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Beyond 'Stay or Go': How coastal communities respond to sea-level rise

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Abstract

Coastal communities worldwide face intensifying climate hazards, yet household-level responses to sea-level rise remain poorly documented. While climate-induced mobility is often framed as a binary choice between staying or leaving, this simplification obscures the diverse strategies households actually employ. This study provides household-level evidence on how coastal communities in Bohol, Philippines, respond to chronic tidal flooding driven by earthquake-induced land subsidence, effectively simulating accelerated sea-level rise. Combining a household survey (N=647) with key informant interviews (N=27) across four municipalities varying in subsidence and flood exposure, we document a spectrum of mobility responses operating simultaneously within communities and households: temporary evacuation, short-distance relocation, labour migration, and immobility. In-situ adaptations — including house elevation, livelihood diversification, and nature-based solutions — are widespread but face limits in the most exposed areas, where some strategies risk becoming maladaptive by locking

households into cycles of debt and repeated loss. Willingness to relocate reaches up to 70% in subsided municipalities, and is shaped by high exposure to flooding and perceived long-term impacts from sea-level rise. Yet significant barriers persist, including livelihood dependence, financial constraints, and delays in government relocation programmes, which create conditions characteristic of trapped populations. Labour migration, concentrated among younger household members, emerges as a critical risk diversification strategy, supported by remittances that buffer climate-sensitive livelihoods, though this may concentrate vulnerability among elderly residents who remain. These findings challenge the simplified "stay or go" narratives of climate mobility and underscore the need for integrated policies that recognise mobility as a legitimate adaptation strategy while addressing the financial, livelihood, and institutional constraints that impede dignified anticipatory movement.

Keywords: Climate Mobility, Adaptation, Sea-Level Rise, Coastal Flooding, Planned Relocation, Trapped Populations, Household Survey, Philippines

1 Introduction

Coastal areas worldwide are facing intensifying risks as the climate changes. Rising sea levels, increasing storm intensity, shifting rainfall patterns and tidal regimes are driving more frequent and severe coastal flooding, erosion, and saltwater intrusion [1]. These hazards threaten the lives, livelihoods, property and infrastructure of hundreds of millions of people who live within low-lying coastal zones, increasingly shaping where and how people live [2, 3]. A growing body of research shows that mobility responses to coastal hazards span a spectrum of outcomes, ranging from short-term evacuation to long-distance migration and planned relocation [4–8]. In this context, mobility is understood as the full spectrum of population movement in response to environmental change, ranging from temporary, seasonal, and circular movements to permanent migration and planned relocation [9, 10]. Conversely, immobility refers to situations in which people remain in place despite environmental risk, whether by choice ("voluntary immobility") or due to constraints that limit their ability to move ("involuntary immobility" or "trapped populations") [9, 11, 12]. The dominant narrative surrounding climate mobility often reduces a complex phenomenon to a binary choice between "staying" and "going." This simplification — common in media discourse, policy debates, and even scientific projections — obscures the diverse and dynamic mobility strategies households actually employ [7, 13–15]. These varied strategies reflect not only differential levels of hazard exposure, but also the capabilities and aspirations of households, shaped by social, economic, institutional, and cultural factors that mediate whether mobility becomes possible, desirable, or constrained [12, 16, 17].

There is a pronounced lack of empirical household-level evidence on the mobility responses of populations in coping with and adapting to climate impacts [4, 6, 8, 15, 18]. This gap is particularly acute for slow-onset events, such as sea-level rise [8, 18], where impacts unfold gradually over time and lack historical analogues. While the most severe impacts of sea-level rise will unfold over coming decades [1], its effects —

such as recurrent coastal flooding, erosion of land, and soil salinisation — are already a destructive reality for frontline communities [5]. Yet, the behaviours, preferences, and constraints of these populations remain inadequately documented. While large-scale modelling studies have highlighted broad patterns of climate displacement and migration, including movements driven by sea-level rise [19–23], mobility decisions are ultimately made at individual, household or community levels [24–27]. These decisions are shaped by factors such as risk perceptions, access to resources, livelihood dependence, and social ties, which cannot be adequately captured by aggregate models [13, 15, 25, 28]. While stated-preference surveys offer insights into hypothetical intentions under sea-level rise scenarios [29–32], there remains a critical gap in studies documenting revealed preferences and behaviours, i.e. how households actually behave when confronted with observable, ongoing sea-level rise [7]. Therefore, studying the early-impact zones of sea-level rise will provide an invaluable window into the adaptation challenges that will confront millions of coastal residents in the coming decades.

This study addresses these gaps by providing household-level, revealed-preference evidence on how coastal communities in Bohol currently respond to recurrent coastal flooding and extreme events in the context of sea-level rise. Bohol, an island province in the Central Visayas region of the Philippines, presents a unique and analytically valuable case study for examining household responses to sea-level rise. Following a Mw 7.2 earthquake in 2013, land subsidence of up to 1m in the island's northwest caused a rapid increase in relative sea level [33], transforming previously manageable high tides into chronic and disruptive coastal flooding. In contrast, other municipalities on the island did not experience comparable subsidence and experience lower levels of flooding. This spatial variation creates a rare opportunity to examine how households respond to different stages and intensities of sea-level rise within similar socio-cultural, economic, and institutional contexts. In effect, earthquake-induced subsidence in parts of Bohol functions as a rapid, real-world simulation of long-term sea-level rise, allowing us to observe how adaptation, mobility, and relocation preferences evolve as coastal risk accelerates.

To capture these dynamics, we combine a comprehensive household survey (N = 647) with key informant interviews (N = 27) across four municipalities that vary in subsidence levels, flood exposure, and livelihood dependence on coastal resources. We examine how households simultaneously navigate chronic flooding and acute shocks, most notably Typhoon Rai, which caused widespread destruction across the region in 2021. In particular, we investigate how households adapt in-situ, how they engage in different forms of mobility, the factors shaping willingness or ability to relocate, and how constraints produce involuntary immobility or trapped populations.

This paper makes four key contributions to the literature on climate mobility. First, by documenting revealed preferences and mobility behaviours – and where households have not relocated, conditional stated willingness to do so – the paper provides empirical grounding for understanding how households actually behave under ongoing sea-level rise. Second, we show that mobility is not a binary 'stay or go' decision but a continuum spanning temporary evacuation, short-distance relocation, labour migration, planned relocation, and immobility, shaped by intra-household dynamics

of age and gender. Third, we identify clear hard and soft limits to in-situ adaptation, with widespread strategies such as house elevation and debt-financed reconstruction becoming maladaptive in the most exposed areas. Fourth, we demonstrate that high willingness to relocate coexists with significant barriers, such as livelihood dependence, financial constraints, and delayed government relocation programmes, producing trapped populations whose vulnerability deepens with each successive hazard event. Together, these findings inform more realistic and equitable approaches to climate adaptation that recognise mobility as a legitimate but often constrained risk management strategy.

While sea-level rise in Bohol at present has largely been through earthquake-induced subsidence, the resulting hazard profile closely mirrors conditions projected for low-lying coastal communities under medium-to-high sea-level rise scenarios: chronic tidal inundation at frequencies and depths that exceed household coping thresholds, compounding acute storm events, and spatial constraints on in-situ retreat. Communities currently experiencing early-stage sea-level rise impacts in deltaic and atoll settings face structurally similar combinations of chronic flooding, livelihood exposure, and constrained mobility [3, 8, 18]. The Bohol case therefore functions as an empirical window into dynamics that will become increasingly widespread as sea levels rise, though readers should note that the abruptness of subsidence-driven exposure compresses adaptive response timescales relative to the more gradual — but ultimately equally consequential — accumulation of eustatic sea-level rise.

2 Results

Our analysis focuses on four municipalities in Bohol — Tubigon, Inabanga, Lila, and Alburquerque — representing a gradient of coastal hazard exposure (Figure 1a). Tubigon contains a cluster of highly exposed island barangays (the smallest administrative division in the Philippines) a few kilometres from the mainland (Figure 1b), which subsided following the 2013 earthquake and now experience some of the most frequent tidal flooding in Bohol. Inabanga also subsided significantly and faces recurrent inundation along its coastal mainland barangays. Lila and Alburquerque exhibit comparatively lower flooding levels, providing useful contrast. This spatial variation enables examination of how household adaptation and mobility responses are differentiated by the level of flooding experienced.

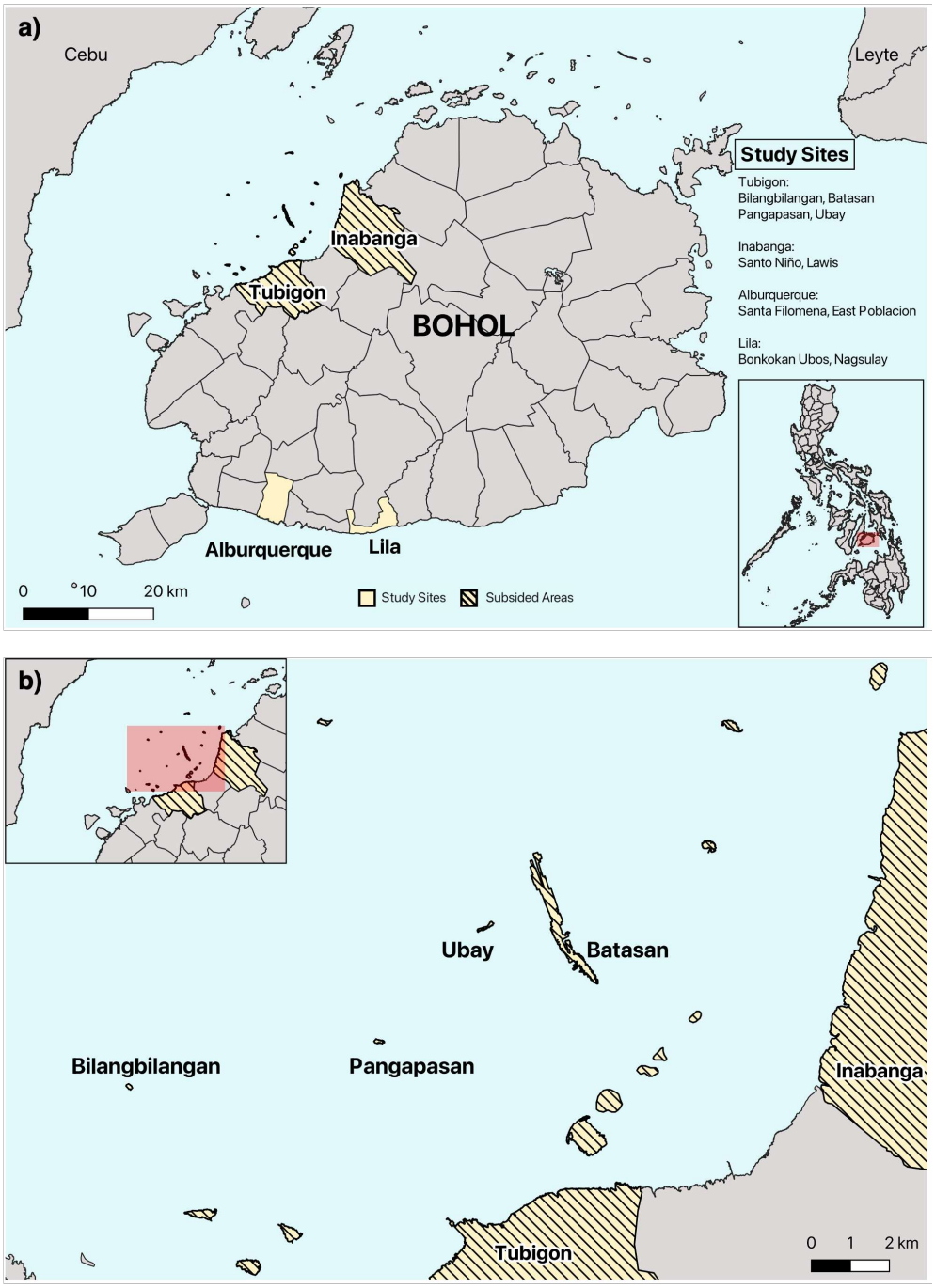


Fig. 1 Map of study sites in Bohol, Philippines showing a) location of the four surveyed municipalities — Tubigon, Inabanga, Lila, and Alburquerque - with hatched areas representing the municipalities that subsided during the 2013 Mw 7.2 and b) island barangays of Tubigon - Bilangbilangan, Pangapasan, Ubay, and Batasan

2.1 Hazard context: Compounding impacts of chronic flooding and acute shocks shaping households responses

Surveyed households face two distinct but interacting hazards in the form of chronic coastal flooding driven by post-earthquake subsidence, and acute shocks from tropical storms, with Typhoon Rai (2021) being the most notable recent destructive event. This distinction between rapid-onset and slow-onset hazards is critical for understanding differential impacts, with some studies indicating that recurrent coastal flooding can be equally or more damaging than extreme events [34, 35].

2.1.1 Earthquake-induced subsidence has transformed coastal flooding from episodic to chronic

The 2013 earthquake triggered land subsidence of up to 1m across Bohol's northwest municipalities. This subsidence fundamentally altered the intensity and frequency of flooding, with 91% of households in Tubigon and 86% in Inabanga now experiencing regular coastal flooding, compared with 21% in Lila and 14% in Alburquerque, where there was no subsidence. KIIs confirmed that flooding before the earthquake was minimal and rain-driven. Now, tides of just 1.7m cause water to enter homes and schools, flood roads, and block access to barangays — conditions that previously occurred when tides exceeded 2.7m. Flooding occurs year-round but is highest from June-December, which coincides with the Southwest Monsoon (June–September) and Northeast Monsoon (October to March), with some communities flooded for up to a week at a time. A previous study in the island barangays of Tubigon found that they are flooded for 44-135 days of the year, with flood heights ranging 20-43cm and lasting 2.6-3.9h a day [36]. Further details on flooding dynamics, physical impacts (e.g. housing damage, saltwater intrusion), and non-physical impacts (e.g. income loss, water contamination, psychological stress) are provided in Supplementary Information.

2.1.2 Typhoon Rai compounded chronic stressors, with lasting impacts on households

Typhoon Rai (2021) affected 97% of surveyed households, with impacts concentrated in subsided municipalities. Maximum flood depths during the typhoon averaged 170cm in Tubigon and 115cm in Inabanga, compared with 86cm in Lila and 46cm in Alburquerque. Housing damage was significantly higher in Tubigon and Inabanga, as was destruction of livelihood assets, particularly fishing boats critical to local economies.

Three years post-Rai, most households had not completed home repairs (∼80% in Inabanga and Tubigon; ∼60% in Lila and Alburquerque), with 98% these households citing financial constraints as the main reason for incomplete repairs. The average repair cost (₱60,000) far exceeded government assistance (₱5,000–10,000), which coupled with delays in receiving these payouts lead many residents to resort to high-interest micro-loans. With average monthly incomes of ₱5,000–7,000 against expenditures of ₱8,000–10,000, many households remain in debt. One informant mentioned that the residents were "not drowned by the typhoon, but are being drowned by debt". This debt burden has direct implications for adaptive capacity as it depletes financial reserves. Low-income households are known to be disproportionately affected

by natural hazards and disaster-induced debt has been shown to create long-term poverty traps, reducing households' resilience and capacity to cope with future shocks [37–39].

Between third to half of households (depending on the municipality) reported income losses, which on average lasted 10 months. Over 40% of households in most municipalities modified their livelihoods post-Rai, often shifting from fishing to aquaculture or to wage labour. The typhoon also fundamentally altered risk perceptions, with the majority of households now reporting they would evacuate immediately upon receiving typhoon warnings, a marked shift from behaviour during Typhoon Rai when many (particularly men) remained to protect property. Further details on typhoon impacts, recovery trajectories, and changes in risk perception are provided in Supplementary Information.

2.2 In-situ adaptation strategies are widely adopted, but have notable limits

Households in Bohol demonstrate multi-layered adaptation strategies in response to coastal flooding. Our findings document a progression from immediate coping measures to more sustained structural and livelihood adaptations. However, many of these strategies risk becoming what the adaptation literature increasingly recognises as "maladaptation" — actions that may reduce vulnerability in the short term but inadvertently increase it over the long term [40–42]. We organise our findings around four categories of in-situ adaptation - structural measures, livelihood diversification, nature-based solutions, and financial coping strategies (Table 1).

Structural measures are the most commonly reported adaptation strategy, with 77% of all surveyed households reporting that they have elevated their homes. KIIs revealed that in subsided areas elevating houses became a necessity after the 2013 earthquake, with residents raising floor levels above the highest observed tide lines. Beyond elevation, households employ lower-cost protective measures such as sandbags, makeshift barriers, and temporarily relocating valuables during flood events. Households are also preparing for future typhoons by retrofitting their houses, stockpiling food and water supplies, and creating household emergency plans. Examples of structural adaptation measures are shown in Figure 2. At the institutional level, local governments have designated no-build zones in the most hazard-prone coastal areas, intended to prevent reconstruction in locations with repeated flood damage.

Livelihood diversification has accelerated in response to both chronic flooding and the acute shock of Typhoon Rai. Over 40% of households reported changing or diversifying their income sources since the typhoon, with rates highest in the most flood-affected municipalities. Many fishing households have shifted to aquaculture (fish and oyster farming) or land-based employment such as daily wage labour as tricycle drivers or in construction. KIIs highlighted that in Sto. Niño (Inabanga), where 75% of the population were fishermen before Rai, only 25% remained in the profession after the typhoon, adding that fishing was no longer a reliable source of income following Typhoon Rai due to declining catch. Community-led initiatives have also emerged, including ecotourism ventures such as mangrove kayaking in Batasan (Tubigon) and whale shark watching in Lila.

Table 1 Summary of in-situ adaptation strategies adopted by households and their limitations.

Category	Description
Structural Measures	**Examples:** House elevation, sandbags, retrofitting, sea walls, no-build zones **Prevalence:** 77% of households have elevated homes; no-build zones in most highly exposed coastal barangays **Limitations:** Elevated homes still flooded during spring tides or monsoons; seawalls incomplete and routinely overtopped; no-build zones ineffective due to livelihood dependence on coast
Livelihood Diversification	**Examples:** Shift to aquaculture, wage labour, ecotourism, and reliance on remittances **Prevalence:** 40% have diversified their income sources since Typhoon Rai; 24% of households receive remittances **Limitations:** Alternative livelihoods often seasonal or generate insufficient income
Nature-based Solutions	**Examples:** Mangrove planting, coastal vegetation restoration **Prevalence:** Government- and community-led initiatives in all surveyed municipalities **Limitations:** High seedling mortality, limited availability of planting sites, protection only up to certain thresholds
Financial Coping	**Examples:** High-interest micro-loans **Prevalence:** Widespread borrowing post-Rai; average repair costs far exceed government assistance **Limitations:** High-interest debt depletes reserves, limits future adaptive capacity, and risk maladaptation

Critically, households increasingly depend on remittances from family members working in urban centres or overseas as a risk diversification strategy. 24% of households reported receiving remittances from family members, with rates highest in Tubigon at 39%. These financial flows provide a stable buffer that is decoupled from local climate shocks, enabling households to afford in-situ adaptations like house elevation and to weather periods when fishing is halted, which is common during monsoons. A growing body of evidence demonstrates that remittances buffer against climate shocks and disasters, with remittances known to increase following acute shocks, and households receiving remittances showing greater resilience and faster recovery [43–47].

Nature-based solutions (NbS), particularly mangrove planting, represent another common adaptation strategy. Motivation for NbS was strongly reinforced by Typhoon Rai, with communities observing first-hand the protective benefits of intact mangrove stands. KIIs in multiple barangays described how areas fringed by mangroves experienced less damage from the typhoon than those without. This experience has spurred both government- and community-led planting initiatives in all the surveyed municipalities. In Lila and Alburquerque, the Greening Disaster Risk Reduction project implemented by the Philippine Red Cross and American Red Cross [48] has provided community training for the adoption of NbS and established mangrove nurseries. However, KIIs also highlighted significant technical challenges such as high seedling mortality due to unsuitable soil conditions and wave exposure, limited availability of

suitable planting sites, and the time required for mangroves to mature to a size where they provide meaningful protection.

Despite their importance, in-situ strategies face fundamental constraints on their effectiveness. Following [42], we distinguish between soft limits — those potentially surmountable with additional resources or policy support — and hard limits that are biophysical and may be insurmountable regardless of investment. Soft limits are pervasive, with financial constraints preventing households from affording adequate structural protection, while institutional gaps leave seawalls incomplete or poorly maintained. KIIs reported that existing structural defences are routinely overtopped, with seawalls and dykes present only in small sections of the coastline. No-build zones implemented in several barangays have had limited effectiveness as households continue to rebuild in hazardous areas due to strong livelihood dependence on fishing, perpetuating a cycle of risk. Hard limits are most starkly evident in Tubigon's island barangays, which range between 1.5–6 ha in area with maximum elevations of just 2m. There is effectively no higher ground to which households can retreat. Even elevated homes are now routinely flooded during spring tides and severe monsoon seasons, with floodwaters reaching knee- or hip-levels of adults, while roads and schools remain regularly inundated. Mangrove planting, while beneficial, is similarly constrained by ecological suitability and offers protection only up to certain thresholds of wave energy and inundation depth.

Where limits are encountered, in-situ adaptation risks becoming maladaptive, increasing rather than reducing vulnerability [40]. Two patterns illustrate this dynamic. First, as documented in Section 2.1, many households financed post-Rai reconstruction through high-interest micro-loans, as average repair costs far exceeded government assistance. This debt burden depletes reserves that might otherwise support future adaptation or enable relocation, effectively locking households into high-risk locations. Second, despite the designation of no-build zones in several barangays, households continue to rebuild in these hazardous areas due to livelihood dependence on fishing and lack of viable relocation options. Both patterns represent "rebounding vulnerability" [40], whereby short-term coping adaptation strategies increase future exposure to climate impacts.

Taken together, these findings reveal that while autonomous household-level adaptation is widespread and resourceful, it can only mitigate, not eliminate, the risk of coastal flooding. For the most exposed communities, particularly the island barangays of Tubigon, the limits of in-situ adaptation may already have been reached. These constraints help explain why, despite widespread efforts to adapt in place, a significant proportion of households express willingness to relocate — a theme we explore in the following section.



Fig. 2 Photographs showing examples of structural adaptation measures in Bohol. a) Seawall in Lawis; b) Seawall in Bilangbilangan island; c) Coral structures repurposed as barriers against flooding and erosion in Bilangbilangan island; d) Elevated house in Pangapasan island; (e) Mangrove forest surrounding Batasan island, spanning 54ha; f) Elevated house in Lawis.

2.3 Households navigate a complex mobility continuum in response to coastal hazards

Our findings reveal that households employ a spectrum of mobility strategies in response to coastal hazards, from temporary displacement to permanent relocation, proactive labour migration, and immobility. Crucially, we observe all forms of this continuum operating simultaneously within the same communities and even within households, with individual households navigating multiple mobility types over time or through different household members. These mobility responses are shaped not only by hazard exposure but also by various other factors, such as household composition, livelihood dependencies, and institutional context, all of which can either enable or constrain movement. These mobility types are summarised in Figure 3 and Table 2, and elaborated upon in the following sections.

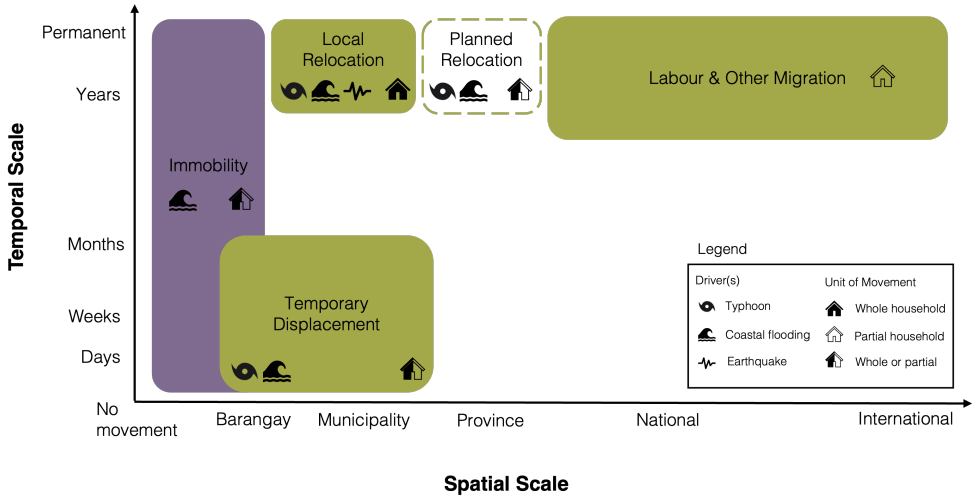


Fig. 3 Typology of observed mobility responses to coastal hazards in Bohol, mapped by spatial and temporal scale. Icons indicate the hazard drivers associated with each mobility type and the unit of movement. Immobility spans across temporal scales, coloured in purple, and mobility types are coloured in green. Dashed borders for Planned Relocation indicate intended rather than realised movement.

2.3.1 Temporary movements are a widespread and recurring adaptation strategy

Temporary evacuations and displacements have commonly been observed in response to rapid-onset hazards, such as typhoons [4, 49, 50]. Similarly we found that during Typhoon Rai, 66% of households reported having to move temporarily. Of this group, 57% of households evacuated to designated evacuation shelters, 26% stayed with family and 15% stayed with friends. These moves were all short-distance within

Table 2 Typology of observed mobility responses to coastal hazards in Bohol, describing the drivers of each type of mobility, the spatial and temporal scale, and empirical evidence from the study.

Type	Description
Temporary Displacement	**Drivers:** Typhoon, coastal flooding **Temporal scale:** Days to weeks **Spatial scale:** Local (same barangay or municipality) **Unit of movement:** Whole household or partial **Evidence:** 66% of respondents displaced during Rai; median displacement 1–3 days, some up to 1 month; 16% displaced during recurrent flooding; 15% report men stay behind to protect property.
Local Relocation	**Drivers:** Typhoon, coastal flooding, earthquake **Temporal scale:** Permanent **Spatial scale:** Local (same barangay) **Unit of movement:** Whole household **Evidence:** 5% relocated due to earthquake; 3% due to Rai; up to 24% due to coastal flooding in some municipalities.
Planned Relocation	**Drivers:** Typhoon, coastal flooding **Temporal scale:** Permanent **Spatial scale:** Local (likely same municipality) **Unit of movement:** Whole household or partial **Evidence:** 39–70% express willingness to relocate if flooding worsens. Government relocation sites planned in Tubigon and Inabanga.
Immobility	**Drivers:** Coastal flooding **Temporal scale:** – **Spatial scale:** – **Unit of movement:** Whole household or partial **Evidence:** High willingness to relocate but major barriers exist - chiefly livelihood dependency, lack of funds and institutional delays in relocation programmes.
Labour & Other Migration	**Drivers:** Education, work, marriage **Temporal scale:** Long-term / permanent **Spatial scale:** Local, regional, international **Unit of movement:** Partial (typically youth/young adults) **Evidence:** 19% of households have migrant members. Movements driven by education, jobs and marriage; destinations range from same municipality to other provinces and overseas. Remittances and mobility networks contribute to income diversification and adaptive capacity.

the same baranagay or municipality. While median displacement lasted 1-3 days, a sizeable number of households (7% in Inabanga and 13% in Tubigon) were displaced for a month or longer. Critically, return did not signify recovery. Many households prioritised rebuilding their boats over their homes to resume fishing livelihoods, and in the interim lived in tents or makeshift shelters close to their homes, which went on for months for some households. Phased recovery and protracted displacement in this manner is prevalent yet under-recognised in post-disaster contexts, and the duration of displacement needs to be factored to comprehensively capture the impact of extreme events on households [50, 51].

We found that this pattern of temporary movement is not confined to rapid-onset events but is also a repeated coping strategy for the recurrent coastal flooding experienced by households. 16% of households reported that they temporarily relocate when coastal flooding occurs. Among these households, the dynamics of these movements are similar to that observed during Typhoon Rai, with 65% of households evacuating to designated evacuation shelters, 35% staying with family and 18% staying with friends (percentages are over 100% because households evacuate to combinations of these locations), again short-distance within the same baranagay or municipality.

These temporary movements exhibit gendered dynamics, with 15% of households reporting that men stay behind during evacuations to protect property and assets while women, children, and elderly members evacuated. Such risk-taking behaviour has been found to cause higher mortality rates among men during typhoons in the Philippines [52], and aligns with broader evidence on gendered responses in disaster settings [53, 54]. This gendered pattern creates differential exposure within households, with implications for how we conceptualise household-level vulnerability and mobility outcomes.

These findings highlight that temporary movement is not a singular response to extreme events, but a recurring and embedded adaptation strategy. As coastal flooding becomes increasingly chronic, these short-distance, short-duration movements serve as a critical means of coping with and managing risk.

2.3.2 Relocation has been triggered by hazards but remains highly localised

Relocation has also emerged as a direct consequence of these hazards, though its pattern is one of localised retreat rather than long-distance migration. 5% of households reported that they relocated due to the earthquake, and 3% due to Typhoon Rai. Coastal flooding has also triggered the relocation of 4% of households in Lila, 23% in Tubigon and 24% in Inabanga. Survey and KII data confirm that these moves were overwhelmingly triggered by hazard-induced destruction of homes and the perceived danger of previous locations. These relocations have been predominantly short-distance, confined within the same barangay. This pattern of highly localised relocation reflects both the strong place-based nature of coastal livelihoods and the limited availability of alternative sites within reach of fishing grounds. However, these localised moves may not adequately reduce the exposure of households to coastal hazards. Particularly in the case of the island barangays of Tubigon, which range between 1.5-6 ha in area and a maximum elevation of 2m, there is hardly any retreat that is possible within the islands. This spatial constraint, coupled with livelihood dependence on coastal resources, means that even households who have relocated may remain highly exposed to future hazards.

2.3.3 Willingness to relocate is high, but capacity remains constrained

While households are predominantly employing in-situ adaption measures in response to coastal flooding (see section 2.2), there is a high degree of willingness to relocate

in the future if flood levels worsen. This willingness is highest in the municipalities of Inabanga (70%) and Tubigon (66%), which were most severely affected by land subsidence and chronic coastal flooding, compared to 53% in Lila and 39% in Alburquerque (Figure 4a). These patterns suggest that households are increasingly aware of the long-term risks posed by relative sea-level rise and recognise the limitations of current in-situ adaptation strategies.

A LASSO logistic regression model identified key factors associated with the willingness to relocate. Details on the model development can be found in Section 4 and model performance statistics are in Supplementary Information. The strongest predictor of relocation willingness was the perceived impact of sea-level rise over a 50-year time horizon (OR = 3.99, 95% CI: 2.81–5.71, $p < 0.001$), with households who perceived large long-term impacts having roughly four times the odds of expressing willingness to relocate (Figure 4b). This influence of risk perception on the willingness to relocate is consistent with previous studies showing that perceived impacts of future sea level changes influences migration intentions [18], particularly through perceived threats to livelihoods and emotional reactions such as worry and fear [55]. In Bohol, KIIs routinely highlighted that residents are acutely aware of climate change and its impacts, with many residents expressing worry about extreme events and flooding, and the impacts on their safety and livelihood. Previous hazard-induced relocation, due to the 2013 earthquake and coastal flooding, as well as the housing repair cost incurred from Typhoon Rai also increase willingness to relocate. The cumulative impacts of consecutive extreme events have been demonstrated to reduce coping capacity, especially among lower-income households, and studies have shown that previous flood experiences can increase future migration and relocation intentions [32, 56–58]. Respondents in their 20s showed higher willingness to relocate, consistent with broader patterns in the mobility literature, where younger adults tend to exhibit greater openness to relocation due to fewer place-based attachments, better livelihood prospects, and longer time horizons over which to recoup the costs of moving, whereas older adults show stronger place attachment and preferences to adapt in place [3, 59–61].

Conversely, several factors were associated with lower willingness to relocate. Not experiencing coastal flooding reduced the odds of relocation willingness by roughly half (OR = 0.52, 95% CI: 0.35–0.77, $p < 0.01$), confirming that direct hazard exposure is a key driver of relocation intentions. As seen in Figure 4a, willingness to relocate is highest in the two subsided municipalities that experience the highest levels of flooding, compared with the non-subsided municipalities. Notably, however, even in the non-subsided municipalities, between a third and a half of households indicated they would move if flooding were to worsen, suggesting that awareness of future risk, not only current exposure, shapes mobility intentions. Larger household size was marginally associated with reduced willingness, likely reflecting the logistical and financial difficulty of relocating larger families. Operating a convenience store and employment livelihoods were both associated with lower willingness, reflecting the anchoring effect of place-based livelihoods, that extends beyond the natural resource-dependent livelihoods typically emphasised in the immobility literature [12]. While fishers are anchored by their access to fishing grounds, other place-based livelihoods are anchored by their dependence on a local customer base, employer, or a fixed physical location, creating a

different but equally powerful set of constraints that tether them to hazardous areas. As seen from the survey data, although the majority of households in three of the four surveyed municipalities expressed willingness to relocate, the remaining households indicated a preference to stay and these households could remain voluntarily immobile in the future.

In addition to these factors associated with lower willingness to relocate, KIIs provided further insights into the barriers to relocation. Fishers expressed reluctance to move away from coastal resources essential for their income. In Tubigon's island barangays, some men stated that even if their families relocated to the mainland, they would continue residing part-time on the islands to maintain fishing livelihoods. KIIs in Tubigon further revealed that institutional obstacles, such as long delays in government-managed relocation project, and financial obstacles, such as the lack of affordable housing on the mainland, were other impediments to relocation. A government relocation programme, discussed since 2017, had not commenced construction at the time of our study in 2024. Furthermore, proposed monthly housing payments of ₱2,000–₱3,000 for relocation were unaffordable for households with average incomes of ₱5,000–₱7,000 and existing debt burdens.

The combination of high exposure, desire to move, and limited ability to do so is characteristic of what the literature terms "trapped populations" [10–12, 16]. In Bohol, immobility is produced through intersecting constraints of livelihood dependence, financial constraints, and unrealised relocation programmes. Crucially, the inability to migrate can itself increase vulnerability [16]. Unlike mobile populations who can reduce exposure by relocating, immobile or trapped households absorb repeated hazard impacts, creating a cycle where disaster losses erode the financial resources needed to relocate, while continued residence in high-risk areas increases the likelihood of further losses. That even households in non-subsided municipalities express considerable willingness to move if flooding worsens suggests that this dynamic may extend well beyond currently affected areas as sea levels continue to rise. In Bohol, these findings underscores the need for relocation strategies that account for livelihood continuity, affordability, and timely implementation in order to enable mobility for those who wish to move but are currently constrained.

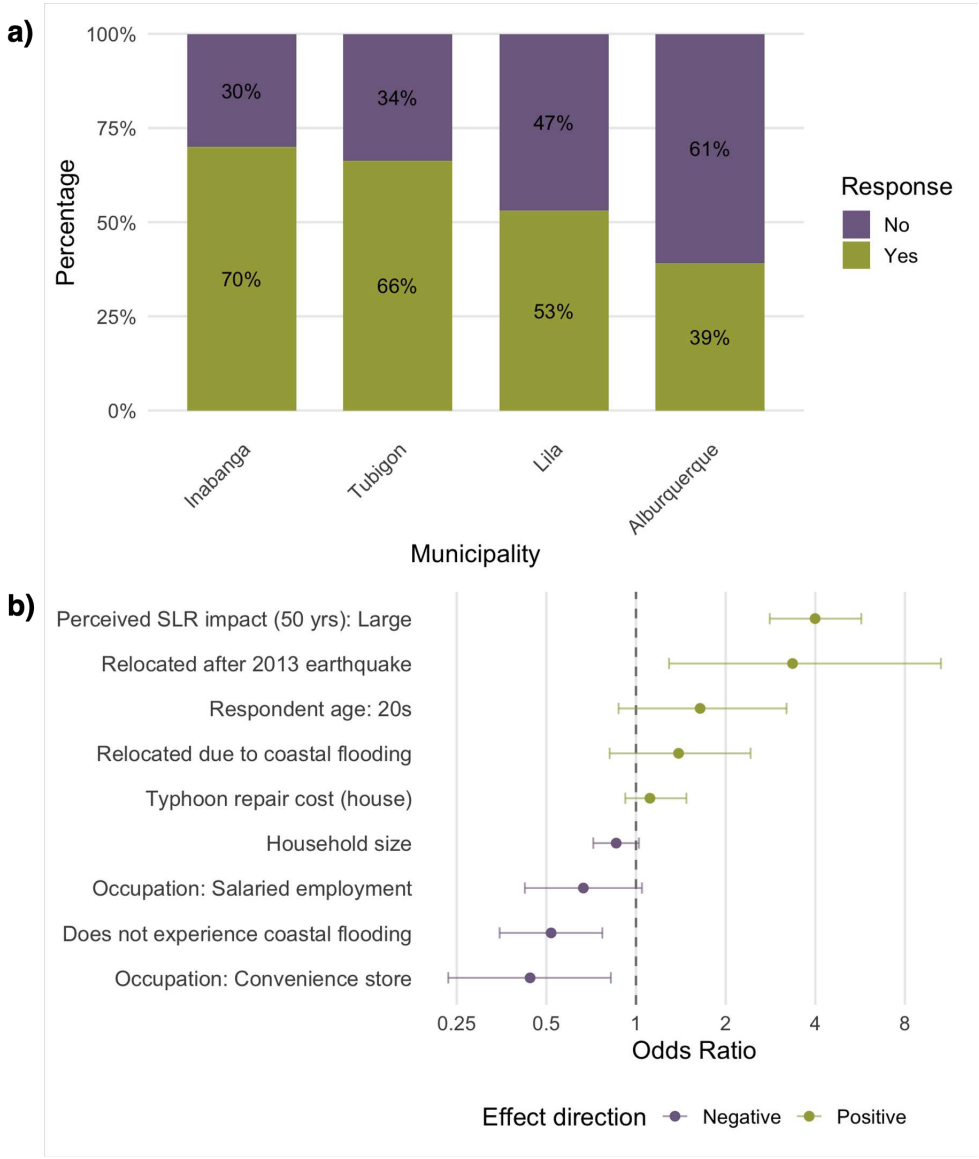


Fig. 4 Willingness to relocate if coastal flooding worsens, showing a) proportion of households willing to relocate, by municipality and b) predictors of relocation willingness from a LASSO logistic regression model, showing odds ratios (ORs) with 95% confidence intervals. Categorical predictors were one-hot encoded prior to model calibration and for these variables, ORs represent the change in odds relative to the reference category (not experiencing the condition or not belonging to the group). For continuous predictors, which were normalised prior to calibration, ORs represent the change in odds per one-unit increase in the variable. SLR = sea-level rise. N = 647 households.

2.3.4 Labour migration is an established mobility pathway, which serves as an important risk diversification strategy

Beyond hazard-related displacement, migration for education, work and marriage are significant ongoing mobility patterns, primarily involving the younger generation. Survey data indicate that 19% of households have family members who have migrated to other locations. The primary drivers were economic opportunity (67%), marriage (64%), and education (20%) (percentages are over 100% because household members can migrate due to multiple reasons), with destinations spanning other provinces within the Philippines (45%), and overseas (7%). A notable portion of moves also occurred locally, within the same barangay (33%) or municipality (17%), often linked to marriage or establishing new households.

These migration patterns exhibit distinct intra-household dynamics shaped by age. Out-migration is concentrated among young adults, while elder household members typically remain in origin location. KIIs revealed that this arrangement often reflects a deliberate household strategy, with elder family members encouraging their children and grandchildren to pursue education and employment elsewhere, viewing urban or overseas opportunities as more secure alternatives to climate-vulnerable fishing livelihoods. Many informants expressed that they viewed such migration as a way for their children or grandchildren to "have a better life". However, this may inadvertently concentrate risk among older family members who remain.

The remittances from labour migration provide a critical financial buffer, diversifying household income away from climate-sensitive livelihoods. The Philippines is one of the largest recipients of remittances globally, with overseas Filipino workers sending home approximately USD 40 billion in 2024 — equivalent to around 8% of GDP [62]. In Bohol, these established migration pathways provide a mechanism upon which climate-related mobility strategies can build.

These finding align with the climate mobilities perspective [9, 10], which recognises that climate-related mobility often builds upon existing patterns of migration rather than constituting entirely novel flows. The findings also align with the New Economics of Labour Migration (NELM) framework [24, 63], which posits that households collectively make migration decisions to diversify income and manage livelihood risk. Migration in this framing is not an individual response to wage differentials between regions, but a household-level strategy to spread risk across different income sources and geographic locations.

In Bohol's context, where in-situ livelihood options are increasingly constrained by environmental change, labour migration provides one of the most viable means for households to buffer risk across generations, even as it reconfigures household composition and may accelerate demographic change in origin communities. The concentration of elderly residents in hazard-exposed coastal areas, while younger generations establish themselves in safer locations, represents both an adaptive strategy and an emerging vulnerability that warrants attention.

3 Discussion

This study addresses a critical evidence gap on household-level mobility responses to sea-level rise. Bohol's earthquake-induced subsidence offers a rare empirical window into household responses to relative sea-level rise — one that captures revealed behaviours of in-situ adaptation and diverse mobility patterbs, and conditional stated intentions where relocation has not occurred. By documenting how communities already living with chronic tidal flooding and other coastal hazards adapt, move, or remain in place, our findings provide grounded insights into dynamics that might become increasingly common as global sea levels rise. Three key themes emerge from our analysis: the spectrum of mobility responses households employ, the prevalence and limits of in-situ adaptation strategies, and the gap between willingness and capacity to relocate that can produce immobile or trapped populations.

Our findings demonstrate that mobility in response to coastal hazards is far from a binary choice between "stay or go". The spectrum of mobility responses we documented — temporary evacuation, short-distance relocation, labour migration, planned relocation, and constrained immobility — often operate simultaneously within the same communities and even within households. Particularly notable are the intra-household dynamics shaping these mobility patterns. Temporary movements exhibited gendered divisions, with men staying behind to protect assets while women, children, and elderly evacuated. Labour migration highlights differentiated responses by age, with youth moving to urban centres or overseas while elders remain. Additionally, the observed pattern of labour migration highlights the importance of situating climate-related movement within the broader context of existing migration patterns. Our finding that 19% of households have migrant members, primarily for economic opportunity rather than environmental reasons, suggests that climate-related mobility in Bohol is not a novel phenomenon but is building upon and reconfiguring these pre-existing migration pathways. In countries such as the Philippines with well-established labour migration internally and internationally, migration networks and remittance economies could create pathways that households can leverage in coping with the impacts of climate change [4].

Households across the study areas have responded to coastal hazards with in-situ adaptation, including structural adjustments, livelihood diversification, and nature-based solutions. This is consistent with a broader literature showing that households typically attempt to adapt in place before considering migration or relocation, particularly where livelihoods and place attachment anchor them to hazardous environments [6, 11]. At the same time, our findings suggest that these efforts are increasingly constrained in the most exposed settings. Households in Bohol appear to be confronting both soft limits, such as financial constraints, incomplete infrastructure, and weak institutional support, and hard limits associated with chronic inundation, low elevation, and limited room for retreat. Under such conditions, some forms of in-situ adaptation risk becoming maladaptive [40], reducing risk in the short term but increasing vulnerability by locking households into cycles of debt, repeated reconstruction, and continued residence in highly exposed areas. These patterns are likely to become more prevalent in coming decades as sea levels continue to rise and coastal hazards intensify, including through the interaction of sea-level rise with storm surges

and tropical cyclones [1]. In such contexts, the hard limits themselves signal that adaptation efforts should shift decisively from in-situ measures to planned, anticipatory relocation. Without proactive support, these communities risk becoming trapped populations facing escalating risk with declining adaptive options.

It is partly this recognition of adaptation limits — reinforced by the acute shock of Typhoon Rai — that helps explain why willingness to relocate is highest in the subsided municipalities, even as households face formidable barriers to moving. This finding differs from [36] that reported households in the island barangays of Tubigon (namely Ubay, Pangapasan, Bilangbilangan and Batasan), preferred in-situ adaptation to relocation. The study reported that communities are "refusing to relocate" to the mainland, through the government's relocation programme. However, as seen from our results, there is a high degree of willingness to relocate in these island barangays, particularly if flooding were to worsen, but they face significant obstacles to relocation, including delays in the government's relocation programme itself, the lack of affordability of houses in the relocation programme and place-based livelihood dependence. It should be noted that [36] conducted their study in 2016, whereas Typhoon Rai occurred in 2021. As shown in our study, Typhoon Rai represented a major shock that destroyed homes and livelihood assets on a scale that exceeded household coping thresholds, with households still recovering from the typhoon to this day, and our regression results confirm that typhoon-related repair costs significantly increase willingness to relocate. Risk perceptions also appear to have shifted in the aftermath of the typhoon, with households modifying their evacuation behaviour and expressing worry and fear about future extreme events. We also find that perceived long-term impacts of climate change and sea-level rise are the strongest predictor of relocation willingness, suggesting that repeated exposure to extreme events and coastal flooding has reshaped how households evaluate their future in these locations.

The empirical insights from Bohol carry direct and urgent implications for climate adaptation policy in the Philippines and other coastal areas facing sea-level rise. National and local policy must recognise migration and relocation as legitimate forms of risk management and climate adaptation. Any relocation initiative must be embedded within a livelihood-sensitive framework, particularly for fishing communities whose work depends on proximity to coastal waters. Relocation without meaningful livelihood support risks exacerbating vulnerability and may push households back into high-risk areas [64]. Our findings also underscore the need for dedicated financial mechanisms to support anticipatory and dignified movement, such as the UNFCCC Loss and Damage Fund, which could play a crucial role in financing planned relocation, affordable housing, and debt relief for disaster-affected households. Such measures would allow households to relocate before conditions become uninhabitable, avoiding long-term entrenchment in hazard zones and reducing the emergence of trapped populations. Taken together, these insights call for a shift toward integrated, people-centred climate mobility planning that addresses both immediate adaptation needs and long-term habitability challenges in low-elevation coastal communities.

Acknowledging the limitations of this study is important in appropriately interpreting its findings. The survey sample is drawn exclusively from origin communities within hazard-exposed areas, rather than from households who have already relocated

to destination areas. Consequently, the study may under-represent relocation pathways that are more successful or driven by opportunities outside the origin community, and may over-represent barriers faced by those who remain. The findings should be interpreted as reflecting origin-side dynamics rather than offering a complete picture of destination experiences or post-relocation outcomes.

Future research should extend beyond origin communities to examine the choice of destination locations and post-relocation outcomes, including livelihood sustainability, social integration, and well-being trajectories, to understand what enables successful relocation. Future work should also investigate how climate stressors compound and reconfigure existing mobility pathways, such as the prevalent labour migration identified in this study. Longitudinal research would be particularly valuable for tracing how household mobility strategies evolve over time as sea levels rise and livelihood opportunities shift. Additionally, there is a pressing need to improve predictive models of climate migration by better integrating household-level determinants of movement, such as climate-sensitive livelihood dependence, financial constraints, and risk perception, moving beyond simplistic exposure-driven projections. Comparative studies across different island contexts could help identify common thresholds and tipping points for mobility, and build a more robust evidence base to guide adaptation policies and interventions.

4 Methods

This research was conducted in collaboration with the Greening Disaster Risk Reduction project [48] of the Philippine Red Cross and American Red Cross, which supports community-based flood risk reduction initiatives in Bohol. The partnership facilitated local access, coordination with authorities, and informed survey design through on-the-ground knowledge of local adaptation practices, particularly nature-based solutions.

4.1 Objectives and design of study

This study formed part of a wider project with two main aims: (1) to understand household-level adaptation and mobility responses to coastal hazards, and (2) to evaluate the role of nature-based solutions and nature-positive insurance products in disaster risk reduction. This paper focuses on the first aim.

The study was conducted in 4 coastal municipalities in the province of Bohol, Philippines, from September to October 2024. The first criteria for choosing these municipalities, as shown in Figure 1, was on the basis of differentiated exposure to coastal flooding. Municipalities in the northwest of Bohol, including Tubigon and Inabanga, experienced land subsidence due to the 2013 earthquake [33] and consequently experience a greater level of coastal flooding. The next criteria for selection was the presence of existing mangrove forests, or the prospect for establishing new mangrove forests. The final criteria for selection was differences in income levels between locations, to examine the effect of income on risk perceptions, adaptation strategies, mobility decisions and valuation of ecosystem services. As per the 2024 income classification of municipalities, which is based on average annual regular income of a given

municipality, Tubigon and Inabanga rank in the 1st class, while Lila and Alburquerque rank in the 4th class, out of 6 classes [65]. Within each of these municipalities, the specific barangays surveyed are indicated in Figure 1. In Tubigon, only the island barangays offshore from the mainland were included, as these barangays are known to have the highest exposure to coastal flooding in Bohol [36]. Further details on the surveyed sites are in Supplementary Information.

Face-to-face household surveys were conducted with an adult household member across the four municipalities, resulting in 647 completed surveys. The representativeness of the survey sample is discussed in Supplementary Information.

The sections of the survey are as below, with the full survey questionnaire in Supplementary Information:

- Household characteristics: respondent demographics, household composition, education, livelihoods, asset ownership, housing tenure, and migration history
- Typhoon impacts and responses: housing and asset damage, flood depth during typhoons, repair processes and financing, non-structural impacts, temporary and permanent relocation behaviour, reasons for relocating or staying, and preparedness measures for future typhoons
- Coastal flooding experiences: timing and seasonal drivers of flooding, flood depths, structural and non-structural impacts, adaptation measures, temporary relocation behaviour, and intentions or barriers related to permanent relocation
- Earthquake impacts: housing damage during the 2013 Bohol earthquake, whether the house experienced subsidence, changes in flooding after the earthquake, and any related relocation
- Climate change perceptions: awareness of climate change and sea-level rise, perceived impacts on the community and household, mobility intentions under future hazard scenarios, and concerns regarding potential government-led relocation
- Mangroves and ecosystem services: presence and condition of mangrove forests, perceived changes over time, storm-related damage, perceived ecosystem services, and income derived from coastal ecosystems
- Coastal protection preferences: attitudes toward mangrove restoration, coral reef conservation, and seawalls; and stated willingness to pay or volunteer for nature-based or engineered protection options, as well as for property and boat insurance
- Financial resilience: household financial coping strategies, savings and insurance uptake
- Household income and expenditure: income data by source, effects of hazards on income, expenditure data by category, and post-hazard expenditure changes

Adaptation strategies and mobility responses were recorded according to each of the main hazards experienced in the study locations - namely typhoons, coastal flooding and the 2013 earthquake. This approach allowed for examination of the interactions and sequencing between in-situ adaptation and various forms of mobility, recognising that these strategies are not mutually exclusive and often form a continuum of household risk management [11, 16]. Questions on mobility strategies drew on the mobility-as-adaptation literature, aspiration-capabilities framework and concepts of "trapped populations" [10–12, 17], and were informed by a review of household-level

studies on climate- and disaster-induced displacement [27, 66–68]. This design enables an integrated analysis of how hazard exposure, household characteristics and risk perceptions shape the spectrum of adaptation and mobility outcomes.

The survey was reviewed and refined by the Greening Disaster Risk Reduction team of the Philippine Red Cross, with additional input from local enumerators to ensure contextual and cultural relevance. Enumerators were volunteers from the Philippine Red Cross Bohol Chapter, residing in Bohol. They participated in a two-day in-person training and the questionnaire was pilot tested in Tubigon by the field team. Surveys were administered in Cebuano (Bisaya), using KoboToolbox, an open-source platform for survey data collection.

Households were selected using a random spatial sampling approach. Polygons representing building footprints were extracted from OpenStreetMap, and random points were generated within these polygons for each barangay. Enumerators visited the corresponding households, and if the selected dwelling was unavailable, the nearest occupied household was surveyed instead, and this substitution was recorded. This method ensured geographic coverage across the barangays while maintaining randomness in household selection.

To deepen our understanding of community-level processes, institutional contexts, and historical experiences, we conducted 27 semi-structured KIIs with local government officials and community leaders. These interviews provided essential context for interpreting survey results, particularly regarding planned relocation programmes, collective adaptation initiatives, and the lived experience of recurrent flooding.

4.2 Analytical approach

Survey data were cleaned and analysed in R (version 4.5.1; [69]).

To identify factors associated with willingness to relocate, we employed a two-stage modelling approach. In the first stage, we used LASSO (Least Absolute Shrinkage and Selection Operator) logistic regression for variable selection. LASSO applies an L1 penalty to the log-likelihood, which shrinks less important coefficients to exactly zero, thereby performing automated variable selection. This approach is well-suited to our setting, where the survey generated a large number of possible predictors spanning household demographics, hazard exposure and impacts, mobility history, risk perceptions, and financial variables, many of which are correlated. The regularisation parameter λ was selected via 10-fold cross-validation using the `glmnet` package [70]. We used $\lambda_{\min}$, the value that minimises cross-validation error, to retain the set of predictors with the strongest predictive signal. In the second stage, we refit an unpenalised logistic regression model using only the predictors retained by LASSO. Model performance was assessed using the area under the receiver operating characteristic curve (AUC-ROC). Results are reported as odds ratios with 95% confidence intervals.

5 Data availability

The data, survey instruments and analysis code supporting the findings of this study have been made available at https://zenodo.org/records/23168500?preview=1&token=eyJhbGciOiJIUzUxMiJ9.

eyJpZCI6IjUwNzdkOGQxLWYxNzktNGRiYy1iYjA5LTM1MjJhZjE1NjMwNSIsImRhdGEiOnt9LCJyYW5kb20iC
AsVbNq_4UObWLICckVSNTD-leOdT9yWbBGHTMPyUJe3VoacdwBwTq9pa3wGJVSe9e03QajRTSrAjuoK043R

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7 Author information

7.1 Contributions

All authors conceived the study and developed the methodology. S.M., M.R. and A.B.-W. carried out the data collection. S.M. performed the formal analysis, prepared the figures and wrote the main manuscript text. M.R. led project administration and D.L. supervised the study. All authors reviewed and edited the manuscript.

7.2 Corresponding author

Correspondence to Sonali Manimaran.

8 Ethics declarations

8.1 Competing interests

The authors declare no competing interests.

8.2 Ethics approval

Ethics approval for this study was obtained from the Nanyang Technological University Institutional Review Board (Reference: IRB-2024-048). The study was conducted in accordance with the approved ethics protocol and the relevant institutional guidelines and regulations governing research involving human participants. Local approval for the study was sought through formal permission for data collection from the Provincial Government of Bohol, and the municipal and barangay government units of Alburquerque, Inabanga, Lila and Tubigon. Fieldwork was carried out in partnership with the Philippine Red Cross. Informed consent was obtained from all participants before data collection commenced. All data were securely stored and used exclusively for research purposes, and no personally identifiable information was included in the analysis or reporting of findings.

8.3 Informed consent

Informed consent was obtained from all participants before data collection. Participants were given information about the purpose of the study, the survey topics, the expected duration, and the potential risks. They were informed that participation was

voluntary and that they could skip questions or withdraw at any time without penalty. By consenting, participants agreed to take part in the study, and to the collection and use of their data for research purposes. All participants were adults aged 18 years or older.

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