Exploring Climate Change Adaptation Pathways for the Guna Yala in San Blas, Panama

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Table of Contents

Abstract……………………………3

Introduction ……………………………3

Chapter 1: Background ……………………………4

1.1 The Guna Yala ……………………………4

1.2 Impact of SLR on the San Blas Islands……………………………5

1.3 The Current State of Relocation Projects……………………………6

1.4 Drivers to Climate Migration ……………………………7

Chapter 2: Literature Review ……………………………9

2.1 Instrumental Variable Approach to Climate Modeling ……………………………10

2.2 Gravity Model for Climate Migration……………………………11

2.3 Radiation Model for Climate Migration……………………………12

Chapter 3: Indigenous Adaptation and Resilience ……………………………14

Chapter 4: Methodology ……………………………18

4.1 Introduction……………………………18

4.2 SLR Model ……………………………19

4.3 Suitability Analysis ……………………………22

Chapter 5: Data Analysis and Results……………………………23

5.1 SLR and Coastal Flooding …………………………. 24

5.2 Gardi Sugdub Case Study…………………………… 25

5.3 Suitability Analysis ……………………………26

Chapter 6: Results and Discussion ……………………………29

6.1 SLR and Coastal Flooding……………………………29

6.2 Gardi Sugdub Case Study ……………………………30

6.3 Suitability Analysis……………………………31

Conclusion……………………………34

References ……………………………36

Abstract

The impacts of climate change will most acutely and severely affect coastal communities and force the migration of peoples, nations and cultures. Particularly for indigenous groups, forced migration and community separation is a threat to their survival [3]. This study focuses on developing methodology for climate migration planning for the Guna Yala, an indigenous group residing in Panama's San Blas Islands [5]. Sea level rise (SLR) is a materialization of climate change that is uncontrollable even in the most optimistic emissions scenarios [29] and will leave islands more vulnerable [7][29] to both climate processes such as thermal expansion, and climate events, such as storm surges and extreme flooding [1]. Current literature in climate migration modeling focuses on the development of a minimum data model for migration that can be applied globally. This study highlights the literature from three papers that offer such models [18][17][18][19]. However, this research falls short of applicability for planning due to its lack of specificity and minimal consideration for cultural resilience. The Guna Yala proven their adaptivity and resilience against adversity from the natural and political world and have developed unique cultures and practices that alter their interaction with the environment [5]. The study develops an SLR model and suitability in ArcGIS to aid in climate planning. The SLR model utilizes Representative Concentration Pathway (RCP) 2.6 and 8.5 [31][32][33], as well as a model of storm surges [29][7], to aid in the creation of a timeline for migration. The suitability analysis utilizes factors that integrate cultural adaptations of the Guna Yala into coding decisions for suitability, such as the need for a site with arable land, that is close to the coast, and far away from other communities. The analysis compounds the suitability of 11 socio-ecological factors, demonstrating that La Chorrera, a region east of Panama City, is most suitable for relocation, and that likely migration timelines estimate migration at or before 2050.

Introduction

As noted by the Intergovernmental Panel on Climate Change (IPCC) in 1990, climate change driven migration may be the greatest single impact on humanity [1]. Professor Norman Myers estimates that we will see 200 million climate migrants by 2050, a number which is widely accepted by the international community. Migration due to climate change has and will continue to disproportionately impact vulnerable communities, whose rurality, low socio-economic status, and lack of political representation compounds it's effects [2]. Particularly, indigenous peoples will have high exposure to environmental changes [3]. As climate change progresses, estimating the location, timing and scale of climate migration will become essential to the study of climate change impacts, as well as the development of proactive policies for marginalized communities. As J. Ribot remarks, "vulnerability does not simply fall from the sky"; it is socially constructed [4].

This study will focus on the Guna Yala, an indigenous tribe in eastern panama, who reside on the low-lying San Blas islands [5]. As a group that will undoubtedly experience some of the first severe effects of SLR, they will need to adapt and plan in order to protect their community heritage and to ensure that eventual migration will preserve their language and culture. In order to best assist in the planned relocation of the Guna Yala, this study will conduct a suitability analysis of the surrounding regions based off social and environmental factors and discuss the viability of these projections for planning efforts. It will also model the likely impacts of SLR on inundation in San Blas in order to create a visual incentive for planning and aid in the development of a timeline for migration. This study will deviate from many approaches to climate modeling by focusing on empowering the resilience and adaptive capacity of this strong cultural group and suggesting an approach that takes that into account when planning for strategic relocation. Particularly, I suggest an interdisciplinary approach which utilizes tools from environmental planning and policy to achieve empathy and applicability in the selection of relocation destinations.

This study will evaluate current methods for modeling climate migration for areas with low data availability and suggest a shift in focus towards modeling that is useful for planning and takes into account cultural resilience to environmental change. I suggest that a suitability analysis and SLR model mapped in ArcGIS that takes into account cultural adaptations, social, and ecological factors is optimal, and utilize the methodology for domestic relocation of the Guna Yala from the San Blas Islands in Panama.

Chapter 1: Background

1.1 The Guna Yala

The Guna people primarily reside in the Comarca Kuna Yala, the first semi-autonomous region to be established in Panama in 1954 and covers a strip of land on the eastern side of Panama, as well as over 400 coral islands off the coast known as the San Blas Islands [5]. They primarily live on the largest 48 of these islands with a population of around 30,000. The administration and politics of the region are entirely separate to mainland Panama and consists of elected community representatives known as Sahilas [6]. The economy of the Guna Yala is primarily based off subsistence agriculture and community approaches to welfare. The primary food sources on the islands are seafood, but they are supplemented by food crops crown on the mainland such as rice, yams, yucca, plantains, bananas and pineapples. The main industries are tourism and coconuts [6].

Access to technology and contact with mainland Panama is minimal, meaning there is a severe lack of data in the region from which to base quantitative predictions. The Panama Census tracks district population every 10 years [39][41], resulting in inconclusive data on historical domestic migration. As a group with prohibitively low access to capital and technology, and whose communities reside on low elevation islands [7], the Guna Yala will be severely impacted by SLR.

Regional inundation due to SLR, in addition to shifting meteorological patterns, will have an impact not only on the size of the San Blas Islands, but the subsistence agriculture practices off which the Guna economy is based. These impacts will require adaptation measures, including but not limited to strategic relocation.

1.2 SLR Impact on San Blas

IPCC Chapter 4 on impacts of climate change on islands describes the increased impact of climate change on coasts [7]. The global mean sea level is rising and accelerating with high confidence due to anthropogenic factors [7]. The report outlines factors of coastal residence that make it increasingly vulnerable to the impacts and rate of SLR. These are thermal expansion in equatorial adjacent areas, extreme sea events, and non-climatic anthropogenic drivers [7].

SLR does not occur uniformly due to thermal expansion, ocean dynamics and land ice loss. These create variations of 30% above and below the GMSLR [7]. Importantly, changes in wave height and period have larger effects on coastal flooding than the average sea level [33]. The IPCC reports that increasing GMSLR will result in increasing frequency of extreme sea level events such that they will become common by 2100 under all climate scenarios [7]. Particularly, the report documents the increased risk for coastal communities of tropical cyclones, storm surges and marine heatwaves. The report projects that low-lying cities and small islands at almost all latitudes will experience these events annually by 2050 [7]. These extreme events as well as relative SLR will likely result in habitat contraction, loss of functionality and biodiversity and lateral and inland migration [7]. Events such as storm surges can increase the sea level by 15ft, causing severe flooding [29][7].

The report also comments on the exacerbation of climate effects due to human interactions with the land. Specifically, the presence of man-made barriers that prevent inland migration of marshes and mangroves and limit the availability and relocation of sediment will worsen effects of SLR [7]. In the case of the San Blas islands, this is indeed a concern. In an attempt to deal with their increasing population, the Guna mined the surrounding coral reefs that would have otherwise helped protect the islands from flooding to build up the land-area on their islands [7]. "From 1970-2001, nearly 80 percent of the peripheral coral disappeared as the Guna population more than doubled, Guzman and other Smithsonian researchers found" [7].

In order for adaptation to these effects to occur, significant short-term planning will be needed. The report remarks that "taking a long-term perspective when making short-term decisions", particularly, accounting for uncertainty and local-specific risks will be needed to the tackle this issue [8]. Proactive and adaptive measures will need to be put in place to organize relocation efforts and develop initiatives to combat the effects of SLR in the short term.

1.3 Current State of Relocation Projects for Gardi Sugdub

In 2017, the BBC documented the intended domestic migration of the Gardi Sugdub, a sub-community in the Guna tribe, who have noticed their islands beginning to shrink and are planning an eventual relocation. The Gardi Sugdub's population of 2,000 [39] is planning to resettle in a 17-acre site on the mainland [9]. This relocation initiative was launched in 2010 in collaboration with the indigenous people, the Panamanian Government and independent organizations. It is the only initiative of its kind. Despite the promises made to the Gardi Sugdub by the Panamanian government about relocation support, no concrete actions have been implemented [10]. Displacement Solutions, the organization driving the agreement between the two, remarks that we should not expect the spontaneous migration of individuals from the island to the mainland, but that the operation is a collective enterprise that will happen gradually and likely not completely until a natural disaster where displacement is necessary [10]. The intention of the planned relocation is for the Gardi Sugdub to have a viable community resettlement option when the 'trigger point' of their migration occurs. This is in contrast to the likely alternative, where the community is forced to disband and migrate to Panama City, where they will be living in the poorest neighborhoods surrounding the city [10]. This initiative is one of the first of its kind and provides an example of what may be possible for all low-lying island communities that are facing climate change. However, the political and economic factors that complicate the feasibility of this project (as seen by the Panamanian government's lack of concrete action on this initiative) demonstrate the difficulty of such a project.

To create an incentive for such relocation projects, an understanding of the general time at which forced migration will occur may be of help both from a logistical perspective, and to drive a sense of urgency. This study will aim to assist the organizations pushing for planning for this indigenous community through the development of a visual tool for understanding SLR impacts on community infrastructure.

1.4 Drivers to Climate Migration

Planning for the migration of an entire indigenous group will require significant planning, funding and infrastructure that must be in place long before the islands become submerged. It is for this reason that estimations of the timeline and severity of climate change impacts on these islands must be understood.

When examining this case study of the Guna people, it's important to understand the climate and non-climate drivers to their potential migration. Climate drivers of migration from a meteorological perspective are divided by the IPCC into the categories of climate processes and climate events [1]. Estimating climate migration requires predictions about the frequency, severity and location of climate events. It also requires assumptions about how and when communities decide to migrate. An analysis of climate and non-climate drivers to migration builds context around these decisions.

1.4.1 Non-Climate Drivers

Socio-economic status plays a significant role in an individual's mobility, which is a key feature of the ability to migrate [1]. The International Organization for Migration describes migrations decisions in areas characterized by out-migration in terms of those who are unable to move and those who choose not to move [12]. 99% of the Guna people have an International Welfare Index value of under 70 and reside in the poorest province in Panama [13]. With low access to funds to move and rebuild, their ability to migrate is limited. There are different degrees of mobility due to a range of reasons, including lack of knowledge about opportunities outside their geographical and cultural environment, social and cultural ties, physical immobility, gender and age [14]. For the Guna people this is particularly relevant, as the revolution of 1954 year is a point of historical pride for the indigenous people, and thus they have a strong value for their land [5]. Thus, we can classify immobility as being voluntary or involuntary. In the case of the Guna people, both types of immobility play into migration decisions, impacting perceived utility trade-off of relocation and adaptation. These socio-economic factors deeply complicate the decision calculus of individuals and communities when deciding whether or not to migrate in the face of challenges due to SLR.

1.4.2 Climate Drivers

Climate drivers of migration from a meteorological perspective are divided by the IPCC into the categories of climate processes (SLR, salinization of agricultural land, desertification, growing water scarcity etc.) and climate events (flooding, storms, glacial lake outburst floods etc.) [1]. Climate processes have a more gradual impact on migration as conditions tend to worsen over longer periods of time, and individuals have slowly increasing incentives to migrate. Climate events on the other hand, tend to cause more drastic migration due to the destruction of property, and emergency relocation measures [1]. The severity of climate change impacts is heterogenous both between countries and domestically due to a variety of factors, ranging from proximity to coastlines to agricultural sensitivity. There are also likely to be some regions that are positively affected by climate change in the short run. A study predicting economic damages under UN mitigation targets notes that countries like Canada and Russia are likely to experience GDP gain from global warming in the short run, due to the tundra becoming arable land [15]. In order to accurately model migration drivers from climate change, an understanding of the likely temporal shifts will need to be established.

The IPCC fourth report on adaptations to SLR for low lying islands presents a graphic that summarizes the drivers and necessary adaptations [7].

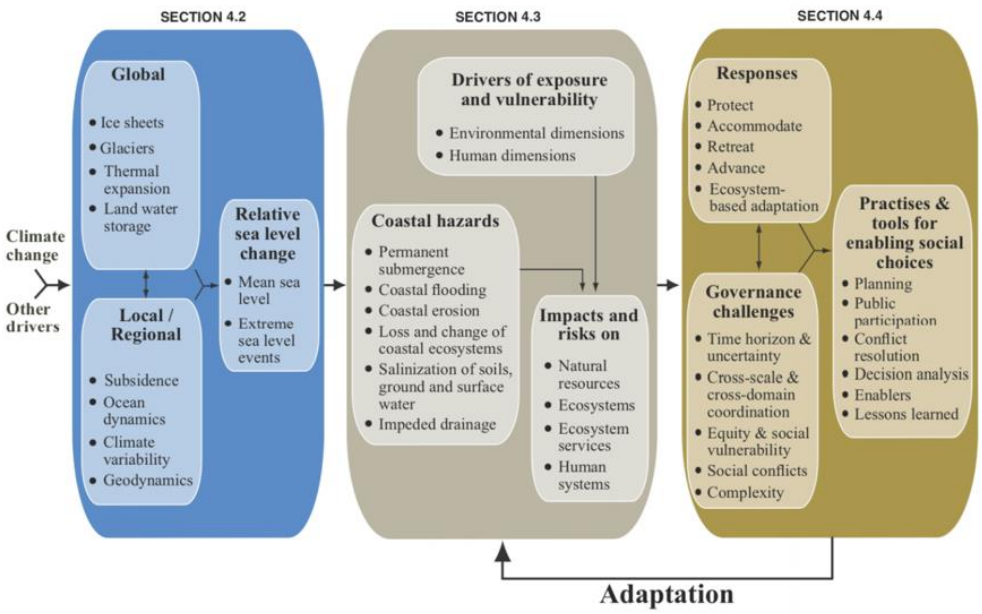


Figure 1: Drivers and Adaptations to Sea Level Rise for Low Lying Islands, Source: IPCC 4th Report [8]

Chapter 2: Literature Review

Current approaches to modeling migration offer insight into the potential ways to forecast Panamanian indigenous migration for relocation and adaptation planning. It is important to firstly note that migration decisions are often multicausal and rarely due to environmental stress alone [1]. In the case of the Guna Yala, this is especially pertinent as community and cultural identity are extremely closely tied to their land and autonomy [5]. A suitable model for migration will therefore take into account both human and natural factors in migration decisions and strive for a high level of specificity. This section will discuss a sampling of the approaches to modeling climate migration both with regard to their suitability to assisting the Guna Yala and limitations. The three approaches that will be detailed are an instrumental variable approach for migration modeling, a gravity model and a coupled radiation and SLR model.

2.1 Instrumental Variable Approach to Migration Modeling

The primary criteria that determine the suitability of a modeling approach for migration are specificity and accuracy. Feng et al offers a mechanism to measure migration due to climate change in scenarios where migration data is known by utilizing an instrumental variable approach to investigate the linkage between climate change, crop yields and Mexico-US border migration [16]. Instrumental variable approaches allow for the isolation of the relationship between crop yields and migration without controlling for all other factors explicitly. The study estimates the model using a fixed-effects two-stage least-squares approach to compare two time periods and assumes that the migration between the US-Mexico border is happening unilaterally (from Mexico, to the US) [16]. The study utilizes border data from 1995 to 2000 and 2000 to 2005, to examine its correlation with crop yields as an instrumental variable for climate change. The outcome of the study indicates that the estimated semi-elasticity of emigration with respect to crop yield is approximately -0.2. This means that a 10% reduction in crop yields is likely to lead to an additional 2% of the population of Mexico to emigrate [16]. This indicates that by approximately 2080, climate change will induce 1.4.-6.7 million adult Mexicans to emigrate as a result of declines in agricultural productivity due to climate change. This was found at a highly statistically significant level, suggesting that biases from small sampling and weak instruments are minimal [16].

Feng et al's utilization of agricultural productivity as an instrumental variable for climate change does offer a potential strategy for climate modeling in regions where this data is abundant. The methodology for quantifying migration flows is particularly robust because it is based off the isolation of climate impacts on historical data. As Feng et al remarks, policymakers require plausible forecasts to prepare for future migration flows due to climate change [16].

A limitation to this approach is that it assumes that migration due to climate change will be linear as agricultural yields worsen. However, this may not be the case if behavioral or community-based factors influence migration decisions (e.g. fear of never recovering agricultural yields may induce mass migration of farmers to the US, resulting in a non-linear migration flow [16]).

This approach has been found to be robust in estimating the correlation between agricultural yield and cross border migration historically but may be more difficult to apply to future projections. The authors remark that the specific case study circumstances such as changes in migration policies between Mexico and the US, and inter-government policies to support or subsidize farmers limit the applicability of the methodology [16]. Temporal unknowns and adaptation measures will impact the accuracy of any predictions of migration flows into the future under all methodologies.

The requirement for data specificity in order to implement this modeling approach is a significant limitation for application to the Guna Yala. Panama's lack of internal migration data, as well as specific demographic data on regional groups (beyond population and some socio-economic indicators) makes this approach unsuitable for this case study. It is useful to note that the lack of data availability in this case study is likely to be emblematic of other vulnerable coastal areas in developing countries, who are often thought of as the most vulnerable populations to climate change [1]. Thus, it is unlikely that an instrumental variable approach to modeling migration will be scalable across developing and un-monitored areas. Feng et al discusses this in the study, remarking that the accuracy of the results is largely in part to the strong efforts of the US government to measure US-Mexico migration [16].

2.2 Gravity Model for Migration

The minimum data requirement for migration modeling has been explored by a variety of studies in response to the inapplicability of more robust methods of quantification. The earliest such approach was the gravity model for migration [18]. This model is based of physics concepts and has been applied in a variety of climate migration studies, most relevant of which is a recent paper that utilizes the gravity model in integrated assessment models. Beneviste et al employs a gravity model for migration and employ four scenarios of border policy to investigate the impact of border policy on exposure and vulnerability to climate impacts [17].

Gravity models utilize variables that revolve around economic opportunity, proximity (both geographic and cultural) and migration costs [18]. Bilateral migrant flows in the model are a function of population sizes and per capita income levels (of origin and destination groups) and also include a set of bilateral characteristics of the locations indicating suitability for migration [17]. Through ordinary-least-squares regression, the gravity model offers a model for migration that has been shown to have high adjusted R squared values of between 0.8 and 0.9 in many studies [17].

The limitations of the gravity method are very similar to the preceding critiques. As noted by Poot et al, the gravity model was developed in a time where minimal data was available for specific regions [18]. As more data becomes available, the ability to disaggregate migrant flows (which is a major limitation of the gravity model), increases significantly. This is shown by the instrumental variable study described above. In this case, there may be potential for the modification and re-utilization of the gravity model as a method for migration modeling, however it is more likely to provide a general estimation of population projections rather than specific directives for policy purposes.

2.3 Radiation Model for Migration

A potential re-utilization of the gravity model is suggested by Simini et al, who study the applicability of the associated radiation model for mobility as a method for migration modeling.

Simini et al provides a universal model for migration patterns through the implementation of a radiation model for mobility [19]. Simini critiques the well-known gravity model for its reliance on a variety of adjustable parameters that vary by region and offers a stochastic process to capturing local mobility decisions that only requires an input of the population distribution [18]. The radiation model simulates migration between cities and was applied to a study on predicting human migration in Bangladesh.

This study by Davis et al offers an iteration of radiation the model applied directly to SLR [19]. Given the context of this literature review in investigating modeling methods for an area particularly impacted by SLR, this model offers a potential method for the San Blas islands.

Davis et al utilizes the methodology to begin analysis at the individual level. The model, at the level of the individual, assigns an absorption threshold associated with the population density of their location of origin, such that individuals from highly populated regions have a higher absorption threshold than those in less dense regions [19]. At the city level, each city has a probability of absorbing an individual where absorbance is the maximum of the population in that city. Thus, an individual will decide to migrate to the location of the highest proximity with an absorbance larger than their threshold. The model uses a statistical mechanics approach to simulate fluxes between regions within a country. Davis et al examines the models fit to available internal migration data from the 2011 Bangladesh Census, finding that lifetime migrants had an r-squared value of 0.75. Davis et al modifies this baseline radiation method to incorporate considerations of SLR by accounting for the fact that inundated areas are much more likely to be experiencing out-migration. They measure inundation using STRM data on elevation in Bangladesh which is a high-resolution digital elevation model [38]. They evaluate the raster cells by setting an increasing sea level threshold equal to SLR projections from the IPCC in four representative concentration pathways for the year 2100 [23]. Thus, the cells with an integer value above the sea level elevation are non-inundated, while those below the threshold are.

The change in preference due to the inundation is calculated by reducing the population of inundated regions according to the population living within an area of a radius equal to the distance between two districts, keeping the remainder of the original radiation model consistent.

There are numerous limitations to this approach. Although it provides an easily applicable model to other case studies, the migration fluxes modelled do not take into account adaptive measures by a household or government against inundation, in addition to any confounding factors that may make this inundation worse. As discussed, the Guna Yala mining of the coral reef surrounding their islands is likely to increase susceptibility to climate events [9]; this would not be accounted for by the model and would increase its inaccuracy.

Another limitation to this approach is the aggregation of migrant flows. As discussed by Davis et al, the timing, delay or prevention of migration flows can be influenced by a variety of factors including household or community adaptive measures [19]. Additionally, migration from regions inundated by SLR will occur before the time at which the area is completely flooded and is likely to be more closely related to the occurrence of climate events. Lastly, as discussed in the background section regarding the disproportionate effects of SLR on island communities, the GMSLR does not demonstrate the heterogeneity of regional impacts of SLR [7]. Thus, the projections from this model are likely to be more conservative because they under-estimate the severity of SLR inundation in island communities, and migration is more likely to happen sooner than if SLR was the only climate impact due to increased frequency of climate events.

All forms of predictive analysis are susceptible to the fact that decisions that we make today and in the short-term future will impact the accuracy of modeling attempts. Davis et al discusses the reality that it may be impossible to incorporate future adaptation measures and opportunities into modeling beyond the timeframe of most planning policies [19].

These many iterations of models attempting to model migration fall short of accurately predicting migration for planning purposes. While useful for general expectations of population movement for application in education or incentives to begin thinking about strategic relocation, in the case of the Guna Yala, a more specific suitability analysis will be required for effective planning. This study will suggest an alternative to the modeling approach that is useful for minimum data areas and offers regionally specific recommendations for relocation efforts through a methodology that can be applied to similar case studies.

Part 3: Indigenous Adaptations and Resilience

Although the physical processes of climate change have been a primary focus for literature on climate migration, the relationship between environmental change and migration is deeply complicated by factors of a more human nature. Studies often overlook a cultural perspective. Particularly when it comes to indigenous groups, community adaptability is a significant characteristic.

Indigenous peoples often share social, cultural and spiritual ties to their land, both in terms of the physical environment and associated spiritual environment [3]. Livelihoods, health and wellbeing are closely linked to subsistence agriculture and land and water management practices that have persisted for generations. This creates a strong connection held by many indigenous groups to their land that influences their responses to environmental change. However, while their environmental connection is strong, their vulnerability is particularly high due to land dispossession, resettlement, and socio-economic disadvantaged that is closely linked to the structural challenges and colonialism they have historically faced [3].

This interplay of vulnerability and resilience is an important piece of the study of climate migration. Social-ecological resilience must therefore be a part of the conversation [5]. Apgar et al, in a study about the Guna adaptation and transformation highlights that resilience is an important concept that is emerging to guide and support more inclusive approaches to the management of combined social and ecological systems [5]. The concept of resilience can be used to think holistically about the characteristics that impact the "capacity of individuals, communities, and systems to survive, adapt and grow in the face of stress and shocks, and even transform when conditions require it" [22]. Brown discusses the relationship between resilience and vulnerability. Particularly, that vulnerability emerges in some cases as a function of deficit, absence or weakening of coping as well as adaptive capacities that are exceeded by the magnitude of changing conditions. In this sense we can see vulnerability as the opposite of resilience. However, Brown discusses the flip side of this, that both vulnerability and resilience can co-exist and vary among groups, over time, and through different stressors [22]. Thus, it is essential in discussing indigenous adaptations to climate change that we do so not just from the lens of their heightened vulnerability, but their ability to adapt as well.

Brown and Westaway highlight that the common resilience of indigenous peoples includes their capacity, connectedness, adaptation and feedback, indicating that social change is necessary for social-ecological system (SES) resilience [23]. This social change involves the adaptation of community structures, subsistence practices, and culturally informed ways of life [22]. Apgar et al emphasize that this adaptation and transformation is essential to indigenous survival of environmental change [5]. Social change also recognizes the capacity of actors in a

SES to learn, combine, experience and adjust to maintain a resilient system [24], and can also be referred to as incremental adaptation [25].

Indigenous resilience is particularly important to examine not only for the purposes of this case study, but because it applies to the most vulnerable populations in the world. This is particularly relevant to environmental change because of the strong relationships between Indigenous people and their land as they inform belief systems and daily practices [3]. Nature is frequently referred to on interpersonal terms, where it is capable of reciprocity, collaboration and harm. This creates a sense of connection and responsibility between native peoples and their environment and has been shown in some studies to demonstrate strong health outcomes [24]. This connection can both help and hinder resilience. Due to the strongly entrenched attachment to land, the disruption of the environment becomes a societal disruption. It is important to note that a history of land dispossession and resistance to colonialism has had the likely impact of bolstering indigenous resilience, whilst also strengthening their ties to land [3]. For the Guna Yala, whose 1925 revolt helped establish their autonomy from Panama in 1954 [5], this is certainly the case. Thus, there are significant contributing factors to the resilience and desire to 'stay and fight' of indigenous peoples, and such strong desire to adapt must be taken into account when planning for environmental change.

In order to understand potential pathways to climate change adaptation for the Guna Yala, their current practices of transformation and change must be understood. Apgar et al explore the adaptations of the Guna people that allow them to exhibit social change and SES resilience. With community-based approach to governance, their society is deeply tied to their environment. Despite slight modernization and shifts in activities, the Guna demonstrate high levels of social cohesion and village life that is managed through a traditional government [5]. A particular determinant of the connection between the Guna and their environment is the *Bab Igar*, a spiritual framing that connects the people to the earth and guides collective decision-making processes in the community [5]. Apgar utilizes a participatory approach to examine what facets of their society allows the Guna to adapt to their environment and observes the following characteristics:

Enabling Conditions for Adaptive Capacity	Skills, knowledge, practices and underlying processes
Use of collective memory	For the purpose of remembering oral history and observing natural cycles
Maintain a relationship with ecosystems	Provides context for a relationship with nature through *Bab Igar* and interactions directly with nature
High Social Cohesion	Individuals have a collective identity, there are a diversity of groups within the community and there are strong and tight social networks
Collective management of resources	Through territorial autonomy, institutional structures and collective decision-making processes
Management of relationships with other knowledge systems	Through filtering for incoming information, structural links to other processes and input from diverse views

Source: Skills, knowledge, practices and underlying processes that enable conditions for adaptive capacity [5]

The study concludes that creativity and innovation are required in responding to opportunities for change and are driven through spiritual and cultural practices, and that the Guna Yala's focus on critical self-reflection is a particular driver to their SES resilience [5].

Through tribulations of environmental and societal change, the Guna Yala have persisted as a cultural group due to their high social cohesion and interpersonal relationship with the natural world. Thus, an effective adaptation pathway to rising sea levels must empower the strong sense of agency of the Guna people and maintain their autonomy. Although many climate migration planning efforts are motivated and implemented in a 'top-down' approach, the historical and cultural underpinnings of Guna society indicate that a grassroots approach will likely increase buy-in and utilize the most adaptive capacities of indigenous resilience.

Part 4: Methodology

4.1 Introduction

A multi-stakeholder, community-driven approach to climate migration will require information to assist planning and decision making. This study will suggest a process for evaluating the suitability of a domestic regions for relocation and apply this to the Guna Yala case study. Particularly, the utilization of a suitability analysis as described below may utilize the innovation and creativity discussed by Apgar et al [5] in order to inform inputs for the analysis.

Geographic information systems science can be used for planning and management and is particularly useful for conducting land-use suitability analysis aimed at identifying the most appropriate regions for an intended use by optimizing for preference, requirements or predictors of some activity [26]. Using ArcGIS to select characteristics of spatial variables that are suitable for relocation may be an alternative to modelling migration that optimizes many geographic, economic and cultural features. Originating in the hand-drawn overlay techniques by American Landscape Architects, a suitability analysis is the superimposition of maps that shade the areas in a region that offer the creates opportunity or constraint for a given project [28]. The McHargian approach to the weighting of particularly suitable or unsuitable areas involves the creation of a new variable in each factor maps attribute table and assigning a weight to its classification, indicating desirability [27]. The most suitable areas achieve the most positive weight, while the least would be assigned a negative weight. GIS-based land-use suitability techniques have increasingly become integral components of urban, regional and environmental planning activities.

As opposed to models that attempt to predict the timing of migration for the purposes of population management, a suitability analysis provides pathways and options for adaptations. When coupled with expectations of SLR, this creates a framework from which policymakers, non-governmental organizations and communities alike can plan relocation and adaptation efforts.

This study will focus on three implementations of geographic information systems to assist in the planning of climate change adaptation for the Guna Yala. The first of which is a suitability analysis as described above. The second is a SLR model that visually demonstrates the likely impacts of SLR on the coast of Panama and highlights areas that will likely have to relocate before their residence becomes fully inundated. This model will assist in the highlighting of regions of concern for SLR as well as offering probable timelines for planning according to different climate scenarios. The third model will model the infrastructure damage to the island of Gardi Sugdub, in order to provide incentive for the planning of migration initiatives and assist in an understanding of the direction and timeline of SLR. This will provide information for other districts in planning for population fluctuations.

4.2 SLR Model

The SLR model utilizes features in the 3D Analyst toolbox of ArcMap, a program within ArcGIS. This is a very simplistic model of SLR, unlike studies such as one from Biging et al, which use complex hydrology models to achieve higher accuracy levels of prediction for SLR impacts on San Francisco's transportation infrastructure [47]. A simplistic model for SLR was chosen due to the intended application of this literature on regional planning in underdeveloped areas, where large data processing capabilities are unlikely to be possible (due to both financial and data availability constraints).

SLR was modelled under a variety of time series and emissions scenarios in order to represent the variation in projections in current research. According to the UNDP, the Caribbean Sea is projected to experience a higher degree of SLR than most areas to the world. [29] This is likely due to its proximity to the equator as well as other geophysical factors. It is generally accepted that by the end of the 21st century, the sea level will be between 1-2 meters (3.28-6.56 ft) above present levels [29] It is important to note that the report states that SLR is a "chronic and unidirectional, negative threat to coastal areas in the Caribbean and globally, even if global temperatures are stabilized at 2-2.5 C" [29].

4.2.1 Representative Concentration Pathways for Global Mean SLR

The Representative Concentration Pathways (RCP) are climate scenarios developed in the Fifth Assessment Report of the IPCC. There are four pathways, RCP 2.6, 4, 6, and 8.5, in order from least to greatest radiative forcing (carbon emission) [28].

This study will utilize their RCP 2.6 and RCP 8.5 to model SLR, to provide a conservative and generous estimate for SLR. Note that these increases are based off 1986-2005 baselines for sea level, with a 66% central probability [28]. These data points are the mean of the expected range with a 95% confidence interval.

RCP Pathway	**2050**	**2100**	**2300**
RCP 2.6	0.98ft	0.98-2.13ft | mean: 1.55ft	2.06-4.32 ft | mean: 3.19ft
RCP 8.5	0.98ft	1.77-7.05ft | mean: 4.41ft	5.47-18.40 ft | mean: 11.9ft

RCP Scenarios, Source: [31][33]

The following graphs represent the IPCC predictions for both the 2.6 and 8.5 RCP scenarios.

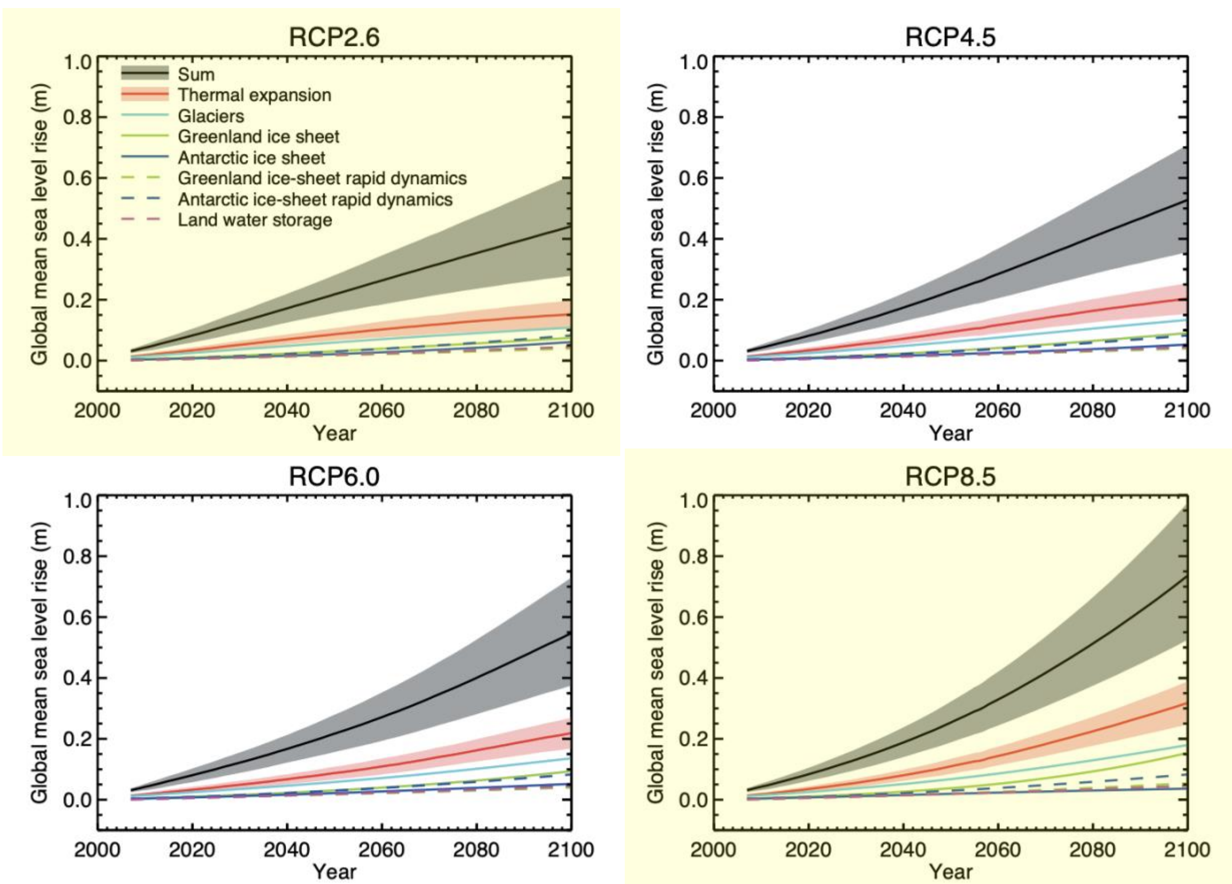


Figure 2: RCP Scenarios, Source: IPCC Chapter 13 - Sea Level Change [28]

4.2.2 Projections for Coastal Flooding

As discussed in the introduction, regarding drivers to climate migration, it is not only climate processes such as SLR that will impact migration, but the frequency of climate events such as coastal flooding. Particularly because the San Blas Islands do not have robust infrastructure to manage extreme flooding, and because of the high proximity of houses to the shoreline, this is likely to be a significant driver to migration. During the introduction, it was discussed that extreme flooding events will occur annually by 2100 [33]. Extreme floods occur when a storm surge and high tide occur simultaneously and has a likely range from 10-20ft above mean sea level [29][7]. This study will model the effect of the mean, a 15ft flood above mean sea level in order to model the effects of climate events [33].

It is important to note that these projections are likely under-representations of climate drivers for migration, due to the exclusion of weather patterns, impacts on agriculture, impacts of thermal expansion, and many more variables. A minimum level of processing is significantly more feasible than a complex hydrology model for local and regional planning.

4.3 Suitability Analysis

A suitability analysis layers regional factors together and assigns them weights for their respective suitability for a given problem and displays them as an aggregation [27]. This is useful for planning for climate migration because it is a visual representation of the most and least suitable areas for relocation and can provide data driven locations. This suitability analysis utilized data from the Smithsonian Tropical Research Institute that aggregated a variety of ArcGIS shapefiles with spatial distributions of social and ecological factors. These shapefiles were reclassified in ArcMap 10.8 and displayed as an aggregate of opportunities and constraints. Opportunity maps display areas that possess suitable characteristics for relocation with a positive weight [26]. Constraint maps display areas that possess suitable characteristics for location with a negative weight [26].

4.3.1 Opportunity Factors

Variable Name	**Variable Description**	**Data Source**	**Rationale for Variable Selection**
VPOCLUEL	Access to electricity	Corregimientos and Neighborhoods 2010 Census Report, Smithsonian Tropical Research Institute (STRI) [39][41]	Access to electricity indicates a higher living standard and access to services that migrants may need access to.
VPO	Far from occupied homes	Corregimientos and Neighborhoods 2010 Census Report, STRI [39][41]	The Guna Yala's independence and autonomy will be supported through the selection of a relocation destination where they can move as a community, requiring a significant distance away from currently occupied houses.
Roads	Proximity to roads	Panama's OSM Road Network, STRI [46]	Proximity to roads allows for accessible travel to the desired location.
Medical Facilities	Proximity to medical facilities	Health Institutions in Panama, STRI [42]	Medical facilities are necessary infrastructure that may be required if migration is forced by a natural disaster.
Districts	Proximity to San Blas Islands	Panama Corregimientos Boundaries, STRI [39]	Areas near the San Blas Islands in Comarca Guna Yala will be easiest to migrate to and most similar culturally.
Arable Land	Abundance of land viable for farming	Geology of the Republic of Panama, STRI [36]	Areas with farming capacity will allow the Guna to maintain their practices and utilize their already developed industry.

4.3.2 Constraint Factors

Variable Name	Variable Description	Data Source	Rationale for Variable Selection
VPOSAGPO	Limited access to clean water	Corregimientos and Neighborhoods 2010 Census Report, STRI [39][41]	Areas with low access to clean water would provide obstacles to re-settlement.
VPOSSESA	Limited access to sanitary facilities	Corregimientos and Neighborhoods 2010 Census Report, STRI [39][41]	Areas with low access to clean water would provide obstacles to re-settlement.
Rivers	Avoid high proximity to major rivers	Panama's Hydrology Network, STRI [44]	Avoiding areas that are close to rivers would prevent damages due to flooding.
National Parks	Avoid National Parks	Panama's Protected National Parks, STRI [45]	National Parks are protected areas and residence is prohibited.
Storm Surge	Avoid areas vulnerable to flooding	Panama Digital Elevation Model – 5 meter resolution, STRI [38]	Areas that are likely to be flooded are unsuitable for relocation in the long term.

Part 5: Data Analysis and Results

5.1.1 Flow Chart for RCP Scenarios 2.6 and 8.5 and Storm Surges

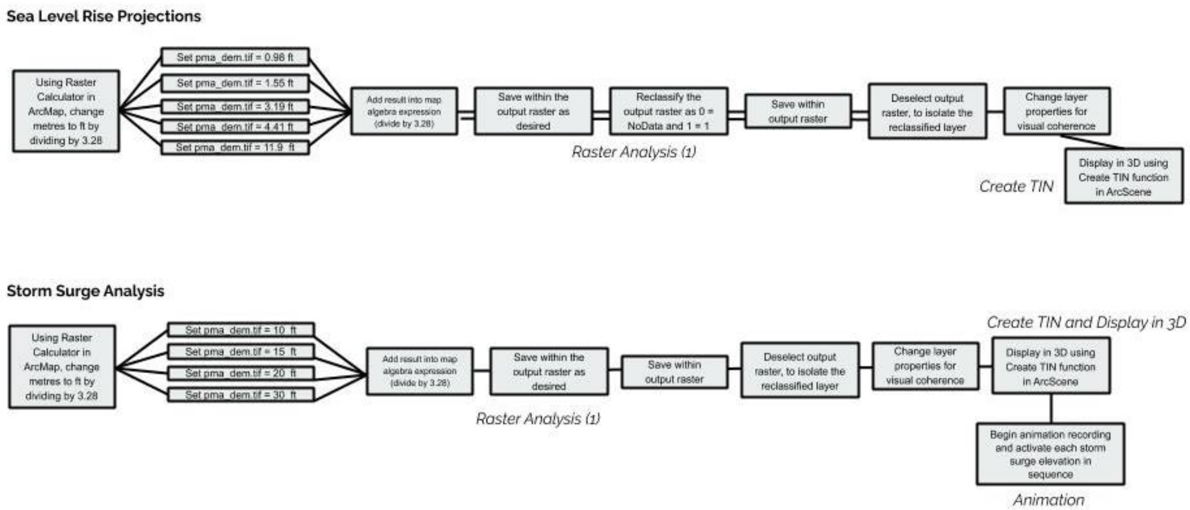


Figure 3: Flow Chart to Code SLR and Storm Surge Maps

5.1.2 RCP 2.6 SLR Mapping

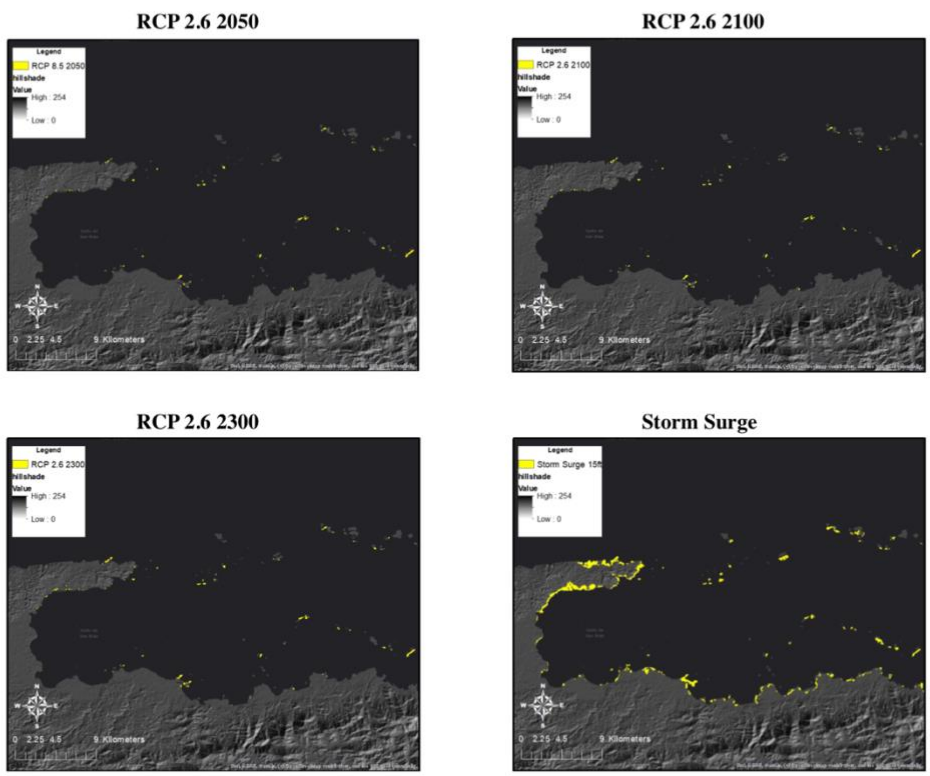


Figure 4: RCP 2.6 Sea Level Rise and Storm Surge Projection 2050, 2100 and 2300

5.1.3 RCP 8.5 SLR Mapping

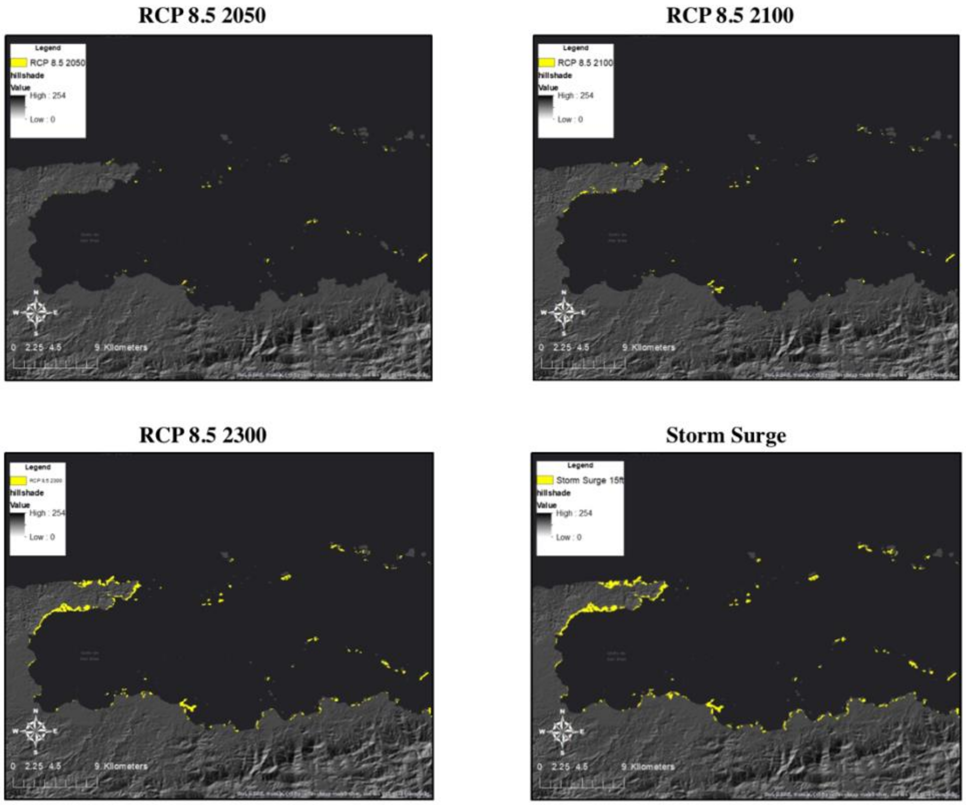


Figure 5: RCP 8.5 and Storm Surge Projections 2050, 2100 and 2300

5.2.1 Flow Chart for Gardi Sugdub Case Study

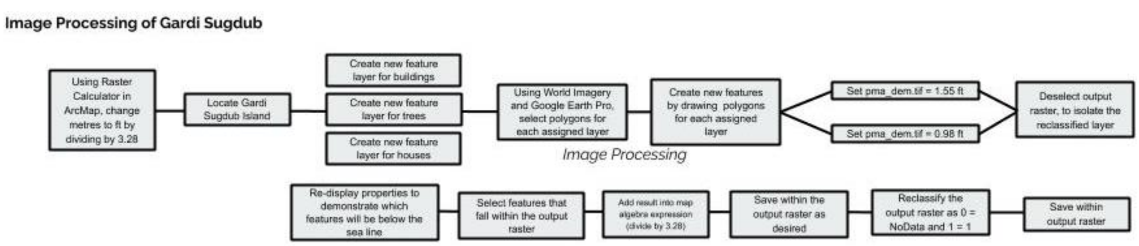


Figure 6: Flow Chart to Code Image Processing for Gardi Sugdub

5.2.2 Final Map of Gardi Sugdub Case Study

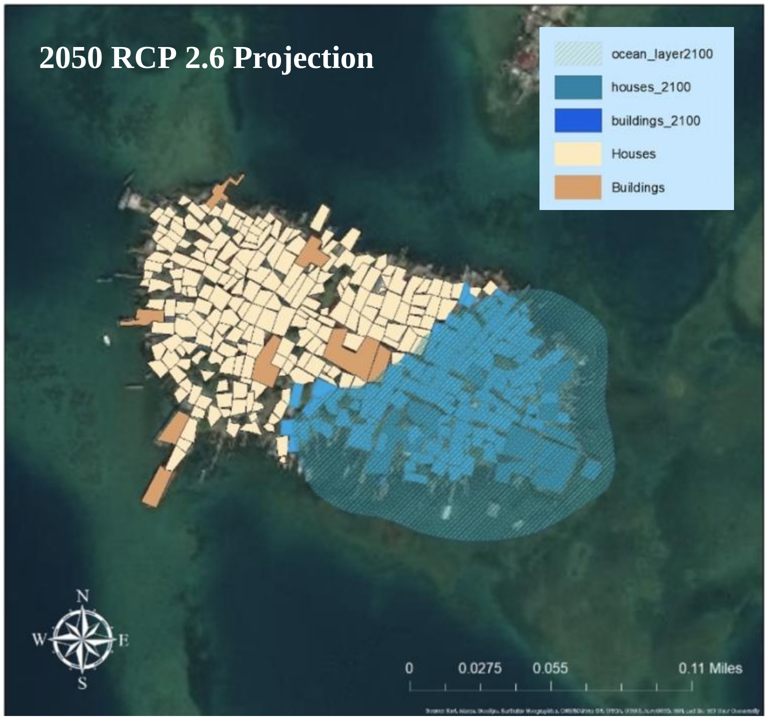


Figure 7: Gardi Sugdub 2050 RCP 2.6 Projection

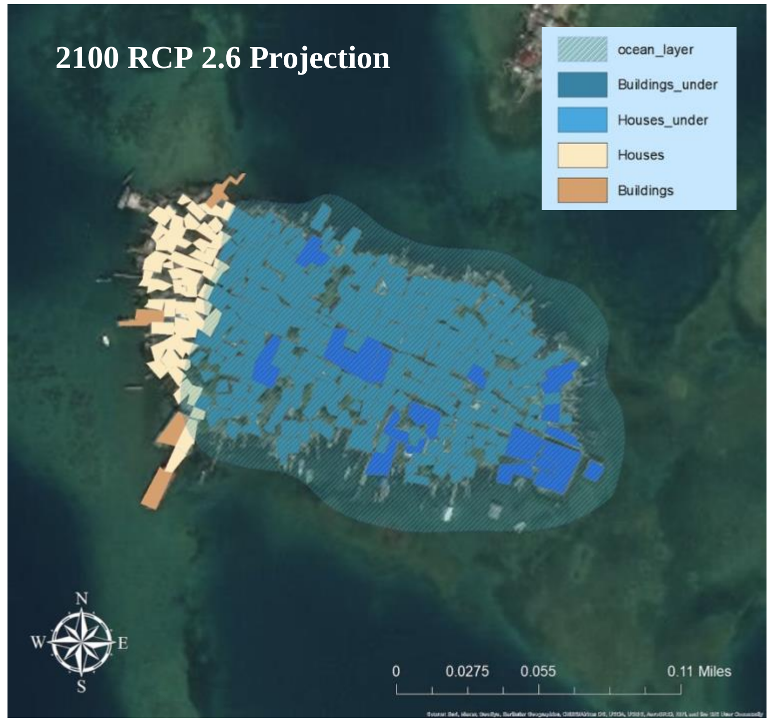
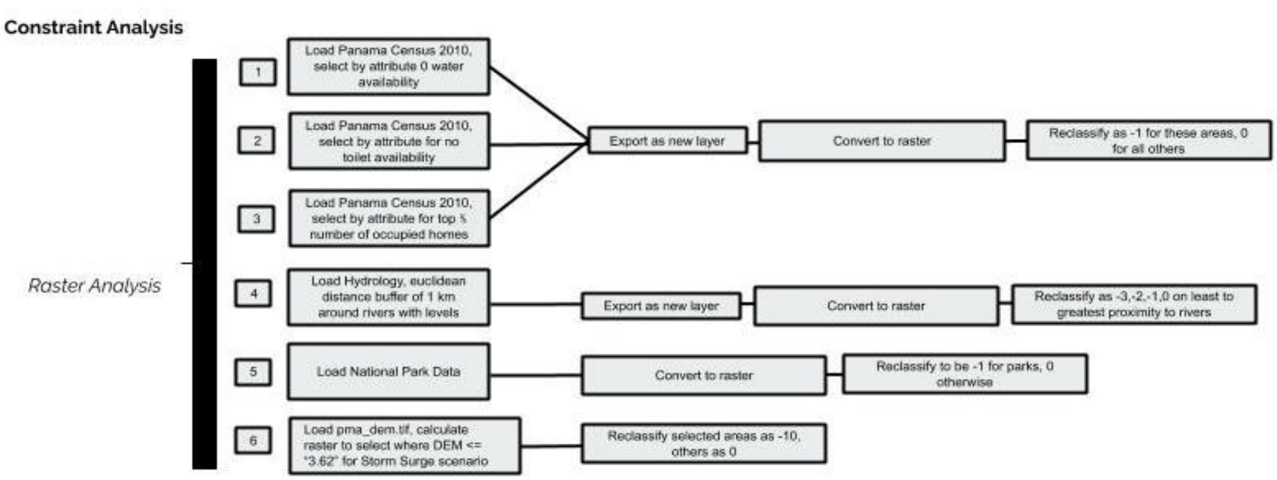


Figure 8: Gardi Sugdub, 2100 RCP 2.6 Projection

5.3.1 Flow Chart for Suitability Analysis



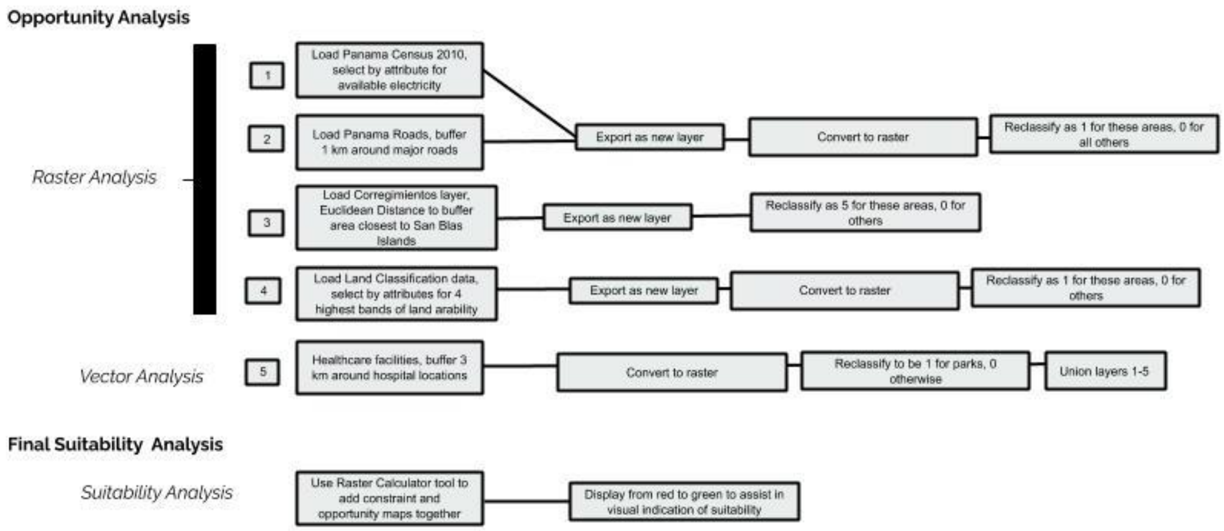


Figure 9: Flow Chart to Code Suitability Map

5.3.1 Suitability Maps

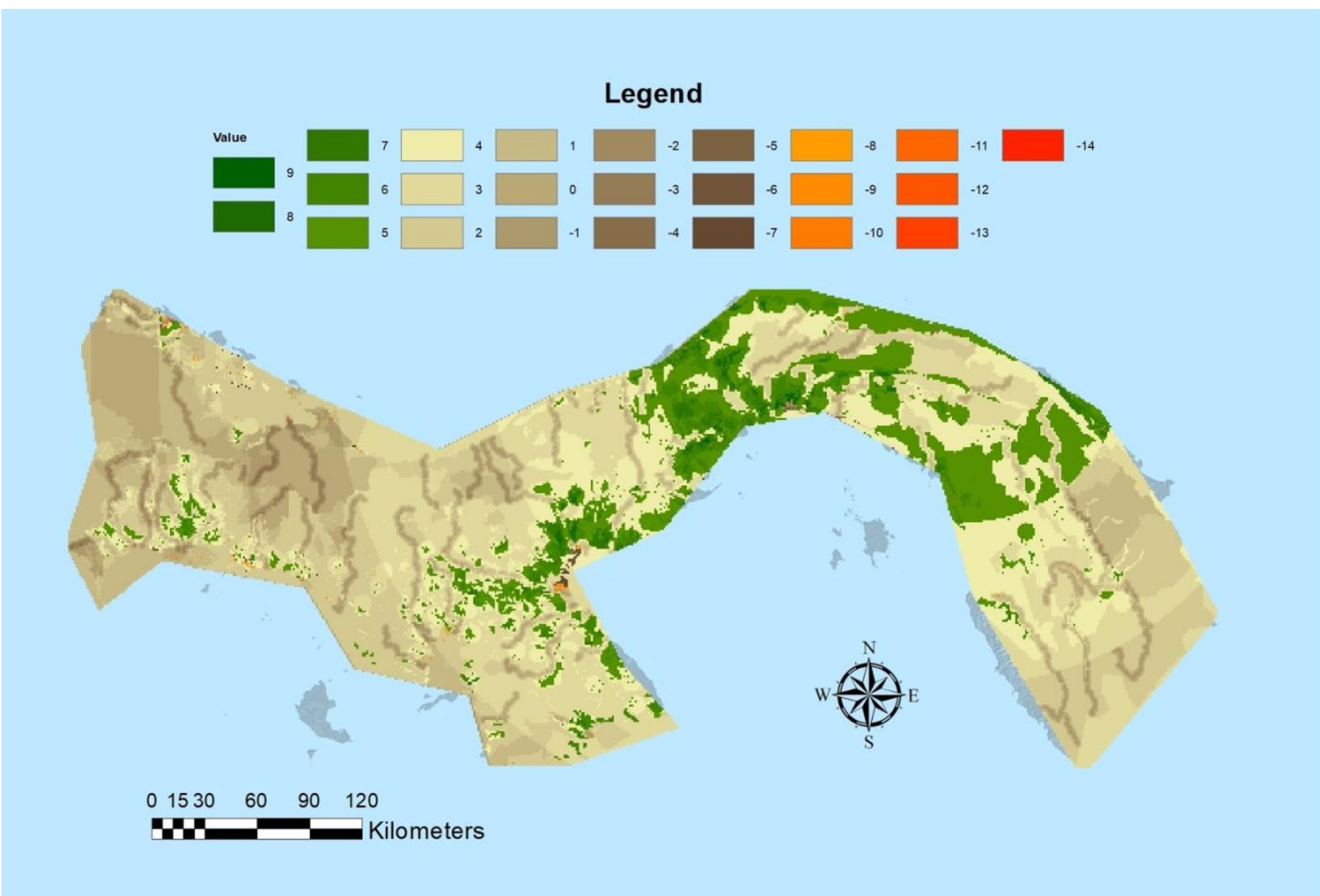


Figure 10: Final Suitability Map

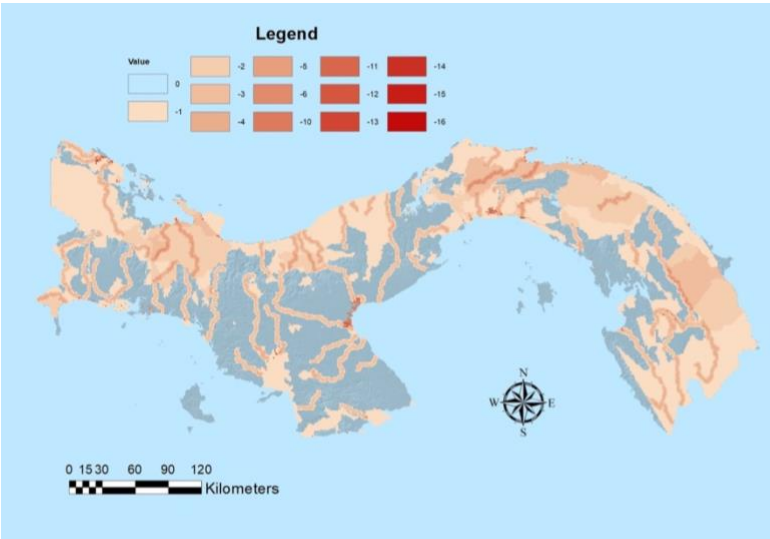


Figure 11: Constraint Map

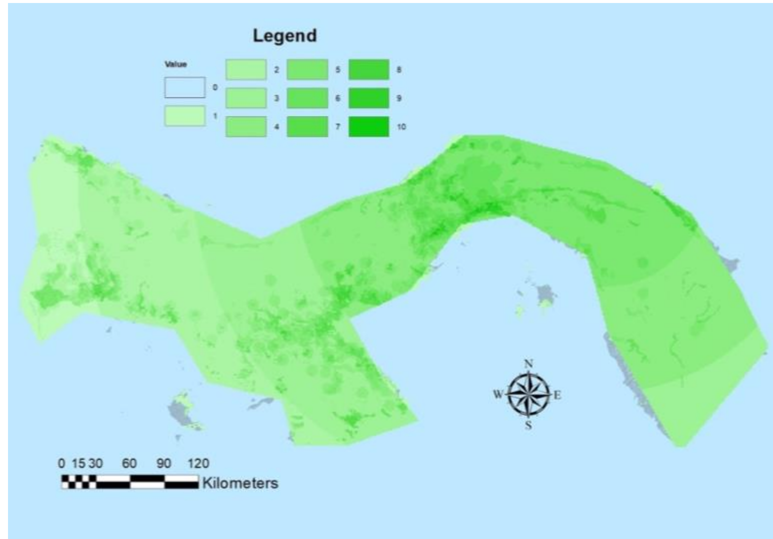


Figure 12: Opportunity Map

Part 6: Discussion and Results

6.1 SLR Model

Based off the maps for both 2.6 and 8.5 RCP scenarios, climate migration will be necessary the next 30 years. Figure 4 and 5 highlight the islands that will be partially or fully submerged and cover the majority of the San Blas Islands under all scenarios. This indicates that planning for climate migration must begin immediately to prevent the loss of culture and community that will likely result from unplanned migration.

While the RCP scenarios are important to understand the scope of expected inundation due to SLR, the impact of storm surges is likely to post a larger danger to the welfare of the Guna Yala. As noted, extreme weather events such as storm surges are likely to become an annual occurrence by 2100 [29][7]. The storm surge model utilizes an average of 15 feet of SLR, which not only floods all 400+ coral islands on which the Guna people live, but parts of the mainland as well. The Guna face storm surges with weak infrastructure, reliance on local farming and acute poverty [5]. These compounding factors indicate that storm surges are likely to force unplanned migration. With these models comes an increased incentive to act and collaborate for the Guna and Panamanian governments alike, as the danger of these storm surges increases as time progresses.

6.1.1 Model Limitations

This approach was completed without specialized equipment in order to ensure its applicability for local policymakers. However, this resulted in the simplification of the hydrology of SLR does present some barriers to accuracy. Particularly, this approach does not take into account regional fluctuations in SLR, and bases projections off of GMSLR. For example, this model does not take into account increased thermal expansion in equator-adjacent areas [8] and the coral reef destruction around the islands [8] that is likely to exacerbate SLR in this area. Additionally, recent studies suggest that RCP 2.6 is no longer a possible emissions scenario given current circumstances [25]. Therefore, this study's analysis of this scenario as a 'best case' is most likely to be a conservative estimate. These factors combined indicate that the SLR models in this study are highly conservative.

6.2 Case Study: Gardi Sugdub

Figure 7 and 8 display a highly conservative estimate for SLR in Gardi Sugdub. This island is one of the most densely populated in San Blas, with a population of 2000. The image processing in Figures 7 and 8 creates a feature layer for the 385 houses on the island. Under RCP 2.6 in 2050, it is estimated that 36% of houses will be inundated by the increased sea level. This projection estimates that 81% of houses will be inundated by 2100. Based off this model, SLR will primarily begin to affect the eastern infrastructure. The Gardi Sugdub talks with the government and private organizations [10] must reach an agreement in order for the community to relocate together. Although the majority of the island will likely remain above sea level by 2050, the partial submersion represents an estimated occupancy of 740 people. This number is based off the assumption that the population is evenly distributed across all 385 houses. With extremely limited data in the region, the exact distribution of residents on the island is unknown. Despite this limitation of analysis, 36% of houses is a non-trivial amount of the population that will likely have to migrate by 2050. With the intention of initiatives being to relocate the Gardi

Sugdub together, 2050 provides a viable time horizon given the level of inundation expected by this time. This graphic offers a visual to be utilized as an incentive to put relocation plans into action in the short term.

6.3 Suitability Analysis

The suitability analysis is an aggregation of the opportunity and constraint maps. The map indicates four viable districts for relocation based off the 11 social and ecological factors described in the methodology section.

Districts

ID_DISTRIT	PROVINCIA	DISTRITO
02	Panamá	Balboa
05	Panamá	Chepo
06	Panamá	Chimán
08	Panamá	Panamá
10	Panamá	San Miguelito

This table from ArcGIS represents the four districts that contain viable areas for relocation as being: Chepo, Chimán, Panamá and San Miguelito, all of which fall within the Province of Panama. These areas, as indicated by their high suitability score, fit within the parameters for a viable location for the Guna resettlement. Particularly, the region directly west of Panama City, known as La Chorrera, offers the highest level of suitability.

Earlier in this study, the disconnect between literature on climate migration was discussed. Particularly, the decision-making processes and cultural resilience of local populations is often disregarded as relevant to the decision to migrate. This study sought to offer an alternative methodology that would cater to the Guna people and be applicable for use by local policy makers around the world to initiate similar relocation initiatives.

Many of the selected variables justify suitability through universal suitability factors. For example, proximity to roads (for ease of transport), proximity to healthcare facilities and availability of sanitary services are likely to be consistently applicable between different regions. However, many social factors particular to the Guna people were considered. For example, proximity to the San Blas Islands was weighted heavily, due to the low mobility of the Guna people as discussed in the background section. It was estimated that a traveling distance greater than 200km would be highly prohibitive, and thus areas closer to the benchmarked location of the San Blas airport were heavily prioritized. The variable choice also sought to incorporate factors that would support the adaptations discussed in Part 4: Indigenous Adaptations and Resilience, which documented the specific adaptations of the Guna Yala ed by Apgar et al [5].

These were included in the layer analysis in the following ways:

Guna Practices for Adaptative Capacity	**Integration into Suitability Layers**
Maintain a relationship with ecosystems	The culturally strong connection with land and sea was integrated through the selection of a region with high proximity to coasts, in order to maintain and respect this relationship and its centrality to culture.
High Social Cohesion	Areas without occupying communities were weighted as increasingly suitable due to the strong community and independent governance of the Guna Yala.
Collective management of resources	Areas with highly arable land were sought in order to maintain the central subsistence farming practice.
Management of relationships with other knowledge systems	The overarching approach to the suitability analysis sought to support community-driven approaches to climate migration, to support the autonomy and interdependence of the community.

6.3.1 Limitations of Suitability Analysis

A limitation of the study is the number of socio-ecological factors that could be processed. This was largely due to desktop processing capacity and lack of country-wide data in Panama. Furthermore, the subjective weighting of each of the layers indicates that there is significant room for bias and data manipulation in the creation of a suitability map. Unlike empirical models such as the gravity, or radiation models discussed previously, the inputs of a suitability analysis are distinctly based on the choice of the map author. For local policy makers utilizing this methodology, a high degree of scrutiny over the selection and weighting of map layers must be present in order to verify the results of the study. The purpose of this map is distinct from a migration model because of its integration of chosen and weighted socio-ecological factors, and thus cannot be compared with regards to its empirical validity. However, the level of specificity achieves on recommendations for the Guna Yala is to a higher degree based off the group's specific needs, rather than general population fluxes.

Another limitation of the suitability analysis is regarding the opportunity layer which buffers San Blas in order to determine which regions are most suitable for relocation (as proximity can be a driver to migration). Because of a lack of detailed road network data, the only buffering that is possible given the data parameters was that which buffered using Euclidean distances. This develops a polygon that demonstrates a 200 km range from the San Blas Airport. The utilization of Euclidean distances does not take into consideration topology or transportation accessibility in its distance buffer, and therefore the 200 km range has a low level of detail for planning purposes. Future studies with increased data availability could utilize Manhattan distances in order to take into account more detailed factors that impact proximity.

Although the integration of these factors into suitability factor decisions is a step towards the inclusion of adaptive capacity in migration planning, it could be significantly improved with input from local experts. The implementation of this methodology for the Guna Yala could include consultation with indigenous leaders to understand what factors are most important for them when determining relocation options. It is important to note that while this analysis offers potential pathways for migration, it is a far-removed analysis from the realities of cultural and ecological factors in Panama. Although this study provides a suggestion of methodology and a sample conclusion given the factors selected, its implementation must be community-driven if it is to be successful.

It is important to note that the suggested methodology is not a direct substitute for the gravity, radiation and instrumental variable models discussed in the literature review. This solution incorporates climate science and environmental planning techniques, while the models discussed fall into the environmental economics discipline. The results of the methodology are therefore not in a medium which allows them to be easily included into damage functions, and therefore unsuitable for large scale estimations of climate impacts. The incorporation of inter-disciplinary techniques is a direct response to the two central flaws discussed in the literature review: the lack of applicability and inclusion of cultural adaptivity in current climate modeling efforts.

However, the models discussed in the literature review section can be modified for inclusion in environmental planning techniques such as network analysis, which could be an area of further research. The Gravity Model discussed in the literature review section can be modified to take into account cultural factors and map relocation destinations by weighting potential locations by their socio-ecological viability and Manhattan distance from the San Blas Islands. With publicly available data, there is not a detailed enough road network shapefile to complete this analysis, but future research could put the methodologies discussed in this study in practice through the utilization of private (paid) data sources.

The overarching limitation of this study and the field of climate migration modeling as a whole is the lack of data in vulnerable regions. Although this can be partially mitigated by the use of privately sourced databases and locally gathered information, low data availability remains a barrier to the development of a methodology for understanding future climate migration.

Conclusion

The key findings of this study demonstrate the urgency for planned relocation initiatives for the Guna Yala and offer a potential methodology for selecting relocation destinations that incorporate factors specific to the culture of the Guna. This analysis was completed through a model of sea level rise applied to San Blas Panama from 2050-2300, as well as an estimation of inundation due to extreme climate events such as storm surges. By 2050, a significant portion of the islands will be inundated due to SLR, and by 2300 we can expect to see inundation of sections of the mainland. After an analysis of the Guna Yala's vulnerability and cultural resilience to climate change, 4 adaptations were integrated into an analysis of suitable regions for relocation through a suitability analysis. The suitability analysis visually demonstrates viable areas for resettlement based off 11 socio-ecological factors, highlighting La Chorrera, which lies to the west of Panama City, as the area with the highest convergence of opportunity. Limitations of specificity due to data availability and GMSLR predictions are present. These limitations could be partially mitigated by the use of higher resolution Digital Elevation Models and utilization of a more complex hydrology model for SLR as opposed to simplified RCP projections. The central limitation of this methodology is its inability to be a direct substitute for the mobility models discussed in the literature review, by offering an inter-disciplinary, solution-based approach for the study of climate migration. This can be progressed upon in future research through the utilization of network analysis to create a gravity model. Overall, this study presents a simplified but viable alternative to climate modeling that achieves the aims of being applicable for planning by local and national governments and sensitive to cultural specificity. Future research is required to mitigate the limitations discussed, increase the applicability of recommendations through community consultations, and further the aim of this research in creating a globally applicable methodology for community-driven migration planning.

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