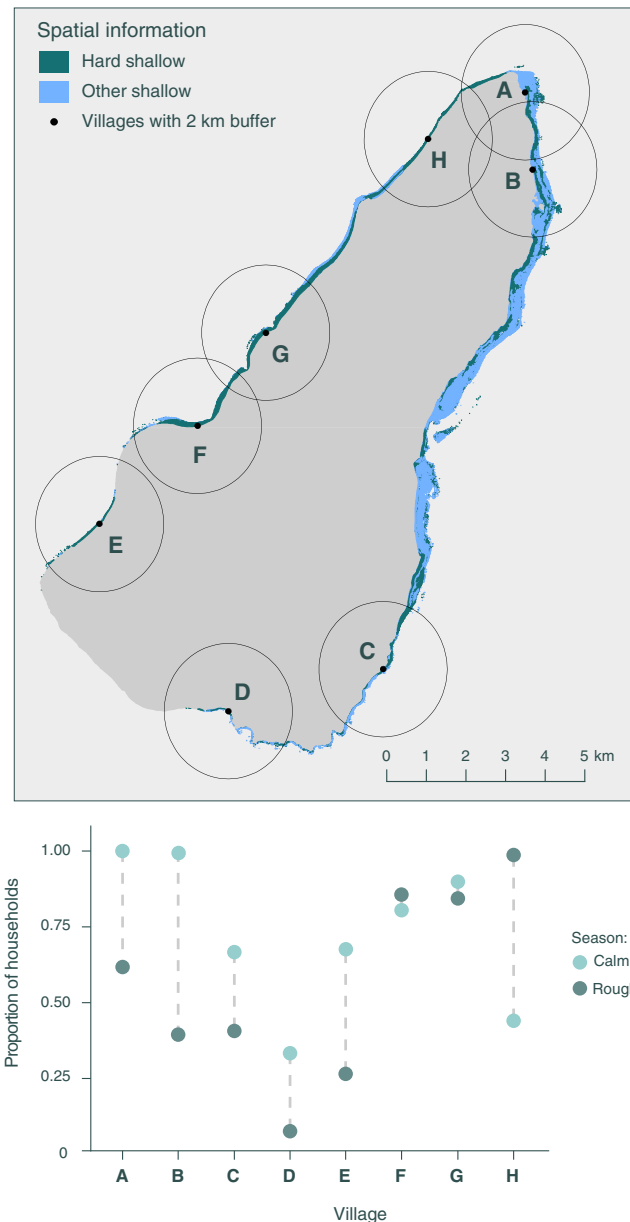


FIGURE 5 Geographical distribution of shallow habitats and community-level trends in seasonal gleaning on Atauro Island. Map showing hard-bottomed shallow habitat and other shallow habitat, including the 2-km buffer used to calculate habitat area around each community. Plot showing proportion of surveyed households that glean in each season in each community. A more detailed view of the distribution of habitats in each buffer zone is presented in Appendix 2.2



FIGURE 6 Seasonal gleaming trends by study community, including (a) seasonal gleaming participation (all surveyed households), and for gleaming households in each season, (b) regularity of gleaming trips, (c) typical catch quantity according to basket level and (d) importance of catch groups

respectively, compared with only two and three households, respectively, in the rough season.

4 | DISCUSSION

Our results reveal marked heterogeneity in seasonal household gleaming. For some households, gleaming was part of marine harvesting strategies year round while others only gleamed in particular seasons, and some not at all. Hence, despite gleaming in the rough season being associated with greater stability in seafood consumption, many households only gleamed in the calm season. As well as being more widespread,

gleaming was also a more regular activity for many households in the calm season and typical catch rates were higher. Differences in seasonal gleaming were explained predominantly by the type and extent of littoral habitat proximate to communities, meaning there were distinct spatiotemporal trends in gleaming. In both seasons, gleaming was more likely in villages with larger areas of proximate shallow habitat and, additionally in the rough season, the proportion of shallow habitat that was hard bottomed and the interaction between hard- and total shallow area were also important determinants of gleaming. These fine-grain insights of seasonal gleaming highlight the importance of studying context-specific perspectives of human–nature interactions to understand relationships between people and coastal ecosystems.

Differences through space and time in the gleaning interactions between people and littoral ecosystems likely represent differences in the relationships that shape and are derived from those interactions. For instance, increased gleaning in the rough season in community H suggests that for households in this community, seasonal interactions with littoral ecosystems are driven by a relationship of choice; gleaning was possible in the calm season but most households in community H chose not to. Comparatively, the finding that differences in seasonal gleaning among other communities were linked to shallow habitat availability indicates the influence of biophysical constraints, which likely shape different relationships between people and littoral ecosystems through space and time. It is unlikely that during the rough season, households who cannot or do not glean perceive their relationship with littoral ecosystems in the same way as those who do glean. Even for households that glean in both seasons, the human–nature relationship gleaning represents can differ seasonally. Previous research in one of the study communities where gleaning was widespread year round (community G) found that value priorities of gleaners varied between seasons, linked to differences in risk, catches and the livelihood context (Grantham et al., 2020). Understanding existing relationships between people and nature and how these influence the ways that societies interact with local ecosystems is key for legitimate environmental policy and management and ensuring sustainable futures are fair and desirable (Chan et al., 2016). Other research has highlighted the importance of context-specific assessments to account for socio-cultural dimensions of relational values (Chan et al., 2012; Klain et al., 2014), particularly to support nuanced assessments of nature's contributions to people (Díaz et al., 2018). Although our analysis does not attend directly to relational values, our findings provide valuable insights about the dynamic relationships between coastal communities and local ecosystems and further support the need for in situ perspectives. Characterising coastal social-ecological interactions requires accounting for spatial and temporal dynamics at scales relevant to fisher decision-making (Moreno-Báez et al., 2012). Specifically, the finding that the biophysical environment can constrain and enable seasonal coastal human–nature interactions, such as gleaning, has important implications for evaluating patterns of resource use, factors mediating benefit access and limits to adaptation. We discuss each of these three points in detail in the following paragraphs.

4.1 | Resource use

Seasonal gleaning trends characterise spatial and temporal unevenness in the gleaning pressure exerted on littoral ecosystems. In coastal areas where gleaning is common year round, littoral ecosystems are exposed to consistent gleaning pressure whereas in areas where gleaning is seasonal, the pressure on littoral ecosystems is more periodic. The greater regularity of gleaning and higher typical catch quantities in the calm season further suggest that in many communities the intensity of the pressure on littoral ecosystems is also seasonally dependent. Ecological assessments of the study

sites were beyond the scope of this research, but our results suggest that, in some locations, the rough season acts as a de facto closed season in the littoral zone, which may have localised sustainability implications through allowing recovery of harvested populations. Assessments of the effects of periodic harvesting in fisheries suggest that intermittent (as opposed to sustained) fishing pressure can have benefits for target species (Bartlett et al., 2009), particularly if closures correspond with key lifecycle stages (Cohen & Foale, 2013). Even short-term closures have been found to support some degree of population recovery for species targeted by gleaners, including shelled molluscs, crabs, octopus and reef fish (Bartlett et al., 2009; Cohen & Alexander, 2013; Oliver et al., 2015). The long-term influence of gleaning on target species populations is uncertain; gleaning has been an important subsistence strategy throughout human history and historic shell middens show changes through time in the abundance and size of gleaned species, which some argue are indicative of over-exploitation while others attribute these changes to underlying environmental conditions (Coddling et al., 2014). Our results suggest that research concerned with human impacts on coastal ecosystems would benefit from evaluations that capture determinants of human–nature interactions at fine grain resolutions to support a more nuanced understanding of the pressure exerted on coastal resources by local communities through space and time. The integration of spatial habitat data with temporally sensitive social data in this research demonstrates the strength of mixed-method approaches for understanding how the biophysical environment influences dynamic human–nature interactions, including seasonal gleaning.

4.2 | Factors mediating access

Weather and the biophysical environment were found to mediate gleaning, thereby influencing access to benefits from littoral ecosystems through space and time. Access, defined as 'the ability to derive benefits from things' (Ribot & Peluso, 2003), determines how various resource users differently benefit from coastal ecosystems and is dependent on context-specific mechanisms (Hicks & Cinner, 2014). We found that household gleaning was dependent on the interaction between season and shallow habitat, which our results suggest was because wave attenuation and water clarity are important for gleaning, particularly in the rough season. Therefore, among communities access to benefits from littoral ecosystems was differently sensitive to sea conditions according to the proximate biophysical environment. Weather-related risks affect fisher decision-making (Pfeiffer, 2020) and poor understanding of behavioural responses of fishers to weather is a key limitation in assessing vulnerabilities of capture fisheries to climate change (Sainsbury et al., 2018). Our findings demonstrate that for gleaning fisheries, strengthening understanding of spatial drivers of access through time may help unpack factors that determine responses to weather conditions.

We also found a positive relationship between gleaning and other types of fishing that may reflect shared dependencies between activities. In both seasons, the odds of gleaning were notably

higher for households that fished than those who did not, although no statistically significant relationship was found between seasonal fishing and gleaning. These results do not support the expectation that gleaning and fishing would interact as complementary activities (described in factor selection for models) with alternating seasonal dynamics. We hypothesise that the positive relationship between fishing and gleaning could reflect the benefits of swell protection for both activities. The sensitivity of fishing methods and habitat use to adverse weather and sea conditions has been highlighted by research in other small-scale fisheries (e.g. Gill et al., 2019; Siar, 2003). If wave attenuation is a shared driver of fishing and gleaning, we can expect the ecosystem benefits accessed through those activities will occur in 'bundles'. In the context of ecosystem services, bundles refer to services or benefits that co-occur repeatedly through space and time (Raudsepp-Hearne et al., 2010). The mechanisms that link bundles create potential co-benefits or trade-offs in ecosystem services derived from social-ecological system management and change (Bennett et al., 2009). For instance, shared dependencies between fishing and gleaning point to potential common vulnerabilities; in communities where increased storminess would have adverse impacts on gleaning, other types of fisheries may also be negatively affected having compound consequences for seafood access. Thus, understanding how the biophysical environment mediates seasonal access to bundles of coastal ecosystem benefits, such as seafood from different types of fishing, is essential for evaluating the impacts of climate change on local communities.

4.3 | Limits to adaptation

Spatial determinants of seasonal gleaning represent context-specific limits to human–nature interactions and, by extension, how they benefit people through space and time. Although gleaning in the rough season was linked to greater seasonal stability in seafood consumption, many households only gleaned in the calm season indicating gleaning was either undesirable or not feasible during the rough season, which our analysis linked to accessible coastal habitat. Therefore, although gleaning was a livelihood strategy for these households it did not provide a steady source of seafood to smooth consumption fluctuations, as has been found elsewhere in Timor-Leste (Tilley et al., 2020). These findings have important implications for understanding geographically disaggregated experiences of seasonality and heterogeneity in the dynamic function of fisheries to coastal livelihoods (Carter & Garaway, 2014). Seasonal food scarcity is the greatest cause of acute hunger and malnutrition globally (Vaitla et al., 2009) and coping with seasonal hunger often lies at the heart of deeper poverty cycles (Devereux et al., 2008). Thus, lean seasons represent a critical time window in the livelihoods of the rural poor. In Timor-Leste, similar to many countries in the Global South, the rural poor experience an annual lean season driven by cycles in subsistence agriculture (Erskine et al., 2014), which on Atauro Island also corresponds with the main rough season. Hence, links alluded to between littoral habitat,

seasonal gleaning and seafood consumption highlight how spatial factors mediate access to benefits from littoral ecosystems during this critical time window, even within the context of one small island. Small-scale fisheries are important sources of subsistence seafood in the Pacific (Charlton et al., 2016), and although seafood consumption is lower in Timor-Leste than other Pacific Island countries and territories, seafood is the main animal protein consumed and a source of vital micronutrients in coastal communities (López Angarita et al., 2019), including in the study communities. Our results demonstrate how temporal aspects of access affect the ability of households to benefit from littoral ecosystems as a source of seafood during periods of food scarcity. These findings support other research that has highlighted how spatial factors determine the ability of small-scale fishers to adapt to normal environmental variability (Sievanen, 2014) and the importance of understanding how dynamic mechanisms of access determine who benefits from coastal ecosystem services (Daw et al., 2011), including as a source of food security (Foale et al., 2013).

5 | CONCLUSION

Using the case study of gleaning in a small-island, low-income country context, this research begins to disentangle the complexities of coastal human–nature interactions at fine spatial and temporal resolutions. We found that constraints and opportunities created by the type and extent of shallow habitat influence how people interact with littoral ecosystems across seasons. Relationships between communities and coastal ecosystems, such as those supported by gleaning, cannot therefore be assumed to be homogeneous through space and time. Particularly in the context of rural communities in the Global South, accounting for dynamics in coastal human–nature interactions and the factors determining when livelihood activities are feasible and desirable is important for evaluating social impacts of climate change. This research demonstrates the insights that can be gained from integrating spatial-habitat and social data to support place-based understanding of how and why people use and interact with coastal ecosystems differently through time. Our findings reveal heterogeneity in how households interact with littoral ecosystems through gleaning and highlight the need for context specific and dynamic perspectives of the contribution of coastal environments to local communities.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

R.G. conceived the research ideas, designed the methodology, collected primary household data and led the writing of the manuscript; R.G., C.R. and J.G.A.-R. analysed the data. All authors contributed critically to drafts of the manuscript, including the theoretical grounding of the paper and agreed to the final version submitted for publication.

DATA AVAILABILITY STATEMENT

Benthic habitat data used in this study were sourced from NOAA and are available at: https://www.nodc.noaa.gov/archive/arc0117/0168914/1.1/data/0-data/Benthic_Habitat_Timor/Atauro/mosaic_wgs84/. Household survey data will be available from the James Cook University Tropical data hub from June 2021, <https://doi.org/10.25903/5ACK-7435> (Grantham, 2021).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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