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Modeling Scenarios of Sea-level Rise and Human Migration: Rita Village, the Republic of the Marshall Islands

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Modeling Scenarios of Sea-level Rise and Human Migration: Rita Village, the Republic of the Marshall Islands

Modeling Scenarios of Sea-level Rise and Human Migration: Rita Village, the Republic of the Marshall Islands

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of the requirements for the degree of
Doctor of Philosophy in Environmental Dynamics

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ABSTRACT

This study explores the relationship between sea-level rise and human migration from Rita Village in the Republic of the Marshall Islands (RMI). As one of only four low-lying atoll countries at the forefront of risks associated with climate change, examining the extent to which sea level will rise and displace residents in the Marshall Islands is of timely importance. The approach to this research is a scenario-based, case study and it examines loss of home, human displacement and subsequent migration in Rita Village as a result of varying levels of sea level rise. The scenario-based approach is based on the four Representative Concentration Pathways as defined by the International Panel on Climate Change, which range from a best case scenario to a worst case scenario of sea level rise. This research also examines distribution of the migration stream resultant from displacement by sea level rise to key destinations in the United States, including Hawaii, Arkansas and Washington State. The major findings suggest that sea level rise will be a key factor in migration from Rita Village to the year 2100. The best case scenario suggests that at least half of the population will be displaced by sea level rise by the year 2100, while the worst case scenario suggests complete inundation and total displacement of the population of Rita Village by 2100. The findings also suggest Hawaii, followed by Arkansas and then Washington State will experience the highest rates in migration of those displaced by sea level in the Marshall Islands.

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A thank you is in order to my colleague and friend, Mark Stege, for providing data and support for my work. I would also like to thank my Marshallese friends both here and in the Marshall Islands for their encouragement and support. I truly hope we find a climate solution that protects your beautiful home country from sea level rise.

And to my husband, Jason and my daughter, Nina; Thank you from the bottom of my heart for holding down the fort and making me laugh on a daily basis, even when the going got tough. I would not be where I am without you two.

DEDICATION

For Jason and Nina, who support and love me unconditionally.

For my Mom and Dad, who inspired my love of learning and believed in me from day one.

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<u>Chapter I</u>

INTRODUCTION

The purpose of this research is to explore the relationship between sea-level rise and human migration from Rita Village in the Republic of the Marshall Islands (RMI). As one of only four low-lying atoll countries at the forefront of risks associated with climate change, examining the extent to which sea level will rise and displace residents in the Marshall Islands is of timely importance. Rita Village, located in the Marshall Islands, serves as the focus area of this research and a proxy for the rest of the country. The goal of this research then is to provide insight into the relationship between sea-level rise and migration, through a scenario-based framework, to inform climate change adaption strategies for inhabitants of the Marshall Islands and other low-lying atoll nations.

This research is merited on several grounds. One rests on the imminent risk associated with sea-level rise in low lying island nations generally, and the Marshall Islands specifically. The deleterious effects of climate change have become visible in this low-lying atoll nation and are an immediate concern for the Marshallese (De Brum et al., 2013; Loeak 2013, RMI Ministry of Foreign Affairs 2014). The latest sea-level rise projections to the year 2100 range from approximately 0.44 meters to over one meter (Church et al. 2013; IPCC 2013; Jevrejeva et al. 2012; Rahmstorf 2007 and 2012). With an average elevation of a mere 2 meters, the Marshall Islands is likely to be one of the first countries inundated by rising seas (Holthus et al. 1992; Rahmstorf 2012).

A second justification is the dearth of research on this and similar topics. While scientists continue to quantify the increasing magnitude of global warming and the potential environmental degradation to many low-lying countries (Australian Bureau of Meteorology and CSIRO 2011;

Barnett and Adger 2003; GRDRR 2011; IPCC 2013; Mimura et al. 2007; SPREP and APAN 2013), the inevitable impacts on human migration from the Marshall Islands remains largely unexamined.

A third justification for this investigation lies in the unprecedented policy and legal issues facing countries forced to fully evacuate due to rising seas. In the event that sea-level rise emerges as a primary factor in migration, the refugee status of those who flee is currently unclear (Gerrard and Wannier 2013). Additionally, the legal framework upon which a country operates when land disappears and the residents disperse is also uncertain (Gerrard and Wannier 2013). A comprehensive understanding of potential scenarios of sea-level rise allow for a more informed legal and strategic approach to protecting the rights of those impacted by climate change.

A final and notable justification for this research is the fact that as sea level continues to rise, adaptive outmigration by some or all of the resident population is likely (Bedford and Hugo 2008). By identifying areas at risk in the Marshall Islands and potential destination communities for those forced to flee, proactive social and economic programs can be implemented by individual migrants, sending communities and receiving communities alike. Anticipating an increase in migration and planning accordingly can serve to attenuate barriers to migration both at the individual and community levels and alleviate much of the stress associated with relocation.

In approaching this research, it is necessary to outline key challenges and limitation at the outset. One limitation is the uncertainty inherent in modeling the complex physical systems of climate change. While climate modeling has become increasingly sophisticated, there remain numerous plausible predictive models of future geophysical changes and socioeconomic behaviors generating a wide range of possible outcomes (Cubasch et al. 2013). To address the challenge of choosing among various predictive models, scenario-based modeling is employed in this research. This scenario approach provides a framework for addressing key uncertainties in the antecedents and drivers of climate change including technological and socio-economic developments (Settele et al. 2012). Indeed, the leading independent international scientific body, the Intergovernmental Panel on Climate Change, based its latest projections in the 2014 Fifth Assessment Report on scenarios of Representative Concentration Pathways (RCPs) (IPCC 2013). Thus utilizing the RCP Scenarios in this research allows for a range of outcomes which explicitly recognize the likelihood of inaccuracies in linear modeling.

Correspondingly, a key challenge also rests in the difficulty of predicting migration patterns (IOM 2009). While many variables have been identified as key components in decisions regarding migration (Massey and Taylor 2004), human agency remains exceedingly difficult to empirically measure. The scenario based methodology addresses this limitation by forgoing predictions based on linear reasoning and presenting a range of potential migration outcomes.

Another limitation is a function of the lack of complete data for all communities and subpopulations in the study area. Due to geographic isolation, poor infrastructure and little previous research, data for many atolls of the Marshall Islands are non-existent. In the face of these deficiencies, this research focuses on Rita Village on the most populated atoll of Majuro. The capital of Majuro currently hosts over half of the Marshallese population, and is one of the only atolls for which more complete data are available.

Similarly, to comprehensively examine migration streams, both sending and receiving communities would be included in the research. However, because there are several receiving communities in the United States with limited data on their Marshallese population, not all will be included in this research. Their exclusion does not imply unimportance, rather a function of the limited data available. To address this limitation, the research will focus on the three most prevalent receiving states of Hawaii, Arkansas and Washington.

Finally, an important challenge in conducting this type of research is related to the interdisciplinary nature of the problem. Scholarship on bridging social and physical sciences to examine the relationship between sea-level rise and migration is relatively scant. Many methods exist for forecasting migration (Bijak 2006), however the literature is lacking in the use of these methods with regards to sea-level rise.

The forthcoming examination of the relationship between sea-level rise and migration necessitates an overview of several topics and definitions of key concepts. To cover each of these in turn, this chapter is organized as follows. First, a broad country description of the Marshall Islands is provided, followed by an overview of existing migration patterns from the Marshall Islands. The chapter concludes with an overview of the organization of remaining chapters.

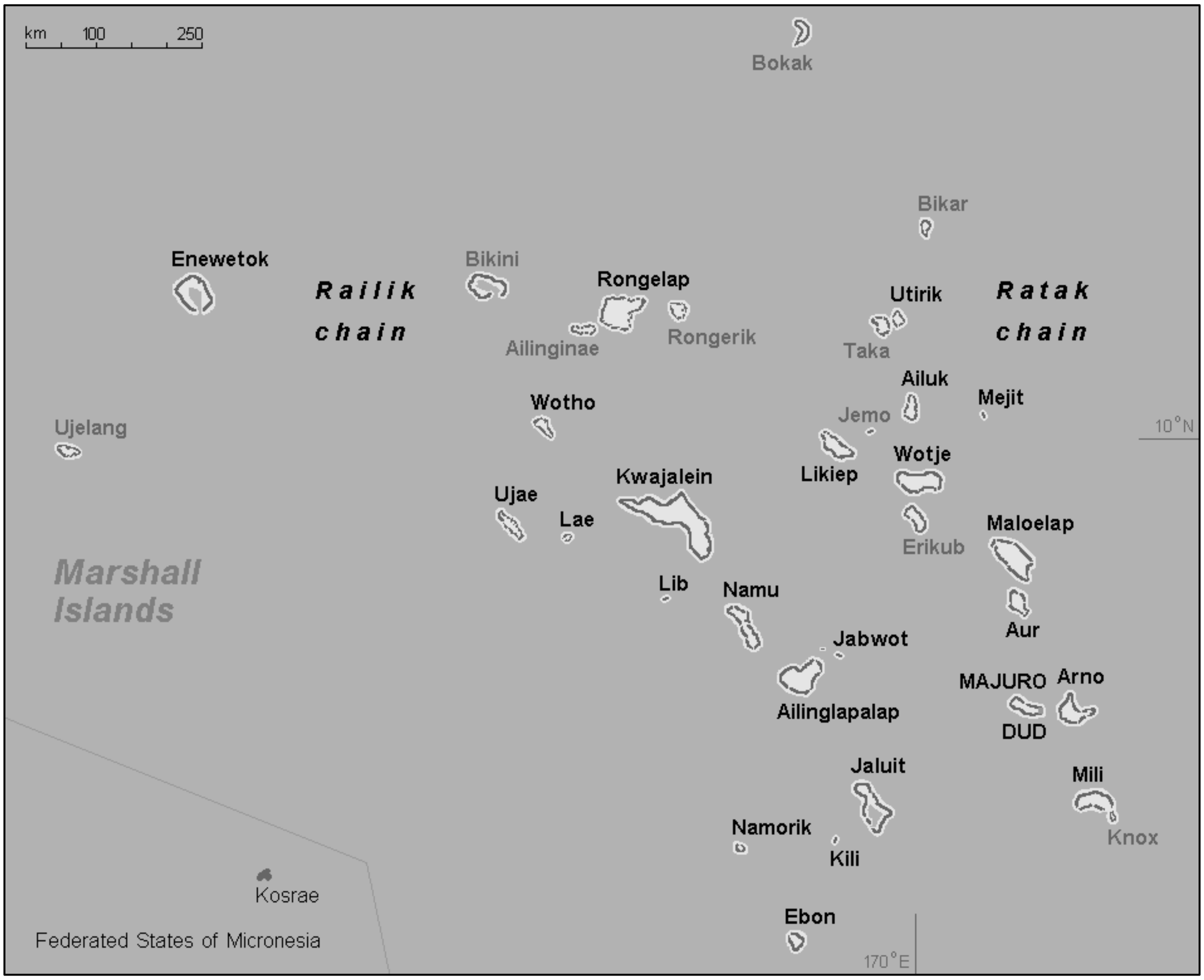
MARSHALL ISLANDS COUNTRY DESCRIPTION

The country description of the Marshall Islands includes the following: geography, formation and settlement; historic and current political structure; economic conditions; culture; demographic structure and composition; existing migration streams; seasonal, yearly and projected climatic conditions; a review of sea-level rise and future projections; and the link between sea-level rise and migration.

Geography, Formation and Settlement of the Marshall Islands

Located near the equator in the central North Pacific Ocean, between 4-14°N and 160-173°E , the Marshall Islands consists of 1,225 small coral sand and coralline algae sand atolls and islands all less than 3 meters above sea level. The land is spread over 1.9 million square kilometers of ocean (Pacific Climate Change Program 2011). As can be seen in Figure 1.1, the core 29 atolls and five islands form two parallel chains, 250 kilometers apart, called the “Ratak” (sunrise) chain and the “Ralik” (sunset) chain (Spennemann 2006). That Ratak Chain consists of Ailuk, Arno, Aur, Bikar, Bokak, Erikub, Jemo, Likiep, Majuro, Maloelap, Meji, Mili, Nadikdik, Toke, Utirik and Wotje Atolls. The Ralik Chain consists of Ailinginae, Ailinglaplap, Bikini, Ebon, Enewetak, Jabat, Jaluit, Kili, Kwajalein, Lae, Lib, Namorik, Namu, Rongelap, Rongerik, Ujae, Ujelang, and Wotho Atolls.

Figure 1.1: Map of the Republic of the Marshall Islands (Behr 2010).



The Marshall Islands exist as a result of Holocene reef growth that began on degraded Pleistocene carbonate limestone platforms 12 to 15 meters below present sea level around 8000 BP (Dickinson 1999). As eustatic sea level[1] continued to rise until around 4000 BP, these coral atolls continued to grow and kept pace with rising sea levels (Dickinson 1999). Empirical evidence suggests there was a sea level highstand that peaked in 4000 BP and the coral grew to that height, which is 1 to 3 meters higher than present day sea-levels (Dickinson 1999).

Although the evidence of this mid-Holocene highstand in the western equatorial Pacific has been questioned in the past (Shepard et al. 1967), the current scientific consensus supports a highstand of 1 to 3 meters higher than present day sea levels, lasting between 5000 and 1500 BP (Grossman et al. 1998; Pirazzoli and Montaggioni 1986 and 1988; Woodroffe et al. 1990; Woodroffe and McLean 1998). Due to geomorphologic variations in the ocean basin, regional variability existed in the extent of this highstand throughout the western Pacific (Mitrovica and Peltier 1991).

Research conducted primarily in the Marshall Islands narrows the highstand for that region to between 4000 and 2000 BP (Buddemeier et al. 1975; Dickinson 1999; Weisler 2001; Yamaguchi et al. 2005). The reduction of the western Pacific highstand is attributed to a process called *equatorial ocean syphoning* (Mitrovica and Peltier 1991). This syphoning occurred when water that was in the equatorial Pacific up to 4000 BP from post glacial eustatic sea-level rise was drawn away from the region to fill areas of the ocean basin that subsided as glacial forebulges collapsed (Mitrovica and Peltier 1991). The highstand dropped around 2000 BP, exposing the atolls (Dickinson, 2009). This highstand, the subsequent syphoning and lowered sea level was integral in the development and colonization of the Marshall Islands.

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[1] Eustatic Sea Level is a change to global sea levels due to changes in the volume of water in the world oceans or changes in the volume of the ocean basin (Meier et al. 2007).

Once above sea level, the atolls began collecting unconsolidated sediment from storm wash (Dickinson 2009). This sedimentation allowed the growth of vegetation and created an environment that could support human habitation (Dickinson 2009). Evidence of this timeline has been supported by analysis of reef flats, which reflect rapid carbonate deposition up until 2000 BP, followed by erosion (Buddemeier et al. 1975; Tracey and Ladd 1974).

Archaeological evidence suggests that the Marshall Islands were colonized not long after the atolls emerged from the ocean (Weisler 2001; Yamaguchi et al. 2005). Based on radiocarbon dates of prehistoric artifacts from Utrōk Atoll, Marshall Islands, human settlement began around 2000 BP (Dickinson 1999; Weisler 2001; Yamaguchi et al. 2005). Little is known about Marshallese prehistory but a general consensus in the limited research suggests the initial colonizers came northward from Melanesia (Irwin 1992; Smith and Jones 2007). The next section provides a capsule summary of the history of this habitation to present day of the Marshall Islands.

Historic and Current Political Structure of the Marshall Islands

The first Melanesian navigators settled and remained free of outside control for over a millennia and a half, until the Treaty of Tordesillas ceded ownership of the Marshalls to Spain in 1494 (RMI Embassy 2005). Spain held the Marshall Islands from 1494 to 1885, until the German government annexed the country from Spain for $4.5 million (RMI Embassy 2005). Germany held a protectorate over the Islands until Japan took military possession in 1914, during World War I (RMI Embassy 2005).

Due to recognition of the strategic military location in the Pacific Ocean, an Allied invasion of the Marshall Islands occurred in 1943 during World War II, effectively ousting Japan

(RMI Embassy 2005). Following the end of World War II, the United States had operative control of the Islands (RMI Embassy 2005). In reaction to the nuclear detonations of World War II and the onset of the Cold War, the United States government began a 12-year nuclear testing program in the Marshall Islands from 1946 to 1958 (Simon and Robinson 1997). Sixty seven nuclear bombs were detonated; 44 on or near Enewetak Atoll and 23 at Bikini Atoll (Simon and Robinson 1997). Rongelap Atoll was heavily impacted by fallout (Simon and Robinson 1997).

The largest detonation, the 15 megaton “Bravo Shot” on March 1, 1954, scattered radioactive fallout over many of the atolls as a result of wind shear atmospheric conditions (Beck et al., 2010). To this day, those relocated from Rongelap and Bikini have not been able to return home (RMI Embassy 2005). Significant levels of radioactive isotopes have been measured, not only on Rongelap and Bikini, but also on Rongerik, Utirik and Ailinginae Atolls (RMI Embassy 2005). Twenty of the 67 nuclear tests were found to have deposited significant radioactive fallout on all 25 inhabited atolls (Beck et al., 2010). Runit Island, the most radioactive of the islands, became a dump site for over 100,000 cubic yards of radioactive soil and debris with human habitation being ruled out forever (Johnson 1980). The long term direct and indirect effects of this testing, including but not limited to increased rates of cancer, destruction of native food sources and loss of culturally significant homeland, are relevant and problematic to this day (Barker 2013; Niedenthal 1997). The nuclear legacy and strategic military arrangements resulted in the Marshall Islands transitioning from a United States Trust Territory to a self-governing country.

The Republic of the Marshall Islands is a relatively young country, having gained sovereignty on October 21, 1986 (RMI Embassy 2005). It is a parliamentary democracy with three branches of government (Executive, Legislative and Judicial) in free association with the

United States (RMI Embassy 2005). The Compact of Free Association, entered into force in 1986 and amended in 2003, allows Marshallese migrants to enter and work freely in the United States indefinitely without typical immigration protocol (U.S. Department of State 2014). In return, the United States maintains a missile testing facility and Naval Base on Kwajalein Atoll, pays monetary nuclear testing reparation to the Marshallese government, and offers military protection and aid (RMI Embassy 2005). The following section outlines the economic conditions of the Marshall Islands.

Economic Conditions in the Marshall Islands

The Republic of the Marshall Islands is classified by the United Nations as a Small Island Developing State (U.S. Department of State 2014). The economy remains relatively small, with a GDP official exchange rate of about US$ 193 million, and is largely dependent on payments from the United States guaranteed through the Compact of Free Association (U.S. Department of State 2014). Between 1986 and 2001, the Marshall Islands received nearly $1 billion in United States aid and lease payments for the use of Kwajalein Atoll as a United States naval base (CIA 2014). Under the renegotiated Compact of 2003, the country will receive an additional $1.5 billion in aid from the United States (CIA 2014).

The Marshall Islands economy also has a natural resource/agriculture sector consisting of fishing, breadfruit, banana, pandanus, and taro cultivation (RMI Embassy 2005). The service sector of the economy is located in Majuro and Ebeye, and is sustained by copra and fish processing, tourism, government expenditures and the U.S. Army base at Kwajalein Atoll (RMI Embassy 2005).

On the outer islands, cash income is generated by production of copra and handicrafts

(RMI Embassy 2005). The total labor force is numbered at 13,060, with a Gross National Income (GNI) per capita of $4,040 (World Bank 2012). Of the 41.7% of the population that participate in the labor force, 3.2% are unemployed (EPPSO 2011). The next section offers a brief overview of the culture of the Marshallese people.

Marshallese Culture

Traditional Marshallese culture was heavily influenced by a necessity to navigate the ocean (RMI Embassy 2005). Stick charts were developed by studying the currents and the sky in order to map atoll locations and swell patterns (RMI Embassy 2005). While urbanization and westernization have reduced the dependency on sailing and navigating skills, the country is initiating programs in navigation and canoe building to keep these traditions alive (RMI Embassy 2005). The diminishing effects of urbanization, high population density and western influence on traditional foodways and culture in the urban centers of Majuro and Ebeye are notable, while the outer atolls are still based in the traditions of subsistence (Saunders 2013). Traditional handicrafts are still a part of the current economy and the craftsmanship is highly regarded (RMI Embassy 2005).

With regard to interpersonal relationships, many individual, family and community interactions are based on land rights inherited through generations of maternal lineage (Kijiner 1999). The land rights are based on a complex matrilineal ownership structure where *wato* (plots of land that runs from ocean to lagoon) are divided up to families under the supervision of *lerooj* (female chief) *or irooj* (male chief) (Stege 2008; Saunders 2013). One of the most significant family events is the kemem, or first birthday of a child, where relatives and friends come together to celebrate with a large meal, singing and dancing (RMI Embassy 2005). Extendedfamily ties are an important part of the culture, creating strong communities rooted in kinship (Davis and Farmer 2012, Sharp and Vas Dev 2006). The Marshallese people are known throughout the Pacific region for their cooperative, kind and sharing nature (Genz 2008; RMI Embassy 2005). These values are considered imperative for existing on very small pieces of land surrounded by ocean (Genz 2008; RMI Embassy 2005).

In terms of religion, Christian missionaries began work in 1857 on Ebon in the Marshall Islands and have continued to present day (Hezel 1994). These efforts have resulted in nearly all Marshallese currently identifying as various denominations of Protestant Christian, Roman Catholic or Mormon (RMI Embassy 2005). Both Marshallese and English are official languages of the Marshall Islands (RMI Embassy 2005). The following section covers the demographic structure and composition of the Marshall Islands as of 2011.

Demographic Structure and Composition of the Marshall Population

A census of the Marshall Islands, conducted in 2011, enumerated a total population of 53,158 (EPPSO 2011). With a median age of 20.3, Males numbered 27,243 while females, with a median age of 20.9, numbered 25,915 (EPPSO 2011). The total number of households is 7,738 with an average household size of 6.8 persons (EPPSO 2011). It is a relatively young population, with nearly 40% under the age of 15 and only 2% over age 64 (EPPSO 2011).

In terms of population distribution, 73.8% of the population now resides on the two atolls designated as urban areas; Majuro (52.3%) and Kwajalein (21.3%) (EPPSO 2011). With a land area of only 9.71 km^2 and a total population of 27,797, Majuro has a population density of 2,860/km^2 (EPPSO 2011). A trend towards continuing urbanization is evident as Majuro had a net migration rate of 598 inter-atoll/island migrants between 2006 and 2011 (EPPSO 2011). Only seven other atolls had more inter-atoll/island in-migrants than out, ranging from 3 to 29 net migrants (EPPSO 2011). The remaining 18 atolls lost between 2 and 150 residents to other atolls during that 5 year time span (EPPSO 2011).

In terms of overall population growth rate, the entire country has seen a decline in the rate from a high of 4.1% during the period of 1980-1988 to a mere 0.4% between 1999 and 2011 (EPPSO 2011). Causes of this decline include a drop in the rate of natural increase (the difference between the crude birth rate and crude death rate) from 3.7% to 2.8% between 1999 and 2011 and a drop in the fertility rate from 5.7 per woman in 1999 to 4.1 in 2011 (EPPSO 2011). The primary reason, however, for the decline in the growth rate of the population is due to out migration (EPPSO 2011). The characteristics and dynamics of Marshallese out migration are outlined in a subsequent section. First, a look at the climate of the Marshall Islands, sea-level rise and the links between sea-level rise and migration are provided.

Seasonal, Annual and Projected Climate Conditions in the Marshall Islands

The Marshall Islands have a warm, tropical climate year-round, with average temperatures around 27°C and an average of 3500 mm of rainfall per year (RMI Embassy 2005). The wet season occurs between May and November and a drier season between December and April (RMI Embassy 2005). However, because the atolls are spread over such a large expanse of ocean, the northern atolls received less than 1250 mm of rain each year, while the atolls closer to the equator receive more than 2500 mm of rain each year (BoM and CSIRO 2011).

From year to year, the climate varies considerably in the Marshall Islands due to the El Niño Southern Oscillation (ENSO) (BoM and CSIRO 2011). ENSO occurs in the tropical Pacific and cycles between El Niño, La Niña and a neutral phase (Chang et al. 2013). In the Marshall

Islands, La Niña tends to create conditions that are wetter than average, while El Niño tends to create a warmer wet season and warmer, drier dry season (BoM and CSIRO 2011).

The Marshall Islands also face extreme weather events such as typhoons, droughts and storm surge, which can cause considerable damage to infrastructure, water supplies and food crops (Graham 2007; Hwang and Hamilton 2014). It is anticipated that these events will be further exacerbated and magnified by sea-level rise over the coming decades (Hwang and Hamilton 2014; Spennemann 1998).

The marginal environment of a coral atoll creates a broad array of challenges to human habitation (Weisler 1999; Yamaguchi et al. 2005). These challenges include scarce and scattered land, a scarcity of fresh water and an extremely low-lying topography vulnerable to storms, king tides and erosion (Rudiak-Gould 2011). Despite the intrinsic vulnerability of atoll life, the Marshallese people have successfully inhabited their atolls for more than two millennia (Weisler 2001; Yamaguchi et al. 2005).

This habitability, however, has recently come under a new threat due to modern, anthropogenic global warming and the associated regional climatic effects including rising sea levels (Barnett and Adger 2003; McGranahan et al. 2007). Temperatures have increased in Majuro since 1956 at a rate of .12° C per decade, rainfall is in a decreasing trend, sea level has risen about 7mm per year since 1993, and the oceans around the Marshall Islands are slowly acidifying (BoM and CSIRO 2011). Increasingly intense and frequent storms, flooding, coastal erosion, drought, salt-water intrusion of the fresh water lens, loss of arable land and complete inundation magnify existing vulnerabilities and threaten future habitability in an unprecedented way (Weisler 1999; Yamaguchi et al. 2005). Of particular concern in this research is the upward trend in sea level. The following section will provide data on the history and future of sea-level rise.

Historic and Future Trends in Sea-level rise

Sea level has always been dynamic on this planet. Due to changes in orbital forcing and natural changes in atmospheric composition, the earth has responded by cycling between glacial and interglacial periods with corresponding fluctuations in sea level (Church et al. 2008; Church et al. 2010). Sea level has changed by more than 120 meters as land ice has accumulated and ablated throughout earth's history (Church et al. 2010). During the last interglacial period, approximately 125,000 years ago, sea level was 4 to 6 meters higher than it is today (Rohling et al. 2008) and temperatures were about 3° to 5° warmer than today (Otto-Bliesner et al. 2006). The last glacial maximum was approximately 20,000 years ago. Between 20,000 and 6000 years ago, as glaciers melted, sea levels rose approximately 1 to 4 meters per century (Church et al. 2010). From about 6000 to 2000 years ago, sea-level rise slowed and only increased a total of 2.5 meters (Church et al. 2010). During the 18th and 19th centuries, sea-level rise was accumulating a mere .2 millimeters per year until the end of the 19th century (Church et al. 2010).

Before 1900, there were only a few tide gauges recording the first instrumental record of sea levels (Douglas 2001). Recording became more common place throughout the 20th century with increasing numbers of tide gauges and the advent of satellite altimetry in 1993 (Church and White 2011). Modern instrumentation has allowed for a more accurate measurement of both Global Mean Sea Level[2] and Local Sea Level[3] (Church and White 2011). The data from these

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[2] The average measure of sea-level using all tide gauge and/or satellite data of relative sea level over a period long enough to average out short term changes due to waves and tides.

[3] The average measure of sea-level from local tide gauges.

instruments, along with coastal sediment cores and other paleoclimate data, suggest it is very likely that the mean rate of global averaged sea-level rise was 1.7 mm/year between 1901 and 2010, 2.0 mm/year between 1971 and 2010, and 3.2 mm/year between 1993 and 2010 (IPCC 2013). Tide-gauge and satellite altimeter data are consistent regarding the higher rate of the latter period (IPCC 2013). These data suggest an increasing rate of sea-level rise that has not been seen in several thousand years (Church et al. 2010).

Although these are the most accurate data to date on sea-level rise, there are limitations to the measurement process. The difficulty of quantifying observed global mean sea level is due to factors including history, location and type of measurement instrumentation and the global variability of sea-level rise due to vertical land motion, regional meteorological effects, modes of climate variability, long-term trends and the relatively short satellite records (Church and White 2011). Also, the physical and spatial dynamics of contributions to sea-level rise, including thermal expansion of the ocean due to warming oceanic and atmospheric temperatures and the melting of glaciers and ice sheets, are complex systems that are not completely understood (Rahmstorf 2007).

Until 1992, tide gauges were the only instruments used to measure sea levels (Woodworth and Player 2003). Although global coverage is much greater today than the 19th and 20th centuries, the distribution of tide gauges is still relatively sparse (Woodworth and Player 2003). Tide gauges measure local sea level in relation to a specific point on land. Complexities arise in analyzing and interpreting tide gauge data due to vertical land movements caused by tectonic motion, subsidence and glacial rebound (NOAA 2011).

These land movement factors, along with climate variability, necessitate the need to observe trends over a long period of time for each individual station to determine local mean sea level changes. Thus caution must be taken in using regional or local tide gauge data, which is highly variable across the globe, as a proxy for global mean sea level. Global Mean Sea level (GMSL) is more accurately reflected by a synthesis of all tide gauge data from across the globe prior to 1992, with increasing accuracy with the advent of satellite altimetry (CSIRO 2010).

Since 1992, high quality satellite altimeters, including TOPEX/Poseidon, Jason-1, OSTM/Jason-2, have provided extremely accurate measurements of global sea levels (CSIRO 2010). However, because of the relatively short time span of satellite data, tide gauge records must be analyzed along with satellite data to gain a clearer picture of the trends of both global and local sea level changes. Satellite data has confirmed that global mean sea levels have much less short-term variability because the volume of the ocean is relatively constant, but that regional variation in sea level is extreme due to the dynamic nature of the oceans (Church and White 2011). Along with the vertical movement of land are climatic variations that affect local sea levels. For example, storm surges and the El Niño Southern Oscillation can dramatically affect local sea levels (Chang et al., 2013).

Looking ahead, under all Representative Concentration Pathway Scenarios, the rate of sea-level rise will very likely exceed the rate of rise observed during 1971 to 2010 (IPCC 2013). This rate increase in due to increased ocean warming and increased loss of mass from glaciers and ice sheets (IPCC 2013). Based on the various scenarios, the projections of global mean sea-level rise range from a low of 0.13 m to 0.98 m for the year 2100 (Church et al. 2010; UNEP 2009; IPCC 2013) Although many of the projections predict only to the year 2100, sea-level rise has considerable momentum and will likely continue for many centuries (Hansen 2008; Hansen et al. 2005; Nicholls et al. 2007).

The western North Pacific has experienced the highest rates of sea-level rise between 1993 and 2009 (Merrifield 2011). The regional differences in sea-level rise can be attributed to climate variability, thermal expansion variability and change in the mass of ice sheets. Climate variability, such that occurs with oceanic oscillations like the El Niño Southern Oscillation (ENSO), can create changes in sea level of up to 0.2 meters in the western North Pacific (Merrifield 2011).

Additionally, the region has higher rates of thermal expansion due to greater sea surface temperatures (Hansen et al. 2006). Ocean water expands as it warms, and paleo-oceanographic data from the western Northern Pacific suggests that this region may be about 1°C away from being the warmest sea surface temperatures in a million years (Hansen et al. 2006). This region also faces a disproportionally great impact from sea-level rise due to melting ice sheets. Because the mass of ice sheets is so great, they exert a higher gravitational pull on sea level (Mitrovica et al. 2001). As the ice sheet melts, the corresponding rate of rise will be lowest right next to the ice sheets and greatest in the equatorial regions furthest from the gravitational pull of the ice sheets (Mitrovica et al. 2001).

Interannual climate variability, thermal expansion variability and loss of ice sheets add a complexity when examining sea-level rise in areas with low-lying islands and atolls. In sum, fluctuations in sea level due to interannual or decadal variation, along with rising mean sea levels, paint a high-risk scenario for residents of low-lying coastal regions of the western North Pacific. The following section briefly examines the link between sea-level rise and human migration.

The Link between Sea-level rise and Migration

Migration of coastal populations as a response to rising seas is garnering increasing attention in discussions and research on the human dimensions of climate change (Dema 2012; Laczko 2010; Perch-Nielsen et al. 2008; Renaud et al. 2011). Changes in development and settlement practices, which have dramatically increased populations and valuable infrastructure on or near coastlines, have amplified the vulnerability of hundreds of millions of people to the deleterious effects of sea-level rise (Boss 2008; McGranahan et al. 2007).

Those facing the most immediate risks of sea-level rise are residents of low-lying islands and atolls (Mimura 1999; Mimura et al. 2007; Nicholls et al. 2007; SPREP and APAN 2013). With sea level projected to continue rising for several centuries (Church and White 2011; Nicholls et al. 2007), and no inland area in which to migrate, those residing on low-lying atolls and islands are particularly vulnerable.

Much of the research on the impacts of sea-level rise on migration fail to link the two variables unambiguously, but instead only factor the environment in more generally (Bates 2002; Castles 2002; Lonergan 1998). Others make an explicit assumption that environmental factors such as sea-level rise are a principle force in migration, creating a new class of “environmental refugees” (El-Hinnawi 1985; Jacobson 1988; Myers 1993; Warner et al. 2010).

However, due to a lack of data and well refined methodologies, there is limited evidence or consensus in the literature that climate change factors can be isolated as a primary driver of migration (Black et al. 2008; Lilleør and Van den Broeck 2011; National Research Council 2013). That said, assessing the impacts of sea-level rise on migration is a little more clear-cut on low-lying atolls. Precluding the development of innovative mitigation or adaptation technology, complete inundation of low-lying atolls would prompt wholesale human out- migration in response to sea-level rise. Prior to complete inundation, other damaging effects of sea-level rise, such as more frequent and intense king tides, are likely to displace many residents of the Marshall Islands, perhaps permanently (RMI Ministry of Foreign Affairs 2014).

Existing Migration Streams from the Marshall Islands

Out migration from the Marshall Islands since World War II can be characterized by distinct phases. In the years following World War II (1950's and 1960's), there was limited, restricted movement into and out of Micronesia[4] in general (Graham 2008). The administration of the Trust Territory of the Pacific Islands by the United States Navy placed a heavy emphasis on control and security, restricting both in and out migration (Graham 2008).

The next phase, occurring in the 1970's and 1980's, saw accessing education as a primary driver of out migration from the Marshall Island (Graham 2008; Hezel and Samuel 2006). This was due in large part to funding through the Basic Education Opportunity Grant (later called the Pell Grant), which provided Marshallese high school graduates financial assistance to attend college in the United States and Guam (Graham 2008).

However, it was ultimately the bilateral agreement to the terms of the 1986 Compact of Free Association between the United States and the Republic of the Marshall Islands that became the driving force in out migration to the United States (Graham 2008, Woo and Aguilar 1993). The Compact stipulated that any citizen of the Marshall Islands may freely enter, work and reside in the United States and its territories and possessions indefinitely and without regard to many of the typical immigration requirements (U.S. Department of State 2003).

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[4] Micronesia currently consists of the countries of Kiribati, Palau, Nauru, The Marshall Islands and The Federated States of Micronesia and the U.S. Territories of Guam, Wake Island and the Northern Mariana Islands.

Thus, key determinants of migration from the Marshall Islands have shifted from primarily educational opportunities to also include seeking better health care and more employment opportunities (Graham 2008). With a struggling educational system, health care system and economy in the Marshall Islands, coupled with open access to the United States, the push to seek opportunities outside of the Marshall Islands is considerable (IMF 2014; World Bank 2006).

Without adequate data on out migration from the Marshall Islands, net embarkation data from the U.S. Transportation database is one way to examine this out migration. This measure captures all movement of passengers into and out of the country (U.S. Department of Transportation 2014). Net embarkations (departures over arrivals) of air passengers from the Marshall Islands between 1991 and 2006 totaled 15,234 (Graham 2008). Of that total, 11,746 departed from Majuro (Graham 2008). That is an average annual net embarkation rate of 783.

Another way to estimate out migration rates is through United States Census data, although that data also includes natural population increase. The 2010 United States Census enumerated 22,434 self-identified Marshallese living in the 50 United States (U.S. Census Bureau 2010). This is an increase of 15,784 Marshallese in the U.S. since 2000, both from natural population increase and immigration (US Census Bureau 2010). As more Marshallese citizens migrate to the United States, there are a few key receiving destinations of choice (USGAO 2011). Hawaii, which is the required gateway state for Marshallese migrants into the United States, has the highest reported population of 7,412 (USGAO 2011). The second most populated destination state is Arkansas, with 4,324, which is the largest Marshallese population in the continental United States (USGAO 2011). Marshallese numbered 2,207 in Washington State, 1,761 in California, 1,028 in Oklahoma, 970 in Oregon, 793 in Utah, 666 in Arizona, 550 in Texas, and 2,723 in other states (USGAO 2011).

Out migration from the Marshall Islands has gone through several phases due to a host of factors including open access to the United States and a desire for better educational, economic and health care opportunities. Hawaii, Arkansas and Washington State have been the primary destinations to date.

The purpose of this chapter was to give an overview of the Marshall Islands, including the geography, history, economy, culture and demographics. This chapter also reviewed the history and future predictions of sea-level rise and an overview of migration from the Marshall Islands. The following section outlines the organization of the remaining chapters of this research.

RESEARCH ORGANIZATION

The research is organized as follows. Chapter II outlines the Cumulative Causation Theory of Migration with added environmental variables as a theoretic/analytic framework for understanding human migration in the face of sea-level rise due to climate change. More specifically, this chapter provides a brief introduction of migration, a review of the history and development of international migration theories, a comprehensive scholarly review of Cumulative Causation Theory, an examination of the inherent difficulties in integrating environmental factors in migration research and a consideration of the potential contributions of the current research in forecasting migration from the Marshall Islands.

Chapter III is concerned with data and methods. Included are the climate and social data to be employed and sources of these data. This chapter is also concerned with an overview of the scenario based, case study research design as well as the justification for the scenario based modeling of sea-level rise and human migration.

Chapter IV presents the findings of the research. These findings include four representative concentration pathway scenarios of migration in the face of various rates of sea-level rise. The findings are presented for the years 2030, 2050, 2070 and 2100.

Chapter V includes the summary and conclusions. Included is a discussion of potential impacts on host communities to an influx of sea-level rise migrants, as well as policy considerations.

Chapter II

ANALYTIC FRAMEWORK

The purpose of this chapter is to provide a theoretic/analytic framework for understanding human migration in the face of global climate change. More specifically, this chapter examines the Cumulative Causation Theory of Migration and the potential to enhance this theoretical framework to include environmental variables. This framework provides an understanding of the social as well as environmental components that reside within the scenarios of Marshall Island population movement. The chapter is organized as follows. First, a general overview of determinants of migration is presented. Building on this general perspective is a review of the history and development of international migration theories. Next is a comprehensive review of Cumulative Causation Theory which is followed by an examination of the challenges inherent in integrating environmental variables into migration research. Finally, contributions of this research in forecasting migration from the Marshall Islands are examined as it relates to the application of environmental variables integrated within the theoretical foundation of Cumulative Causation.

OVERVIEW OF MIGRATION

Throughout history, migration has been a fundamental demographic process worldwide. Continuous migration streams between communities, regions and countries has provided fertile grounds for demographers, social geographers and policy and policy makers ample opportunities to explore the underlying forces that initiate and perpetuate migration over time. Gaining empirical insight into this social process creates a platform upon which these academic, political and humanitarian factions can better address the needs of migrants and the needs of those in communities who send and receive these migrants.

Much of the scholarship on migration is based upon theoretic and analytic frameworks that seek to isolate initiating and perpetuating variables dictating migration flows. Research on the proximate determinants of migration include consideration of variables that induce individual movement include strategies to increase or diversify income sources, desires to pursue educational or employment advancement, or the necessity to seek asylum from famine, war or persecution (Massey and Taylor 2004).

Predominant determinants cited in the literature that perpetuate extant migration streams are as follows. These determinants include a desire to live closer to family and other migrant network connections and the development of cultural and structural institutions and policies that support migrants. Additionally, a final determinant is the cumulatively decreasing risks and increasing benefits of leaving communities in decline and entering established migrant destinations (Massey et al. 1993).

While these broadly defined variables have been identified as key elements in migration decision making there is an emerging recognition that future climate change due to anthropogenic global warming may also serve as a an additional factor in the migration of millions of people in the coming centuries (Stern 2007). Although the effects of changing environmental conditions such as droughts (Herrmann and Hutchison 2006) and floods (Marsella and Ring 2003) have contributed to migration throughout human history, it is only in the last few decades that the topic of anthropogenic climate change has gained currency in efforts to better understand future migration scenarios (de Hass et al. 2010; El-Hinnawi 1985; Jacobson 1988; Perch-Nielsen et al. 2008; Perch-Nielsen 2010). The environmental changes predicted to increase vulnerability for many populations in the future include: increasingly frequent and intense tropical cyclones and storms, heavy rains and floods, drought and desertification, and sea level rise (Schneider et al. 2007; IPCC 2013).

It is inherently difficult to identify individual drivers of migration. Further it is difficult to establish a causal relationship between environmental variables and migration due to the complex interactions and multifaceted forces that motivate relocation. However, as noted earlier the relationship between sea level rise and human displacement may be more easily identified as exacerbating vulnerability in low-lying regions in the near future.

For the estimated 700 million people living in Low Elevation Coast Zones (LECZ) less than ten meters in elevation (McGranahan et al. 2007, Lichter et al. 2011), and the approximately 146 million of whom live an average of one meter above sea level (Anthoff et al. 2006, Lichter et al. 2011), the incipient threat of sea level rise may become a dominating determinant of migration with the next century (Nicholls and Mimura 1998; Perch-Nielsen et al. 2008; Raleigh et al. 2008).

Risks from sea level rise such as loss of land to erosion, loss of infrastructure and arable land, depletion of fresh water resources due to salinization and deteriorating agricultural and economic conditions will exacerbate social, economic, structural and geophysical vulnerabilities. It is not simply increasing sea levels that will motivate increasing numbers of migrants, but also the cumulative escalation of social and economic vulnerabilities that will threaten coastal livelihood. For many of the millions of LECZ residents, the dependence on coastal natural resources for subsistence leaves them in a precariously vulnerable situation in the face of destruction from sea level rise (Lichter et al. 2011).

While sea levels have fluctuated as earth oscillated between glacial and interglacial periods through history, the current rate and projected acceleration of sea level rise is without precedent in the last two millennia (Bindoff et al. 2007). With levels forecasted to rise between .13 meters to .98 meters by the year 2100 (Church et al. 2010; UNEP 2009; IPCC 2013), the need for a comprehensive theoretical approach embedding environmental variables into migration research is of paramount importance. The impetus for understanding the environment/migration nexus is particularly pressing for the residents of the Marshall Islands. Due to its extremely low-lying topography, this country is among the first facing imminent and catastrophic threats to habitability due to sea level rise (Nicholls et al. 2007).

Using migration theories as an analytic framework, retrospective analyses highlighting variables positively correlated with migration allow for an understanding of the forces at work in the movement of individuals and families. Because relocation is driven by many micro and macro level factors varying across time, space and location, an array of frameworks exist for gaining multidimensional insights into migration. Yet, the despite the richness of the current pool of international migration theories there remains a lack of conceptual and as well as empirical guide posts for addressing the myriad issues that arise in assessing the impact of sea level rise on migration. This lack of an established analytic framework creates substantial challenges when attempting to forecast future migration, especially from the Marshall Islands, as changing climatic conditions will play an integral and cumulative role in migration in the coming decades.

The perspective here is that Cumulative Causation Theory holds the most potential of all migration theories to include newly emerging climate change variables in forecasting scenarios of migration. Because this theory incorporates tenets from previous migration theories to include micro and macro level variables, applies an interdisciplinary perspective, a longitudinal time scale, and a focus on the changing dynamics of sending and receiving communities that perpetuate migration, it provides a solid framework for embedding new variables related to environmental conditions. Before more fully discovering Cumulative Causation Theory, it is valuable to review earlier as well as other extant approaches to understanding international migration.

HISTORY OF INTERNATIONAL MIGRATION THEORY

Historically, research has relied upon a few select theories in attempts to illuminate both the rich complexities and strong regularities and patterns of international migration. These theories have evolved over time to reflect the varying social, political and structural trends and the continuously evolving variables that influence and perpetuate migration. The purpose of this section then is to provide a broad overview of the history and development of international migration theories including Neoclassical Economics Theory, The New Economics of Migration Theory, The Dual Labor Market Theory, The World Systems Theory, Social Capital Theory and Network Theory.

One of the earliest migration theories, Neoclassical Economics, is based on a functionalist social perspective in which societies are viewed as a system of aggregate parts that trend toward equilibrium (de Hass 2011). This theory originated to help explain internal migration as it related to economic development (Lewis 1954). When applied to international migration from a macro perspective, this theory posits that migration is simply a result of a geographic imbalance in labor markets (Massey et al. 1993). It suggests that areas with a surplus of workers have disproportionately low wages, whereas areas with a deficit of laborers have disproportionately high wages, and that this imbalance in the labor and wage markets dictates migration to create economic equilibrium (Todaro and Maruszko 1987). From a micro perspective, this theory suggests that this disequilibrium in the supply and demand of labor and wages results in laborers making individual decisions to migrate based on calculations of maximizing personal income potential (de Hass 2011).

Following criticism that the foundations of the Neoclassical Economics Theory were too narrow to adequately explain international migration, the New Economics of Migration Theory was derived (Stark and Bloom 1985). Recognition of additional determinants of international migration bolster this theory by including an understanding that migration decisions are not made entirely by isolated individual actors or controlled simply by economic markets (Massey 1999). Rather, it is understood that migration strategies are made by small groups of relatives and households and that these decisions are not merely based upon income maximization but also upon the minimization of risk in other market failures, diversification of income sources and increasing income relative to other households (Massey 1999). This perspective, in opposition to the Neoclassical Economics Theory, suggests that migration is not simply driven by a desire for personal income gains, but also includes an attempt by households to increase their relative economic standing within the sending community through remittances from migrant relatives sent abroad to work (de Hass 2011). This arrangement protects households from local market failures by having an external source of income.

Although the New Economics of Migration Theory expanded upon the simplistic tenets of Neoclassical Economics Theory and provided differing conclusions as to the initiation and perpetuation of international migration, both theories focused solely on micro-level decision making and failed to consider any macro-level forces at work in international migration (Massey et al. 1993).

To address the influence of large scale forces in migration, the Dual Labor Market Theory provided a framework based entirely upon structural pressure related to permanent demand for immigrant labor inherent to the economic foundations of industrial nations (Piore 1979). This theory suggests that migration occurs, not because of economic push factors in sending communities, but because of the high demand for immigrant workers in receiving communities in industrialized countries (Massey et al. 1993).

Outlining the characteristics of advanced industrialized societies, Piore (1979) considered how these elements create demand for immigrant labor. The first of these characteristics is structural inflation, which describes the condition whereby low-level entry jobs cannot attract employees by simply raising wages as there are structural norms in place that demand wage increases throughout the structural hierarchy.

Another characteristic in industrialized societies that attracts migrant laborers is the difficulty in status-based societies in maintaining a native workforce willing to stay in low-wage jobs. From this perspective it is the immigrant labor force that is willing to fill these low-wage positions when demand increases as native employees refuse low-level jobs that offer no security or advancement (Piore 1979). Migrant workers, on the other hand, are willing to work in such positions that increase their relative economic standing in their home communities (Piore 1979).

Finally, Piore (1979) recognized that changing demographics have altered the available workforce in industrialized countries. Historically, women and teenagers filled many of the low-level, entry jobs. However, demographic changes have occurred including higher rates of women entering middles or upper levels of the work force due to increased opportunities and equality, rising divorce rates leading women to seek higher paying jobs to support a single-parent household, and increasing rates of attainment in higher education by teenagers. These societal changes have shifted women and teenagers away from the low-level jobs leaving those positions open for migrant workers (Piore 1979).

All of these conditions as outlined in The Dual Labor Market Theory entirely disregard the migrant workers as rational actors making decisions that influence their future. This approach operates under the assumption that migrants are largely passive pawns in an economic market and that international migration is simply a result of structural forces at work in advanced industrial societies.

Another macro perspective in international migration underlies the World Systems Theory developed by Immanuel Wallerstein (1974). This perspective argues that economic globalization from industrialized, capitalist countries into industrializing or non-capitalist countries creates an entire demographic of internationally mobile workers due to displacements generated by capitalist markets increasing control of an industrializing country’s land, raw material and labor (Massey et al. 1993).

According to World Systems approach, as new capitalist markets form in developing countries, local workers are displaced as land is consolidated or worked using modern inputs (Massey 1999). This mechanization and land consolidation lessen the need for local labor to farm land or extract raw materials (Massey 1999). The labor markets are often disrupted by new capitalist endeavors in developing countries because of the skewed demand in many of the ventures for female workers (Massey et al. 1993). This gender imbalance leaves a large demographic segment of males who must migrate in search of work. The World Systems Theory, like the Dual Labor Market Theory, approaches international migration from a structuralist standpoint, failing to incorporate rational decision making by individuals and households.

Social Capital Theory and Network Theory, however, return the level of analysis in migration research to the individual or household level (Massey 1999). These perspectives suggest that social capital, which is derived from relationships and networks, promotes and perpetuates international migration (Massey and España 1987). This occurs once someone has migrated and they become social capital by providing an avenue of resources and making each successive act of migration less risky (Massey and España 1987). This perspective integrates a macro perspective by recognizing that as immigrant communities grow a gradual increase in community resources such as housing and employment connections offers more structural support for future immigrants, thus perpetuating international migration (Massey and España 1987).

The influence of these social networks is an integral part of the Cumulative Causation Theory of migration. Unlike previous theories, which focus exclusively on causal factors that induce migration, Cumulative Causation Theory identifies initiating factors but focuses more heavily on factors that perpetuate international migration once the flow has begun. In addition, this theory offers the most expansive and integrative foundation for international migration research by emphasizing the necessity for a temporal perspective when examining individual, household, community and structural factors influencing and perpetuating migration (Massey 1990). The following section examines Cumulative Causation Theory is some detail.

CUMULATIVE CAUSATION THEORY

Because previous theories had not adequately incorporated the multitude of variables at play in prompting and perpetuating migration, an attempt to widen the theoretical lens through which complex migratory processes are understood was necessary. Drawing from varying perspectives, disciplines and previous theories, Cumulative Causation Theory was presented as a more thorough analytic framework upon which to understand the dynamic and cumulative process of migration. In order to better understand this broad overarching approach it is valuable to review of the economic and social variables inherent to the theory. It is also of value to understand the limits to the approach, difficulties in integrating environmental variables in migration research as well as suggestions for how to accomplish this within the Cumulative Causation Theory.

Based upon the work of Gunnar Myrdal (1957) and reestablished in the literature by Massey and his colleagues in the 1990's (Massey 1990; Massey et al. 1994; Massey and España 1987; Massey and Zenteno 1999), Cumulative Causation Theory argues that over time international migration sustains itself because each act of migration alters the social context through which others make their decisions to migrate, ultimately simplifying and stimulating the migratory process for subsequent migrants (Massey 1999).

Research utilizing Cumulative Causation Theory as an analytic framework focuses primarily on the cumulative nature of migration from rural areas by attempting to isolate the influence of several variables that perpetuate migration through altering the social context within sending communities (Massey et al. 1993). These variables include income and employment, land ownership, the development of a migrant culture, the redistribution of social capital and the influence of network affiliations (Massey et al. 1993). Beginning with a single act of migration, each of these variables becomes part of a feedback loop between sending and receiving communities. This cumulative feedback alters the social context within sending communities, ultimately increasing the likelihood of additional migration (Massey et al. 1993).

When assessing the role of each of these variables of migration it is necessary to understand that none operate in isolation and the interaction between these variables can be exceedingly complex. For the purposes of individually defining each of the prevalent variables considered in Cumulative Causation Theory, economic and social variables will be considered in turn under the assumption that they operate in conjunction over time and that each element includes individual, household, community and structural components.

Economic Variables in Cumulative Causation Theory

Income, employment and land holding have all been shown to influence the initiation and perpetuation of international migration (Massey 1990). When considering income in sending communities as a variable in cumulative causation, the theoretical underpinnings of the New Economics of Migration Theory are relevant. That theory posits that the motivation to migrate can stem from the need to increase income, diversify income sources or to increase wealth relative to other households in a community (Stark and Bloom 1985).

Once a single individual or household migrates from a sending community, the remittances sent home increase the wealth of the relatives who remain behind. This change in socioeconomic status highlights the relative poverty of those households that have not participated in income-seeking migration (Massey et al. 1993). The cumulative effect is such that the relative deprivation felt by these households who witness increasing wealth in neighboring households encourages individuals and households to migrate in order to close the gap in income distribution (Massey 1999). This is particularly true when the income differential between sending and receiving communities is extremely high (Massey et al. 1987).

As increasing numbers of individuals or entire households migrate, more families in the sending communities increase their socioeconomic standing through remittance (Connell and Brown 2005). This continues to exacerbate the gaps in income distribution, further inspiring non-migrants to consider migration (Massey et al. 1987; Morawska 2001; Stark et al. 1986; Stark 1991; Taylor, 1992, Taylor et al. 2005).

Another variable in sending communities that potentially perpetuates migration is a shift of land holdings (Massey 1999). Research suggests that remittances from migrants may be used to buy land in their originating country for prestige value or retirement income (Massey et al. 1993; VanWey 2005). As land ownership by absentee-migrants increases, a reduction in the need for farm labor in the community can develop (Massey et al. 1987; Mines 1984; Stark and Levhari 1982). This occurs because migrant-owned land is often farmed using capital-intensive methods, worked by the migrant's family, or left fallow, thereby reducing the need for local farm labor (Massey et al. 1987; Mines 1984; Stark and Levhari 1982). As more migrants buy land in their home countries, a reduction of employment and land investment opportunities occur, thereby reducing future financial security of non-migrants and exacerbating the gap between migrant land owners and landless non-migrants (Massey et al. 1987; Mines 1984; Stark and Levhari 1982). This socioeconomic gap encourages additional out-migration, creating a cyclical and cumulative increase in the numbers of migrant households that can afford to purchase land in their originating community (Massey et al. 1987; Mines 1984; Stark and Levhari 1982).

One particular study of a community in Mexico found that remittances allowed for the purchase of more than two-thirds of the local land by migrants, creating a privileged group of migrant landholders (Reichert 1982). Other studies in Mexico found similar results (Mine 1984; Wiest 1984). A study in Nepal also found that individuals from households with less access to cultivated land were more likely to migrate in search of work (Bhandari 2004). Similar results were found in rural communities of the southern equatorial Andes (Gray 2009). Research in Mediterranean Europe found that agricultural land was left fallow by migrant's families as they became dependent upon remittances for income rather than agricultural productivity (Rhodes 1978). Several other studies have confirmed the cumulative feedback loop between landholding and migration (Fergany 1982; Mines and de Janvry 1982; Swanson 1979; Rubenstein 1979).

Although there are many instances of the positive cumulative effect of landholding on out-migration, it should be noted that a few studies have found that land ownership can have a negative correlation on migration (Barbieri 2005; VanWey 2005). These instances occur when seeking external income becomes unnecessary by actively farming the land with local laborers rather than simply using the land as a display of prestige or a form of retirement capital (Barbieri 2005; Gray 2009; VanWey 2005). Although the economic variables of income, employment and land holding heavily influence the perpetuation of migration, the social dynamics that arise within and between sending and receiving communities equally influence the complex decision to migrate. The following section reviews the key social variables of cumulative causation of migration.

Social Variables in Cumulative Causation Theory

The self-perpetuating nature of migration due to both human and cultural conditions, as partially outlined in the Social Capital and Network Theories, provide many tenets upon which the cumulative aspect of migration can be understood. The social variables most recognized to add a cumulative effect to migratory strategies include the influence of social networks, development of a culture of migration and the redistribution of human and social capital (Massey et al. 1993).

Social migrant networks result from interpersonal relationships such as kinship, friendship and shared community origin which link migrants and potential migrants between sending and receiving communities (Massey et al. 1993). The theoretical foundation of this concept rests on the notion that the first migrants to leave for a new destination have no social network to rely upon to cushion financial and social risks inherent in entering a new and foreign country without network ties (Massey et al. 1993). Therefore, these first migrants assume the greatest social and monetary costs associated with the act of international migration.

However, once embedded within a new community, the new immigrants create network linkages that serve to increase migration due to the reduction of cost and risk that occur when there are already migrants rooted within a receiving community (Massey et al. 1993). Furthermore, once the connection between a sending and receiving community has been strongly established, risk associated with migration, including financial and social risks, are substantially and cumulatively lowered for future migrants from the sending community and surrounding communities as well (Hugo 1981; Massey and España 1987; Massey et al. 1993; Taylor 1986).

Cumulative risk reduction originates when the number of network connections reaches a level in which a migrant social structure develops enough mass to support increasing migration (Massey 1990). Economic risks are thereby reduced due to increased access to information about employment and housing opportunities. Additionally, social risks are reduced due to a built in cultural support network within a receiving community that can provide new immigrants stability and assistance in adapting to a new and oftentimes radically different cultural milieu.

Social networks are the most heavily researched component internal to the cumulative causations of migration due to the powerful influence of social connections on the likelihood to migrate (Alperovich et al. 1977; Boyd 1989; Farmer and Moon 2011; Kau and Shirmans 1979; Liang and Chunyu 2005; Massey et al 1987, Massey 1990; Massey and Espinoza 1997; Shaw 1975; Taylor 1986; Winters et al. 2001). The network connections that are the strongest and most easily identified are among family members. It is found that when one family member migrates, they in turn encourage other family members to join them (Granovetter 1973, 1983; Lansing and Mueller 1967; Tilly 2007).

Several projects have disaggregated network structures to examine variances in the influence of these social connections both between rural and urban areas and between differing countries (Davis et al. 2002; Fussell 2010; Pedersen et al. 2008). Still others focused on gender dimensions of network effects (Curran et al. 2003; Curran and Rivero-Fuentes 2003; Heering et al. 2004; Stecklov et al. 2010). Although results varied within and across national boundaries and between rural to urban and gender divides, the general consensus indicates that network effects are typically a strong determinant of migration in general. However, an attempt to determine the strength of cumulative causation from a Mexican urban area found that the principle mechanisms, particularly network effects, do not function as strongly in urban settings (Fussell and Massey 2004). Another cumulative effect on migration is the change that occurs within public definitions of work over time (Massey 1999). When migrants fill a certain percentage of jobs within a specific employment sector, such as poultry processing, the work becomes stigmatized and labeled as “immigrant work” (Böhning 1972, 1984; Cornelius 2001; Piore 1979). This labeling reduces the likelihood that native residents will pursue those jobs, leaving ample employment opportunities for addition migrants.

Additionally, as a culture of migration develops both in sending and receiving communities, this cultural influence can encourage a continued flow of migration (Massey 1999). For the individual migrant, experiences in migration may change tastes and motivations (Piore 1979). Once a migrant recognizes their social mobility and gains a proclivity for a particular and oftentimes more economically stable lifestyle, the likelihood that they will migrate again is heightened (Massey 1986). Previous migration experience is also a strong predictor of the cumulative nature of return migration (Deléchat 2001).

At the community level, in established sending communities, migration may be seen as rite of passage or accepted norm and those who do not attempt to migrate may be viewed negatively (Reichert 1982). Also, receiving communities develop a culture of migration which encourages additional migration as more services, shops, churches and cultural outlets cater to migrants (Alarcón 1992; Brettell 1979; Goldring 1996; Massey et al. 1987; Rouse 1991).

The final social variable that has been examined in the cumulative causation of migration is the redistribution of human capital (Massey 1999). Initial or pioneering migrants tend to have higher levels of education and socioeconomic status, affording them a higher resilience to the risks of migrating without network support. Research has shown that this encourages or pulls additional human capital out of sending communities as migrant networks form, which further induces migration due to economic stagnation in sending communities from increasing depletion of human capital (Greenwood 1983; Greenwood et al. 1987; Massey 1999; Myrdal 1957).

Limits to the Cumulative Causation Theory

Due to the complexities of social processes such as migration, no single theoretical approach can capture the intricacies of migration. Cumulative Causation Theory attempts a nearly comprehensive theoretical foundation to analyze the complex interactions between migration and income, employment, landholding, a developing migrant culture, the redistribution of social capital and increasing network connections. However, in an effort to strengthen this theory to more adequately explain current and future international migration, a few limitations must be addressed. These limitations include an inability to adequately explain migration from a sending community after a certain threshold of out-migration has been crossed, a lack of geographic diversity in the literature due to the substantial focus of this theoretical perspective on migration from rural Mexico to the United States, and the absence of environmental variables within this theoretical framework.

Concerns on the integration of a temporal aspect to understanding international migration are related to suggestions that the strength of the process of cumulative causation depletes as ties to migrant networks become convoluted over time (Hatton and Williamson 1994; Martin and Taylor 1996; Massey 2003). This “migration hump” is thought to occur when the availability of potential migrants in a sending community is depleted, employment availability or labor demands in the receiving community reduces or terminates, or the migratory stream is hindered by war, international conflict or policy changes (Hatton and Williamson 1994; Martin and Taylor 1996). This “migration hump” results in a temporal limitation to the theory whereby the cumulative nature of migration may cease to exist, and other theoretical perspectives must be relied upon to understand the changing nature of migration beyond this threshold.

Another limitation rests in the need for additional research on cumulative causation beyond rural Mexico. Although ample empirical proof exists for the self-perpetuating and cumulative nature of migration from rural Mexico to the United States (Durand et al. 2000; Durand et al. 2001; Fussell 2004; Fussell and Massey 2004; Massey et al. 1994; Massey and

Espinosa 1997; Massey and Zenteno 1999; Mines et al. 1982; Mines 1984; Wilson 1998), there are relatively few studies have examined the strength of cumulative causation in other countries or from urban areas.

Those that have explicitly integrated a cumulative causation effects (outside of rural Mexico) include a study of international migration from the Fujian province of China related to the national transition to a market economy (Liang and Chunyu 2005), an analysis of the effects of relative depravation on migration from Nepal (Bhandari 2004), an exploration of gender dimensions of migration and cumulative causation in Thailand (Curran et al. 2003), a look at the changing character of migrant flows from Rural Thailand (Garip and Curran 2010), an examination of settlement practices of international graduate students (Szelényi 2003) and a multi-national view of cumulative causation on the Latin American countries of the Dominican Republic, Costa Rica, Mexico, Nicaragua and Puerto Rico (Fussell 2010).

A final limitation, and most salient for this research, is related to the absence of environmental variables as exogenous variables in instigating and shaping migration streams in the face of accelerating global climate change. Even though an attempt to update this theory to address migratory phenomena in the 21st century was conducted, the role of the environment was completely disregarded (Massey 2003).

As aspects of climate change such as sea level rise continue to increase vulnerabilities and increase the odds of migratory adaptive responses by coastal, atoll and marginal populations, it is imperative to integrate environmental variables within this theoretical framework. To more accurately understand current migratory flows and forecast future migration, it would be short sighted to ignore the role of the environment in a contemporary theory of migration. It is this limitation that will be further addressed in an effort to justify the refinement of Cumulative Causation Theory for future migration research.

Integrating Environmental Variables within Cumulative Causation Theory

In recent times there has been a sharpened focus on climate change and migration in academic, political and cultural arenas. Researchers, analysts, policy makers and humanitarian organizations are seeking more appropriate and effective theories and methods through which to research and more thoroughly understand the future of migration (Barnett and Webber 2010; Boano et al. 2008; Boss 2008; Brown 2007; EJF 2009; Gregor 2010; Hugo 1996; Jónsson 2010; Laczko 2010; Lonergan 1998; Marchiori et al. 2010; McLeman and Smit 2006; Nicholls et al. 2007; Perch-Nielsen 2004; Piguet 2010; Raleigh et al. 2008; Warner et al. 2009).

At the forefront of many discussions on the climate change/migration nexus is the amplified vulnerability of the low-lying islands and atolls in the Pacific region (Asian Development Bank 2009, Barnett 2001; Barnett and Adger 2003; Bedford and Hugo 2008; Bedford and Bedford 2010; Boncour and Burson 2009; Connell 1986; Lazarus 2009; Locke 2009; Mimura 1999). Vulnerabilities include loss of land due to erosion, risks to fresh water supplies including drought and salt water intrusion, irreversible damage to vital infrastructure, increased flooding and eventual total inundation by sea level rise (Nicholls et al 2007). Exacerbating these risks is the limitation on in-country migration. Due to the low-lying topography, the restricted size of the atolls, and the densely populated communities (Bright and Chutaro 2007; Nicholls et al. 2007) there are no in-country areas in which to migrate as an adaptation to sea level rise.

Although other factors including economic difficulties and social pressures have driven migration from these islands throughout its history, it is expected that sea level rise will directly impact social, economic and geophysical structures and heavily influence future migration strategies. These increased vulnerabilities could eventually prompt mass migration of the entire Marshallese population within the next century (Rudiak-Gould 2010). These and other low-lying islands are already seeing damaging effects from sea level rise (Brooks 2011; De Brum et al., 2013; Loeak 2013, ; Mimura 2007; RMI Ministry of Foreign Affairs 2014) and credible predictions are forecasting up to an additional meter of sea level rise by the end of this century (Vermeer and Rahmstorf 2009; IPCC 2013).

Despite the increasing prevalence of literature on the influence of climate change on future migration, the research is dominated by qualitative methods or conceptual assumptions, projections and observations (Bedford and Hugo 2008; Black et al. 2008; Brown 2007; Hugo 1996; Locke 2009; Raleigh et al. 2008; Shen and Gemenne 2011), policy briefings and recommendations to address the future of migration related to climate change (Black et al. 2008; Boano et al. 2008; Nunn 2009) or impact and vulnerability assessments (Holman et al. 2005; Holthus et al. 1992; Skoufias et al. 2011).

The occurrence of estimates of migration due to climate change in general, or sea level rise specifically, are remarkable scant. In fact, a review of publications empirically examining the links between migration and the environment using quantitative methods turned up very few articles. Those uncovered included one focused on out-migration from Nepal (Massey et al. 2007), one on the Southern Ecuadorian Andes (Gray 2009), another on sub-Saharan Africa (Marchiori et al. 2010), one on Brazil’s Northeast region (Barbieri et al. 2010), and one in rural

Benin (Doevenspeck 2011). None of these empirically examined the impact of sea level rise on migration.

Furthermore, aside from the study on Brazil’s Northeast region, these studies examine only the correlation between past climatic changes and events on past migratory flows. Literature on modeling and forecasting future migratory flows due to climate change are even more limited (Kniveton 2008). Although many methods exist for forecasting migration (Bijak 2006), the literature is lacking in the application of these methods to incorporate climate and migration. This lack of scholarship is a result of several factors that will be discussed in turn.

CHALLENGES TO INVESTIGATING THE ENVIRONMENT/MIGRATION NEXUS

Disregarding the effects of environmental changes like sea level rise in contemporary migration theory could lead to flaws in an empirical examinations of past, current and future migratory trends. However, given the enormous complexities involved in incorporating environmental variables in migration research, refining the theory of cumulative causation and improving the prognostic capabilities of migration modeling presents several challenges.

The limits and complexities concerned include the fact that sea level rise is a relatively new global phenomenon, so there has not been the impetus to factor that into migration forecasting to date. Also, dealing with inherently unpredictable natural and social systems creates a host of problems for empirical research including inconsistent, unreliable or nonexistent data. Additionally, integrating social and physical phenomena requires multidisciplinary expertise and access to compatible data sets. Finally, disaggregating the role of climate change from other social, political and economic drivers of migration is difficult.

The first challenge of integrating new environmental variables within an analytic framework based upon Cumulative Causation Theory lies in the relatively recent emergence of the recognition that sea level rise will impact coastal populations in the future. Because of the nascent nature of this relationship, there is no precedent for how to accomplish successful integration of climate and migration variables. Despite the recognition that climate change has always interacted in a complex relationship with migratory behaviors (Morinière 2009), relevant data and empirical research on the particular effects of sea level rise on migration are scarce (Hugo 1996). However, as recent discussions on the migration-climate change nexus escalate in frequency, urgency and tone, interest is burgeoning across scholarly disciplines, humanitarian groups and political factions to further the theoretical, methodological and conceptual understanding of this complicated area of research (Bijak 2006; Perch-Nielsen 2004).

Secondly, there is an inherent unpredictability in the highly reactive processes of both migration and climate change. The migratory process of humans is multifaceted, and is influenced by a confluence of variables that cannot be disaggregated with ease (Bijak 2006; Morinière 2009). Attempts at disaggregation have been described as complex (Richmond 2001; Schwarz and Notini 1994; Lein 2000; Hugo 1996), not very likely (Black 2001), inappropriate and impossible (Lonergan1998).

Likewise, climate systems are highly reactive to many variables including some of which are dependent upon future actions of humans (Carter et al. 2007). This unpredictability ensures some level of doubt in the prognostic capabilities of climate change models (Barnett 2001; IPCC 2013). Furthermore, due to the inherently unpredictable and chaotic nature of climate change, a high degree of difficulty in reliably discerning migratory outcomes based upon these uncertain projections exists (Kniveton et al. 2008).

Additionally, integrating the socioeconomic-based science of migration with the physical-based science of climate change requires an understanding of complex data, concepts and methodologies across disciplines. Often times, differing disciplines operate under different conceptual and methodological paradigms, leading to incompatible approaches and data sets. Further difficulties arise due to a scarcity of data that examines longitudinal demographic, migration and climatic variables (IOM 2009). Many countries, including Japan, Mexico, Korea, the Philippines and Egypt fail to ask basic questions about migration or place of birth in their censuses, creating gaps in necessary data (CGD 2009). Additionally, a lack of agreed upon terminology related to environmental migration also presents a challenge for gathering appropriate statistics (IOM 2009).

There are also gaps in the historical collection of climate data, leading to inadequate statistical information for examining past climatic changes. However, gains are being made in data collection with over 11,000 ground stations and at least eight satellites monitoring daily temperatures, precipitation, barometric pressure, and atmospheric concentrations of Earth (UNEP 2009). The growing availability of data allows for more thorough retrospective analyses or for modeling projections (UNEP 2009). However, even with ample data, modeling complex climatic systems is plagued with challenges in accuracy in small scale regional resolution (Christensen et al. 2007; IPCC 2013).

In light of these challenges to empirically forecasting climate driven migration, it is prudent to firm up the theoretical framework of Cumulative Causation Theory. To provide a solid platform for researchers to build their contextualized examinations of migration in the face of changing climatic conditions is essential. This research examines the influence of sea level rise on migration in the Marshall Island by adding environmental variables within the analytic framework of cumulative causes of migration. Refining this theory to suit this avenue of exploration ensures a greater accuracy in the conceptual understanding of the driving forces of migration from the Marshall Islands as sea levels rise.

SEA LEVEL RISE AND MIGRATION FROM THE MARSHALL ISLANDS

Investigating migration from the Marshall Islands and the potential impacts of sea level rise on future migratory flows presents a unique opportunity to examine the cumulative causation of migration with added environmental components. Because there are already established and increasing flows of migration from The Marshall Islands to areas of the United States, predominantly Hawaii, Arkansas and Washington, the cumulative nature of the social networks between the migratory sending and receiving communities can be assumed. And, because the Marshall Islands are at the forefront of the risks associated with sea level rise, the situation is ripe for investigating the changing dynamics of migration as sea level increases vulnerability of the land and population over time. Although simple deconstructions of social and economic variables could provide insight into past motivations for migration, which include such things as desire for better employment, education and health care, the future social and economic structures of the Islands will be entirely different in the coming decades with predicted sea level rise.

The assumption that gradual sea level rise will have a cumulative effect on migration is based on a few suppositions. First, when considering the variables associated with cumulative causations of migration, including income, employment, land ownership, a migrant culture, the redistribution of social capital and the influence of network affiliations, the addition of a macro structural variable such as sea level change is appropriate. As sea level rises, individuals will face increasing pressures to migrate as they lose their homes, land, and employment opportunities. And, as more people migrate away due to these losses, the cumulative effect of the migration network, and the increasing development of a culture of migration from the Islands will be even more pronounced in migratory strategies.

Because there are already established Marshallese migrant communities outside of the Islands, it is hypothesized that the network effect is already operating between the sending and receiving destinations. Increasing the vulnerabilities due to sea level rise of those remaining on the islands will induce further migration. Furthermore, when the vulnerabilities reach a point beyond which the remaining population cannot adapt, wholesale abandonment is likely.

Assessing the vulnerabilities that incremental rises of sea level create is challenging, but imperative, if the forecasts of migration are to be useful. The populations face increasing vulnerabilities to their infrastructure, much of which sits only centimeters above sea level. The agricultural sector faces degradation due to salinization of crops and other productive flora. The fresh water lens, which is the sole provider of potable water and is replenished only by rain water, is vulnerable as well. Additionally, the Marshall Islands are already economically vulnerable (Bright and Chutaro 2007) and economic and social vulnerabilities will increase as encroaching sea levels reduce the abilities of business and communities to operate at expected levels.

The future of international migration presents unprecedented challenges due to the projected changes in global climate. Staying abreast of climate changes and migratory patterns requires vigilance in refining and updating the conceptual theories that methodologies and paradigms are based upon. Without a complete theoretical conceptualization of the general nature of migration, empirical examinations may miss the complete picture.

Moreover, understanding the complex and dynamic nature of migration and the motivations and forces behind it are imperative if policy and humanitarian efforts are to match the changing needs of everyone impacted by migration. Because theoretical formation is about providing an avenue to recognize both the intricacies and general trends of social processes, updating Cumulative Causation Theory with environmental variables increases the likelihood that a research framework based upon this theory will capture the true nature of migratory behaviors in the face of changing global climates.

The purpose of this chapter was to provide a theoretic/analytic framework for understanding human migration in the face of global climate change. This framework incorporates environmental variables into the Cumulative Causation Theory in order to gain a more complete assessment of the impact of sea level rise on human displacement and migration. In the following chapter, the data and methods for the research are outlined in detail.

Chapter III

DATA AND METHODS

This chapter presents the research design, data and methodology employed in examining the relationship between sea-level rise and migration in Rita Village in The Republic of the Marshall Islands. It is organized as follows. First, the research design framework is discussed. This includes an overview and justification for use of a scenario-based case study approach. Second, types and sources of data used in the research are presented, divided into subsections of geographic data, climate data, population/housing data and migration data. Third, methods employed to conduct this research are outlined including scenarios of inundation and migration. Finally, issues of reliability and validity are discussed followed by limitations of the study.

RESEARCH DESIGN

As noted above, this section presents a detailed description of the approach adopted for the current research. More specifically the section describes the scenario-based case study approach in some detail and includes consideration of its suitability for use in the current context. Limitations of the research approach are also outlined.

Research Design Framework

As noted in the introductory chapter, the purpose of this research is to explore the relationship between sea-level rise and human migration from Rita Village in the Republic of the Marshall Islands. The impetus for conducting this research is three-fold. First, the topic of sea-level rise and migration is time sensitive for the Marshallese population. Second, modeling sea-level rise inundation and migration has never been conducted for the Marshall Islands. Filling this research gap by modeling future sea-level rise and future migration scenarios is necessary to increase the body of scholarship on climate change and migration from low-lying atolls. Finally, implicit in this research is the assumption that as appropriate data becomes available, other low lying atolls with significantly similar geographies can use the methods in this research to generate inundation and migration scenarios.

The design of this research is constrained by a dearth of data on the Marshall Islands and a limited capacity within the country for data collection. However, the current data available allows for a basic scenario-based, case-study examination of the relationship between sea-level rise and human displacement. The scenario-based approach is widely used to examine the repercussions of anthropogenic climate change for both the environment and society (Moss et al. 2010). Scenarios define plausible trajectories of the future that are created to explore the potential consequences of anthropogenic climate change with the goal of understanding uncertainty and alternative futures (Moss et al. 2010). Scenario-based modeling allow examination of the Earth’s response to changes in the driving forces of climate change, such as atmospheric composition, and societal changes in technologies, economies and policy (Moss et al. 2010). Scenarios also allow for interdisciplinary research as many factors come into play in the development of a scenario.

To conduct this research, geographical information system (GIS) software is employed to run four different scenarios of sea-level rise over four timeframes in the course of the coming decade on a digital elevation model (DEM) of a sub-section of the capital atoll of Majuro, Rita Village. The inundation models are used to determine number of houses permanently inundated in each scenario and an approximation of the number of people displaced by this inundation.

Using the estimated number of displaced people, exploratory assumptions based on current migration data are made on how sea level inundation will impact the existing migration flow.

This design framework has been employed in other research on inundation and flood-modeling; however the resolution of spatial data used is typically much more coarse and is practical only for determining areas vulnerable to a 1 meter rise or more of sea level (Usery et al. 2010, Mazria and Kershner 2007). These modeling efforts have resulted in user-friendly tools that assist in examining the impacts of sea-level rise on coastal regions with more highly elevated terrain (Douglas et al. 2011).

However, most spatial data for the Marshall Islands has a resolution too coarse to have value in modeling extremely low-lying areas. While options exist for the collection of high resolution spatial data such as LiDAR, it is an expensive method of data collection and has not been done in more remote countries such as the Marshall Islands (NOAA 2014). So, while this design framework has been useful in many research projects on sea-level rise inundation, modeling of sea level inundation and migration has not be successful to date for the Marshall Islands. For the purposes of this research, the higher-resolution spatial dataset that currently exists is adequate for mapping sub-meter increments of sea-level rise. The following subsection presents the justifications used in determining the design of this research.

Justification of the Research Design

This scenario-based, case-study research design is justified on several counts. First, because research examining the relationship between sea-level rise and migration as a result of human displacement is relatively scant, this research design provides an understanding of a complex issue through a relatively fine grained contextual analysis. The scale of this research provides the basis for expanding the methodology to the entire country of the Marshall Islands as the required data becomes available.

Second, this design provides relevant information for the residents of Rita Village as they develop disaster management and adaptation plans in the face of climate change. This research design provides several scenarios of future impacts of sea-level rise whereby varying degrees of potential sea-level rise impacts can be explored. This methodology provides latitude in the analysis rather than a limited linear forecasting method which ties analysis down to one outcome. Because the future of climate change is dependent on factors related to human behavior and technological development, scenario-based modeling is the most appropriate method for accommodating a host of potential futures. The following subsection outlines limitations of the research design employed.

Limitations of the Research Design

This research design is limited by several factors, including the relatively small size of the study area, the lack of inclusion of other climate-related variables in the inundation scenarios, and the lack of data on migration specific to Marshallese. First, the absolute lack of data on elevation in the Marshall Islands constrained this research to a very small village in the country. While the terrain of each village and atoll in the Marshall Islands is remarkable similar, the interpretations of the findings only apply to Rita Village in the Marshall Islands. However, applying assumptions of this research to other low-lying atolls or coastal regions can be done with an aforementioned caveat that sea-level rise affects people and places very differently, but that the basic impacts of sea-level rise have great potential to be very similar across all low-lying atoll countries. The design is such that the research process can be replicated in any area with result specific for that region as long as the data are available.

Another limitation of the research methods includes a lack of inclusion of other climate change variables that could impact inundation and migration rates. These variables include larger climate system variations due to the El Niño cycle, king tides, beach erosion, water salinization and drought. Due to limited data and resources to collect these data, they are omitted from the research design. While it is recognized that the loss of habitability is not only impacted by sea-level rise, this research works under the assumption that these other variables remain constant. In this assumption is that there are more options for adaptability with those variables and they do not necessarily equate to influencing migration.

Another limitation is the lack of long-term migration data for the Marshall Islands. Collecting this data was beyond the scope of this research. Basing the impact of sea-level rise on migration decisions as solely resting on the loss of a home is an incomplete picture of migration decision making process. However, the assumption of this research is that the other socio-economic variables are always at play in influencing migration decisions, and the variable of permanent displacement is in addition to these push factors. While limited, the assumption that one will make that final choice to migrate when a home is lost is justified due to the extremely small and vulnerable state of the Marshall Islands. With an economy in decline and an existing flow of out migration, the final straw for many residents could lie in the permanent loss of a home and land that has been passed through a matrilineal line for millennia. It is understood in this research that migration is a complex act with many influencing factors. The migration results of this research are not presented in a way that suggests that sea-level rise can be isolated as the final causal factor in the decision to migrate. Rather, the migration estimates are simply put forth as a guide for adaptation planning in both Rita Village and potential host communities. The following section provides details of the geographic data that informs the research setting and context.

GEOGRAPHIC DATA

This section considers various types and sources of data used in this research. Within this section is a description of the study site of Rita Village, followed by a review of the digital elevation model (DEM) employed.

Study Site Description: Rita Village, Majuro Atoll, Marshall Islands

The study site for this research is Rita (Djarrit) Village on Majuro Atoll, in the Marshall Islands (Figure 3.1). The impetus for choosing Rita Village as the study site was dictated by two factors. First is related to the time-sensitive nature of this problem. The Marshall Islands are one of four countries that consist solely of low-lying atolls and islands. This geography places the Marshall Islands at the forefront of risks associated with sea-level rise. For this country, research on impacts of sea-level rise in urgently needed.

Despite the urgency of the problem, an extreme lack of data necessary for this kind of research presented the second justification for choosing Rita Village; the only known digital elevation model for the entire Marshall Islands is limited to Rita Village (Stege 2013). Despite current endeavors to fill that data gap, the existing state of elevation data is poor. So, while the scope of this research was limited by the availability of data necessary for modeling sea-level rise, Rita Village is an area in which all the necessary data exists to do a primary examination of the relationship between sea-level rise and migration. The uniform nature of the topography of all of the atolls of the Marshall Islands makes Rita an appropriate proxy for making assumptions on the impacts of sea-level rise for the rest of the country (Dickinson 2009).

Rita Village is located on the Northern end of the capital Atoll of the Marshall Islands, Majuro. Rita (also known as Djarrit), along with Uliga and Delap, make up the urban DUD area of Majuro. This area has urbanized rapidly, experiencing a 1.4% annual growth rate between 1999 and 2011 (EPPSO 2011). As of 2011, 52.3% of the total population of the Marshall Islands (53,158) lived in Majuro (27,797) (EPPSO 2011).

Figure 3.1: 2010 World-View 2 Satellite Imagery of Rita Village on Majuro Atoll, the Republic of the Marshall Islands (U.S. Department of Agriculture, Natural Resource Conservation Service, National Geospatial Management Center 2010).

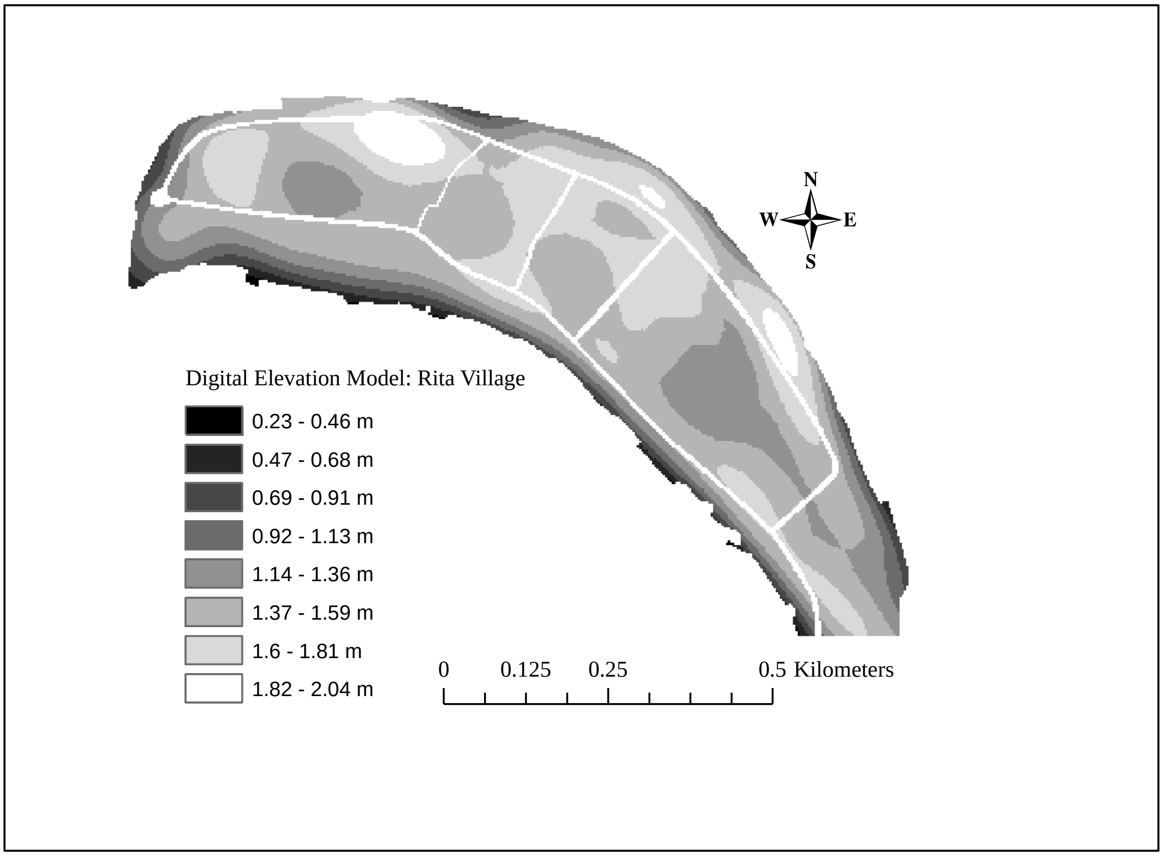
Rita Village is primarily a residential community of the DUD area. While there are no exact population counts available for Rita, for the purposes of this research, an estimate was derived. Based on the census count of 703 housing structures in Rita and the average family size of 6.7 on Majuro, the population of Rita Village is estimated to be 4723 (EPPSO 2011). With an area of 0.42 km^2, Rita Village has a population density of 11,246/km^2, making it one of the most densely populated places on earth (World Bank 2014). With an average elevation of 1 meter, Rita Village is acutely vulnerable to sea-level rise. To map sea-level rise on Rita Village, a digital elevation model is employed. The following subsection is a description of the Digital Elevation Model of Rita used in this research.

Digital Elevation Model: Rita Village

The Digital Elevation Model (DEM) of Rita Village, generated based on a 1983 aerial topographic survey with spot elevation, is the only DEM available for the Marshall Islands with a high enough resolution to map centimeter-level changes in sea-level rise (Stege 2013). Figure 3.2 shows the DEM, with a range of elevation between 0 meters to 2.04 meters (Stege 2013).

The Digital Elevation Model serves as the base layer for the inundation model. The methods used to create the DEM included scanning the original Mylar topographic maps that comprise Rita, opening them in ArcGIS 10.1 and overlaying them onto a DigitalGlobe WorldView 2 (WV-2) satellite base map (Stege 2013). The maps were georeferenced using linear rectification and projected to the WGS 1984 UTM Zone 59N coordinate system (Stege 2013). Spot elevations were digitized and the DEM was generated using krigging interpolation with a cell size of 3 meters (Stege 2013). The internal datum of 0.0m depicting the low water mark was set as vertical datum for the DEM (Stege 2013).

Figure 3.2: Digital Elevation Model (DEM): Rita Village, Majuro, Marshall Islands (Stege 2014).



The use of this DEM is justified in that it is the only existing elevation model for the Marshall Islands. There is a dearth of elevation data for this country as indicated by an ongoing international, inter-agency effort to fill this gap in data (Lunetta 2014).While it is suitable for the purposes of this research, there are a few limitations associated with this digital elevation model.

One limitation is the 1983 collection date for the primary elevation data. Topographic changes since that time have not been incorporated into the DEM. Another limitation is the quality of the DEM data. Methods for capturing this data in 1983 were by means of an aerial topographic survey, which is not the highest resolution method and may result in data deficiencies. However, while other satellite imagery exists for the Marshall Islands that could be used to produce elevation models, it is all 1/3 arc second data, which has a resolution of ~10 m (Guerin et al. 2007). That resolution is not adequate for mapping sea-level rise in sub-meter increments. Therefore, this 1983 topographic survey data are the most current and highest resolution elevation data for Majuro is the only choice for primary elevation data for this DEM.

Another limitation is the result of the lack of ground-truthing conducted for the current DEM. While this elevation model is useful for the purposes of this research, it must be noted that there may be variations in the terrain currently not represented in this DEM. Despite these limitations, the DEM is the only available elevation model and is sufficient for the purposes of this research.

The following section is devoted to the presentation of climate data used in this research, justification for the use and limitation inherent in the selected data.

CLIMATE DATA

The purpose of this section is to present climate data used in this research. The section is organized as follows. First, the Representative Concentration Pathways are outlined, which give basis for the scenario methodology used in this research. Next, sea-level rise data is outlined. Finally, mean sea level measurements adopted in this research are presented.

Representative Concentration Pathways (RCP’s)

To conduct a scenario-based examination of sea-level rise induced migration, the analytic framework of the inundation modeling in this research is based on the Representative Concentration Pathways detailed in the International Panel on Climate Change’s Fifth Assessment Report (IPCC 2013). These RCP’s are not fully integrated scenarios, but are projections of radiative forcings[5] that serve as input for climate modeling, pattern scaling, and atmospheric chemistry modeling (IPCC 2013).

The estimates in each pathway are based on the radiative forcing of greenhouse gases and changes in the output from the sun, but do not include direct impacts of changing land use (albedo) or mineral dust forcing (Moss et al. 2008). The pathways, developed by four individual modeling groups and named to reflect the level of radiative forcing reached at the end of the century, serve to create a reliable analytic framework across various disciplines interested in developing socioeconomic and climate futures (Moss et al. 2008, van Vuuren et al. 2011).

In conjunction with developing the RCP's, the Coupled Model Intercomparison Project (CMIP5) was developed involving 21 climate modeling groups from around the world (Hibbard et al. 2011). The CMIP5 provides a consistent model ensemble into which inputs are run to determine how various earth systems might react under each RCP scenario. Outputs from climate experiments and projections are comparable across disciplines due to the consistency of the RCP inputs and the CMIP5 models (Hibbard et al. 2011). The global mean sea-level rise scenarios generated by the CMIP5 models using the four Representative Concentration Pathways, RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5, are the key outputs used in this research for modeling sea-level rise induced migration. The four Representative Concentration Pathways are described in turn, followed by a description of the global mean sea-level rise projections to be used in this research.

RCP 2.6 is representative of scenarios leading to very low greenhouse gas concentration levels by 2100 (2.6 W/m^2) and is representative of the research on mitigation targeting a limit to

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[5] Radiative Forcing is defined by the IPCC (2013) as "the change in the net, downward minus upward, radiative flux (expressed in $W\ m^{-2}$) at the tropopause or top of the atmosphere due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the sun."

the increase of the global mean temperature to 2°C (IPCC 2013). Assuming global participation, this pathway is theoretically achievable if the cumulative global emissions of greenhouse gases from 2010 to 2100 are reduced by 70% compared to a baseline scenario (van Vuuren et al. 2011). Conditions that need to be met in order to achieve this reduction in emissions include a rapid reduction in emissions over a period of decades with a peak of emissions in 2020, a rapid implementation of emissions reducing technologies, and steep reductions in non-CO_2 gases (van Vuuren et al. 2011).

RCP 4.5 is a pathway representative of scenarios that stabilize radiative forcing to 4.5 W/m^2 in the year 2100 (Thomson et al. 2011). The success of this scenario is dependent on limiting emissions through changes in energy production including shifts to electricity, increased use of technology that lowers emissions including the incorporation of carbon capture and geologic storage to the global energy system (Thomson et al. 2011). In addition to emissions reducing efforts in the energy sector, land use change including expanded forest lands, is also paramount to achieving the stabilization of radiative forcing to $4.5W/m^2$ (Thomson et al. 2011).

RCP 6.0 is a pathway that describes long-term trends in greenhouse gas emissions, short-lived species and changes in land use and land cover that stabilize radiative forcing to 6.0 W/m^2 by the year 2100 (Masui et al. 2011). In this scenario, emissions peak around 2060 and then wane the rest of the century (Masui et al. 2011). The success of this pathway is based on assumptions that emissions will be reduced in a cost-effective way in the global market through policy directed emissions permits (Masui et al. 2011).

RCP 8.5 is the pathway with the highest greenhouse gas emissions to the year 2100 (IPCC 2013). This scenario is based on assumptions of a lack of climate change policies, high global population growth to 12 billion by 2100, relatively slow economic growth and slow progress in energy efficiency technologies (Riahi et al. 2011). All of these assumption lead to high energy demands long-term, resulting in high emissions in this scenario (Riahi et al. 2011).

These four RCP's provide a range of scenarios of radiative forcings to the year 2100. Used as input in the CMIP5 climate modeling ensemble, these scenarios project a range of outputs of the rate of global mean sea-level rise. The decision to use these scenarios as the analytic framework is justified based the recognition of several factors related to the difficulties inherent in climate projections. Because human agency is virtually impossible to predict, the scenario framework allows for various interpretations on how humans will behave in the coming decades with respect to climate change. From individual actions, to national policies and global agreements, the future of emissions and relative climatic affects are unknown. The RCP scenarios create a continuum representing a high rate of human actions to reduce emissions to a scenario showing very little human action to regulate emissions. These four RCP's allow for a range of analyses of future changes in sea-level rise with respect to various rates of radiative forcing. Another justification for using RCP's is the result of the parallel processes through which these scenarios were generated. Because these scenarios are not fully integrated socioeconomic, emissions and climate projections, but simply radiative forcing measures, the resultant measures can serve as input across many disciplines. This creates a consistent analytic thread across research communities that promote interdisciplinary collaborations (Hibbard et al. 2011).

Limitations of this analytic framework include uncertainties associated with forecasting complex and multifaceted climate systems and social-based systems. Due to these inherent complexities, projections from the analytic framework can only be presented as potential outcomes. Definitive, linear projections are not realistic outcomes within this framework.

The following subsection outlines the global mean sea-level rise data employed in this research, which was generated by the CMIP5 project using the Representative Concentration Pathways.

Sea-level rise Projections

Sea-level rise data for each RCP scenario in this research are process-based projections of global mean sea-level rise (GMSL) during the 21st century, based on results from 21 CMIP5 climate models and found in the Working Group 1 Contribution to the IPPC Fifth Assessment Report: The Physical Science Basis (Church et al. 2013).

Table 3.1: Global Mean Sea-level rise (GMSL) on January 1 on the years indicated with respect to a GMSL baseline of 1986-2005. Values shown are the median and likely range in meters (Church et al. 2013)

	RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Year 2030	0.13 (0.09-0.16)	0.13 (0.09-0.16)	0.12 (0.09-0.16)	0.13 (0.10-0.17)
Year 2050	0.23 (0.17-0.30)	0.23 (0.17-0.29)	0.22 (0.16-0.28)	0.25 (0.19-0.32)
Year 2070	0.31 (0.21-0.41)	0.35 (0.25-0.45)	0.33 (0.24-0.43)	0.42 (0.31-0.54)
Year 2100	0.44 (0.28-0.61)	0.53 (0.36-0.71)	0.55 (0.38-0.73)	0.74 (0.53-0.98)

Table 3.1 shows the Global mean sea-level rise projections in meters with respect to Global mean sea levels during the 1986-2005 timeframe (Church et al. 2013). Values are

presented both as the median level and the *likely*[6] range of sea-level rise (Church et al. 2013). This temporal time frame of this research models Global mean sea-level rise for the years 2030, 2050, 2070 and 2100. The elevation data available for Rita Village is too coarse to model yearly sea-level rise increments, which range from 3 to 10 millimeters per year (Church et al. 2013; Australian Bureau of Meteorology and CSIRO. 2011).

Analyzing sea-level rise over the course of twenty to thirty years avoids potential misinterpretation of seasonal variations in sea-level rise and allows for more detectable increments of sea-level rise in Geographic Information Systems. The median value of GMSL rise for each year and each RCP will be employed in the modeling of sea-level rise in this research. The median value accounts for uncertainties in the climate models that contribute both to over and under estimating the projected rates of sea-level rise. In table 3.1, the median value is reported in front of the range values.

This sea level data was chosen because it represents the contributions of climate scientists across the globe and is published in the most comprehensive report on climate change to date, the IPCC Fifth Assessment Report (IPCC 2103). Additionally, scientific understanding of sea-level rise has increased substantially since the last IPCC report in 2007, giving a high rate of likelihood that these latest projections are scientifically sound (Church et al. 2013).

Limitations of this data arise as significant uncertainties remain as to the magnitude and rate of ice-sheet contribution to GMSL rise for the 21st century and the variations by region in the distribution of sea-level rise. The regional variations could create significant impacts in the region of study in this region as the Marshall Islands are located in an area of the Pacific Ocean

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[6] The *likely* range is defined by the IPCC as the range of GMSL rise given for each RCP that combines the uncertainty in global climate change, represented by the CMIP5 ensemble, with the uncertainties in modeling the contributions to GMSL by ice sheets, land ice and thermal expansion (Church et al. 2013).

that is seeing higher rates of rise than previously projected (need citation). For the purposes of this research, the more conservative median measures will be used, with the caveat that regional ocean dynamics suggest this region could see rates of rise at the upper end of the *likely* range. The following subsection discusses the measure of Mean Sea level used in this research.

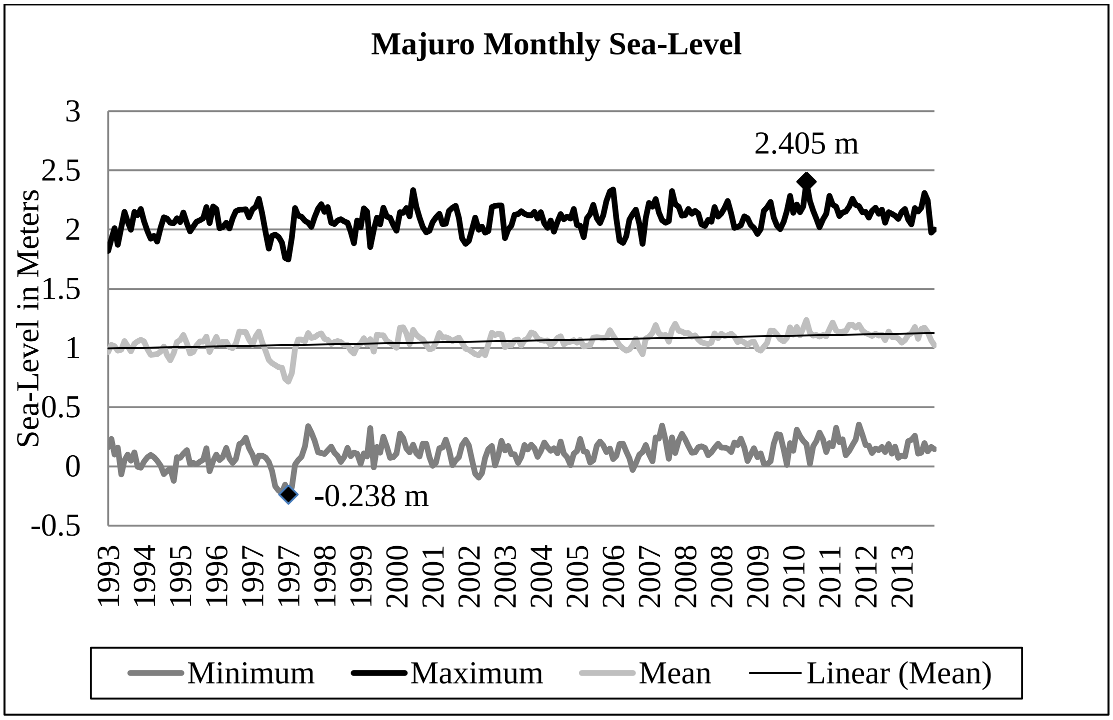
Mean Sea level

Monthly sea level readings for Majuro in the Marshall Islands are used in this research in order to determine the baseline mean sea level for this area. These data were collected from the Pacific Sea Level Monitoring (PSLM) project, which operates under the Climate and Oceans Support Program in the Pacific Region of the Australian Bureau of Meteorology (National Tidal Centre; Bureau of Meteorology 2014). This sea level monitoring project is a continuation of the 20-year South Pacific Sea level and Climate Monitoring Project (SPSLCMP) (National Tidal Centre; Bureau of Meteorology 2014).

This data source was chosen due to the temporal and technical quality and ease of availability. A SEAFRAME (SEA Level Fine Resolution Acoustic Measuring Equipment) gauge was installed in Majuro, Marshall Islands, in May 1993, for an Australian Aid program developed in response to concerns in the pacific region to climate change (AusAID 2007). This station continuously monitors sea level, air and water temperature, atmospheric pressure, wind speed and direction. It is one of several monitoring stations in the Pacific region gathering data on sea level and climate. This station is continuously maintained, calibrated and leveled against land-based marks to maintain vertical datum control (Hill and Lal 2014). The SEAFRAME data are transmitted hourly via satellite. Due to the relatively short time frame of data collection, sea level trends are prone to the effects of short-term ocean variability due to ENSO events

(Australian Bureau of Meteorology and CSIRO 2011). However, this data will be useful for short-term analysis of sea level changes. CGPS (Continuous Geographical Positioning Systems) have been installed on all of the islands that have SEAFRAME gauges. The CGPS provides data on whether the island as a whole is moving vertically in reference to the International Terrestrial Reference Frame (AusAID 2007). Figure 3.3 depicts monthly sea levels in meters from 1993 to 2014, including high tide (maximum), low tide (minimum) and mean sea level.

Figure 3.3: Monthly Sea Level Measures in meters between 1993 and 2014 (National Tidal Centre; Bureau of Meteorology 2014)



Based on these measures spanning from 1993 to 2014, mean sea level for the Majuro area is 1.062 meters. This research uses this regional mean-sea level measure as the baseline for projections of future rates of sea-level rise. Doing so accommodates the daily variation in sea level that is a direct result of high and low tide, which has varied from a record high measure of

2.405 meters to a record low of -0.238 meters (PMSL 2014). The following section is an overview of the housing and population characteristics of the study site of Rita Village on Majuro Atoll.

HOUSING AND POPULATION DATA

The purpose of this section is to provide the data on housing and population for Rita Village. The section is organized as follows. First, methods for collecting and analyzing housing data are provided followed by population data collection methods.

Housing Data

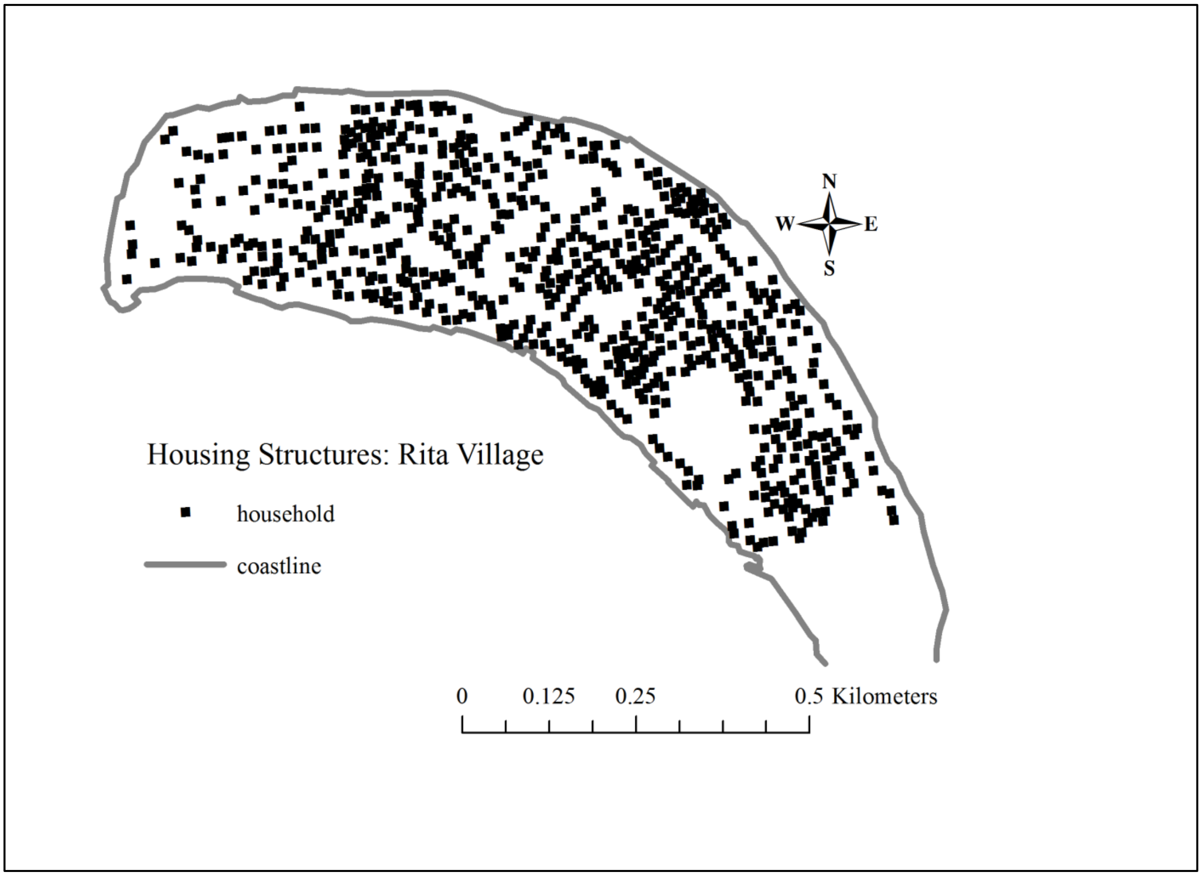
Spatial data sets of population and housing were generated to overlay the digital elevation model. The housing layer is a key element in measuring infrastructure loss as a result of sea-level rise. This layer includes mapping the houses in the study area. To identify each individual home, DigitalGlobe WorldView-2 (WV-2) Multi Spectral/Pan data mosaic satellite imagery was used (U.S. Department of Agriculture, Natural Resources Conservation Service, National Geospatial Management Center 2010).

Housing Variable Specification

To generate the housing layer for the GIS inundation modeling, a square point was placed on every structure identified in the satellite imagery of Rita Village that measured 4,999 square feet or less. This measure is justified based on the 2011 Census of the Marshall Islands in which 98.9% of the housing structures in the country measured 4,999 square feet or less (EPPSO 2011).

Those structures that measured less than 4,999 square feet and were not counted and were identified as buildings within an industrial or public works setting and unlikely to be residences. A total of 703 housing structures were identified in Rita Village from the 2011 Census of housing of Rita Village in the Marshall Islands and 703 corresponding square points were placed on the infrastructure map to identify these structures (Figure 3.4).

Figure 3.4: Household Structures: Rita Village, Majuro, Marshall Islands.



It is important to note that two of the larger structures on Rita Village are the Rita Elementary School and the Marshall Islands High School. The schools are not identified on the housing layer for the research; however, these are important structures for the residents of Rita in times of flooding. These are the only two-story structures in Rita and on most of Majuro and are used as temporary shelter during flooding incidences (Jaynes 2014). The following subsection discusses population data employed in this research.

Population Data

In order to model population displacement, secondary data were collected from the Marshall Islands 2011 census (EPPSO 2011) to get an estimate of the current population living in Rita Village. This census was conducted as a total enumeration of the population and housing of the Republic of the Marshall Islands. The census of population complied data on the size and distribution of the population as well as information about the demographic, social, economic and cultural characteristics (EPPSO 2011).

Population Variable Specification

Based on the census, a population estimate for Rita Village was determined by using the average size of 6.7 persons per household and multiplying it by the total number of 703 houses identified in Rita Village (EPPSO 2011). The calculation resulted in an estimated total population of 4,710 people in Rita Village as of 2011 (EPPSO 2011).

The use of this data and the subsequent population calculations is justified as the census is the most current and single source of population counts for the Marshall Islands. However, limitations of this data include the lack of a precise population count for the study area, making the estimation the best option for identifying the number of residents in Rita Village. The following section presents the migration data used in the research.

MIGRATION DATA

The purpose of this section is to review the migration data used in this research. The migration data provides basis for the assumptions made on potential migration streams from the Marshall Islands as sea-level rises.

Migration Variable Specification

The migration estimation of this research is based on the number of people displaced by sea-level rise and the pull of social networks in the three states with the highest percentages of Marshallese in the United States. The assumption is that permanent displacement will result in out migration out of the country due to the unique circumstance of having no inland are to which one can migrate. The research simply states that those residents who lose their home to sea-level rise will have to leave the country. However, predicting migration decisions such as destination are beyond the scope of this research.

A key limitation in this specification is the understanding that predicting migration decisions of individuals is difficult at best. Additionally, isolating the influence of sea-level rise on the decision to migrate is beyond the scope of this research. Despite these limitations, a few key assumptions are made concerning migration destination for the discussion and conclusions section of this research. One assumption is that a large influence of migration is the result of cumulative impacts of push factors in a sending community. It is assumed in this research that sea-level rise will become an additional push factor for migration, along with existing determinant of migration such as employment, health care and education.

Additionally, cumulative causation incorporates the influence of social networks as a pull factor for destination choice by migrants. This research assigns an equal pull factor for each

Marshallese individual living in the United States. Under this assumption, the weight of pull can be based on the percent of the population in an area. For example, Hawaii has 30 % social network pull, Arkansas has a 19.3 % social network pull, and Washington has a 9.8 % network pull on migrants leaving the Marshall Islands for the United States. These population distribution data are from the United States Census Bureau from the 2010 census, which represents the most recent and first enumeration of the United States population in which residents could self-identify as Marshallese.

Based on these assumptions, the measures for all three destinations are calculated. The limitations in this measure revolve around the prospective nature of this specification. Because there are no data available on which to base concrete predictions, this estimation is the best viable measure for migration. Additionally, while three destination measures are conducted in this research, the discussion of this research places a particular focus on the destination of Arkansas for the Marshallese.

The final assumption is based on current rates of out migration from the Marshall Islands. In terms of overall population growth rate, the entire country has seen a decline in the rate from a high of 4.1% during the period of 1980-1988 to a mere 0.4% between 1999 and 2011 (EPPSO 2011). Causes of this decline include a drop in the rate of natural increase (the difference between the crude birth rate and crude death rate) from 3.7% to 2.8% between 1999 and 2011 and a drop in the fertility rate from 5.7 per woman in 1999 to 4.1 in 2011 (EPPSO 2011). The primary reason, however, for the decline in the growth rate of the population is due to out migration (EPPSO 2011). With an existing culture of out migration (Graham 2008), the assumption of this research is that an addition push factor of housing and land loss due to sea-level rise will add to this migration stream. The limitation of this assumption is that predicting human agency is incredibly complex and beyond the scope of this research. Thus, the assumption that those displaced will emigrate stands for this research, based on current knowledge of out migration from the Marshall Islands. The next section provides an overview of the methods used in conducting this research.

METHODS

The purpose of this section is to describe and justify all methods used for analysis of this research. The section is organized as follows. First, the methods for developing the inundation scenarios for Representative Concentration Pathways 2.6, 4.5, 6.0 and 8.5 for the years 2030, 2050, 2070 and 2100 are presented. Second, the method for calculating housing loss is provided. Third, the method for calculating population displacement is covered. Finally, the migration scenarios are presented.

Inundation Scenarios

The technological methodology for developing the sea level inundation scenarios used in this research is comprised of several steps. First, the only known Digital Elevation Model for Rita Village is added to ArcGIS 10.1, overlayed on a WorldView2 satellite imagery basemap. Second, mean sea level is established with respect to existing vertical datum and sea level data. Third, map algebra is executed in ArcMap 10.1 to identify areas below sea level measurements based on mean sea level projections for Representative Concentration Pathway Scenarios 2.6, 4.5, 6.0 and 8.5 for the years 2030, 2050, 2070 and 2100. Finally, areas of inundation are identified. Each of these steps will be described in turn.

First, the WorldView2 satellite imagery of Rita Village was added to new map document in ArcGIS 10.1. The Digital Elevation Model was then overlayed so the existing land and infrastructure of Rita Village was visible and had corresponding elevation data. Next, the mean sea level measurement of 1.062 meters was added to each of the median sea level projections for each Representative Concentration Pathway for each time period. Adding this measure accounted for the difference between low and high tide in Rita Village as the Vertical Datum in the DEM was set at 0 meters. The resulting values are seen in table 4.1.

Table 4.1: Sea-level Rise Figures Derived from Adding Mean Sea level in Rita Village (1.062 meters) to Predicted Median sea-levels (meters).

	RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Year 2030	1.062 + 0.13 = 1.075	1.062 + 0.13 = 1.075	1.062 + 0.12 = 1.074	1.062 + 0.13 = 1.075
Year 2050	1.062 + 0.23 = 1.085	1.062 +0.23 = 1.085	1.062 + 0.22 = 1.084	1.062 + 0.25 = 1.087
Year 2070	1.062 + 0.31 = 1.093	1.062 + 0.35 = 1.097	1.062 + 0.33 = 1.095	1.062 + 0.42 = 1.104
Year 2100	1.062 + 0.44 = 1.106	1.062 + 0.53 = 1.115	1.062 + 0.55 = 1.117	1.062 + 0.74 = 1.136

The resultant values were used in the map algebra function of ArcGIS 10.1 to generate raster layers representing inundation areas based on sea-level rise data input. For example, the map algebra expression for the inundation model for the RCP 2.6 for the year 2010 was [DEM > 1.075m]. The generated map indicated all areas on the Digital Elevation Model that were below 1.075 meters high. These are the areas that would see inundation with a sea-level rise of 0.13 meters under the RCP 2.6 scenario in 2030. This function was repeated for RCP scenarios 4.5, 6.0 and 8.5 for the years 2030, 2050, 2070 and 2100. The next section details the process for generating a population layer in ArcGIS 10.1.

Housing layer

In order to estimate number of houses impacted by each scenario of inundation, an infrastructure layer was generated in ArcMap 10.1. The process involved identifying structures by sight on the WorldView2 satellite imagery, using a measuring too to verify that the structure was below 4,999 square feet and then placing a point in the center of each structure, creating a point feature class layer. This layer was overlayed on the existing DEM and satellite layer in order to easily identify houses that were covered by water in the inundation model. Any point that was covered was counted as impacted, even if 100% of the structure was not covered. This was adopted under the assumption that if water is in the center of your home, it has been impacted by the inundation. The count was taken in ArcMap 10.1 and recorded in the analysis section. The next section discusses the generation of the population layer.

Population layer

The method for creating a population layer involved using the infrastructure layer and embedding a number of people per household into each point. Based on the 2011 Marshall Islands census, each household was given a value of 6.7 people. The method for calculating displacement was entirely dependent upon designation of a house as impacted by inundation.

The logic stands that if a house is flooded, the inhabitants are displaced. The key assumption, based on the current population growth rate in the Marshall Islands of 0.4%, is that population rates will remain relatively stable to the year 2100 (EPPSO 2011). It would take the population 273 years to double with that growth rate (EPPSO 2011), so the population numbers are held constant for the purposes of this research. The following section outlines how land area loss was calculated.

Land Area Loss

The method for calculating land area loss was as follows. First, the total number of pixels in the digital elevation model of Rita Village was identified as 33,474 pixels. This number was divided by the total land area of Rita Village, which is 0.42 km^2. This gave an area value of each pixel of .000012547 km^2. To measure area impacted by inundation, the attribute table for each inundation map was examined to see how many pixels fell into the inundation area. This number was then multiplied by .000012547 km^2 to get an estimate of land area inundated. The following section discusses the migration model employed in the research.

Justification for this method rests in the systematic grid of pixels that make up land are in GIS. This makes the measure of land loss easily computable based on the number of pixels impacted and the collective measure of the land area represented by each pixel. Subsidence[7] was considered when developing this land area loss calculation; however it was not added as the rate of subsidence in the Marshall Islands is imperceptivity slow at an average of just over 2.3 cm per 1000 years (Stoddart 1972). The following section outline the migration model used in this research.

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[7] Subsidence is the gradual sinking of an area of land.

Migration Scenarios

The methods for generating the migration scenarios for this research were two-fold. First, human displacement due to inundation was recorded for each inundation scenario for the years 2030, 2050, 2070 and 2100. Total numbers of displaced are then given a cumulative causation network “pull” value corresponding to the percentage Marshallese population in the three most popular destination states in the United States. This measure is based on the 2010 Census of the United States (US Census 2010). For example, because 33.0% of all Marshallese in the United States live in Hawaii, that state gets a “pull” measure of 33% on the total number of people displaced. Correspondingly, Arkansas has a pull factor of 19.3% and Washington State has a pull factor of 9.8%. The numbers of Marshallese currently living in other destinations outside the Marshall Islands are much smaller and are therefore excluded from this migration measure.

Justification for this measure rests solely on the fact that the only migration data available is a measure of relocation from the Marshall Islands in the United States. For further insight into other factors impacting the cumulative cause of migration from the Marshall Islands and to the United States, further data collection and research is required.

Reliability and Validity

Issues of reliability and validity are considered in this research in the following manner. First, threats to reliability have been identified in the necessity to make many assumptions in this research process. However, while assumptions have been made, the steps taken to increase the reliability of the findings of this research are in the methods. Clear steps for measuring the outcomes of this research are provided, are replicable and would yield the same results when repeated.

Threats to the validity of this research are as follows. First, steps were taken to ensure that this research was an examination of the potential relationship between sea-level rise and migration, not an attempt to assign a causal relationship. Additionally, to avoid issues of internal validity that would result because of the inherent difficulties in predicting climate change and human migration behavior, scenarios are used as a way of presenting an array of potential and possible outcomes with the caveat that predicting the future is impossible.

Limitations

The limitations of this methodology rest on a few key factors. First, there is a dearth of data on Marshall Islands. Physical elevation data are scant and outdated. Data on migration are also inadequate. This creates a research platform that relies heavily on assumptions. While these assumptions are grounded on previous research and knowledge, they create some questions of validity. To address this limitation, the scenario methodology was chosen. By creating an array of outcomes, the research is not positing deterministic outcomes, but rather, data-driven interpretations of various migration outcomes based on climate scenarios.

However, the scenario methodology can be seen as a limitation in that it doesn’t provide a deterministic, linear tool for research. To address this limitation, much of the scenario development is based on reliable climate change data. While the migration data is more scant, the scenarios of this research provide a clear picture of sea-level rise, giving current residents of Rita Village a guide for planning adaptive coping strategies.

The purpose of this chapter was to present the data and methods used to examine the relationship between sea-level rise and migration. The following chapter presents the findings of this research.

Chapter IV

FINDINGS

This chapter is devoted to reporting the findings of the impact of this research. The chapter is organized as follows. First, findings are presented for the Representative Concentration Pathway (RCP) 2.6 Scenario, followed by findings for the Representative Concentration Pathway 4.5 Scenario, the Representative Concentration Pathway 6.0 Scenario, and then for the Representative Concentration Pathway 8.5 Scenario. Land loss due to inundation, housing loss and population displacements due to inundation are outlined for each RCP Scenario for the years 2030, 2050, 2070 and 2100. Next, the migration scenarios are presented for each RCP. The chapter concludes with a summary of the results.

Representative Concentration Pathway 2.6 Inundation Scenarios: 2030, 2050, 2070 and 2100

The purpose of this section is to present the finding of the inundation models for Representative Concentration Pathway 2.6 for the years 2030, 2050, 2070 and 2100. RCP 2.6 is representative of scenarios leading to very low greenhouse gas concentration levels by 2100 (IPCC 2013). The findings include sea-level rise projections, inundation results, a measure of houses impacted, the number of people displaced and the land area lost to inundation. The findings are presented both for the individual time period and as a cumulative measure from 2030 to 2100. Findings are first presented in table format followed by visual representation of the inundation models.

RCP 2.6: Summary Tables

As can be seen in table 4.1, sea-level rise for RCP 2.6 is 0.13 m by 2030, which inundates 0.06 km^2 of land, inundates 82 houses and displaces an estimated 549 people. By 2050, the predicted rate of sea-level rise is an additional 0.10 m, which inundates 0.03 km^2 of land, inundates an additional 41 houses and displaces an additional 275 people. By 2070, the predicted rate of sea-level rise is an additional 0.08 m, which inundates and additional 0.05 km^2 of land, inundates an additional 73 houses and displaces an additional 489 people. By 2100, the predicted rate of sea-level rise is an additional 0.13 m, which inundates an additional 0.09 km^2 of land, inundates an additional 140 houses and displaces an additional 938 people.

Whereas Table 4.1 describes the impacts per time period, table 4.2 describes the cumulative impacts of sea-level rise to the year 2100. As can be seen in table 4.2, by the year 2030, sea-level is predicted to rise 0.13 m, inundating 0.06 km^2 of land (14% of the total land area), inundating 82 houses and displacing 549 people (12% of the total population). By 2050, cumulative sea-level rise is predicted to be 0.23 m, cumulative land loss is 0.09 km^2 (21% of the total land area), cumulative houses inundated by this point are 123 and the total displaced population rises to 824 (17% of the total population). By 2070, cumulative sea-level rise is predicted to be 0.31 m, cumulative land loss is 0.14 km^2 (33% of the total land area), cumulative houses inundated by this point are 196 and the total displaced population rises to 1313 (28% of the total population). By 2100, cumulative sea-level rise is predicted to be 0.44 m, cumulative land loss is 0.23 km^2 (55% of the total land area), cumulative houses inundated by this point are 336 and the total displaced population rises to 2251 (48% of the total population).

Table 4.1: RCP Scenario 2.6 Impacts for Each Individual Time Period on Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters) per time period	Area Inundated (km^2) per time period	Houses Inundated per time period	Estimated Number of People Displaced per time period
Year 2030	0.13 m	0.06 km^2	82	549
Year 2050	0.10 m	0.03 km^2	41	275
Year 2070	0.08 m	0.05 km^2	73	489
Year 2100	0.13 m	0.09 km^2	140	938

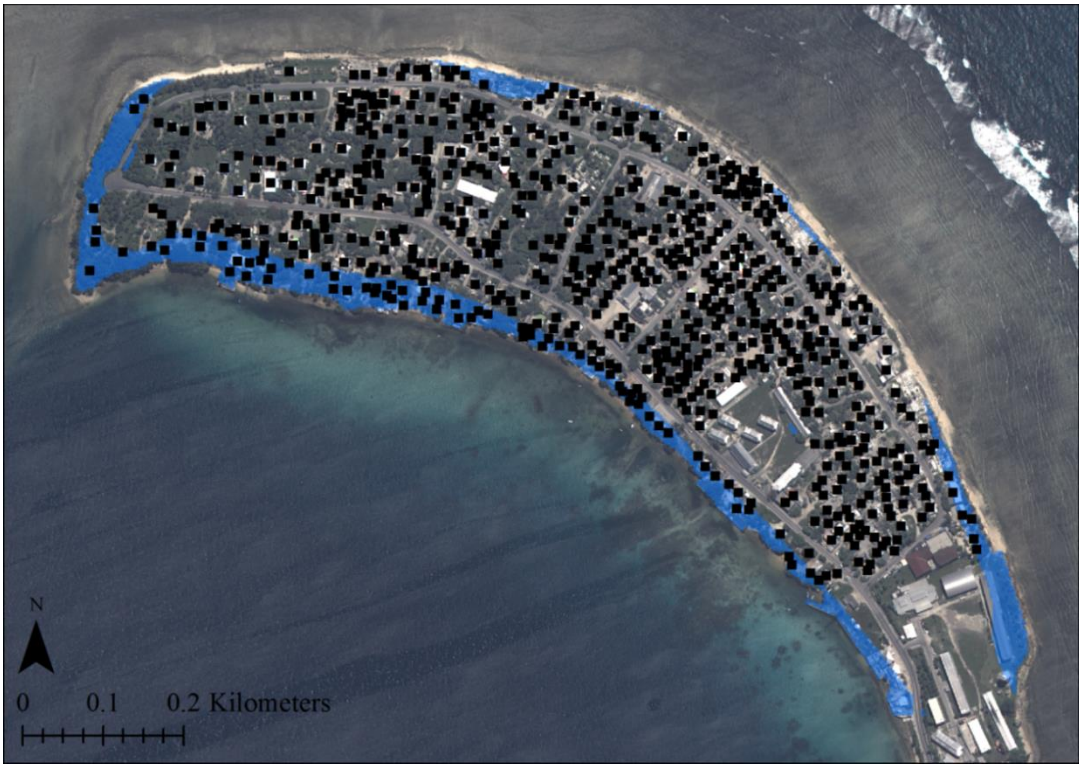
Table 4.2: RCP Scenario 2.6 Cumulative Impacts on Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters)	Area Inundated (km^2)	% of Total Land Area	Houses Inundated	Estimated Number of People Displaced: Total	% of Total Rita Population
Year 2030	0.13 m	0.06 km^2	14%	82	549	12%
Year 2050	0.23 m	0.09 km^2	21%	123	824	17%
Year 2070	0.31 m	0.14 km^2	33%	196	1313	28%
Year 2100	0.44 m	0.23 km^2	55%	336	2251	48%

RCP 2.6: Year 2030

The RCP 2.6 Scenario in the year 2030 has a predicted median sea-level rise of 0.13 meters with respect to the global mean sea level of 1996-2005. As can be seen in Figure 4.1, the inundation model shows the entire south (lagoon) side, the far western side and a few areas on the northern and eastern ocean side of Rita Village with inundation. The total number of houses inundated is 82, including those that are fully or partially submerged. The estimated total number of people displaced is 549. This represents 12% of the total population of Rita Village. The area of land inundated is approximately 0.06 km^2, which represents 14% of the land in Rita Village. No roads are impacted in this scenario.

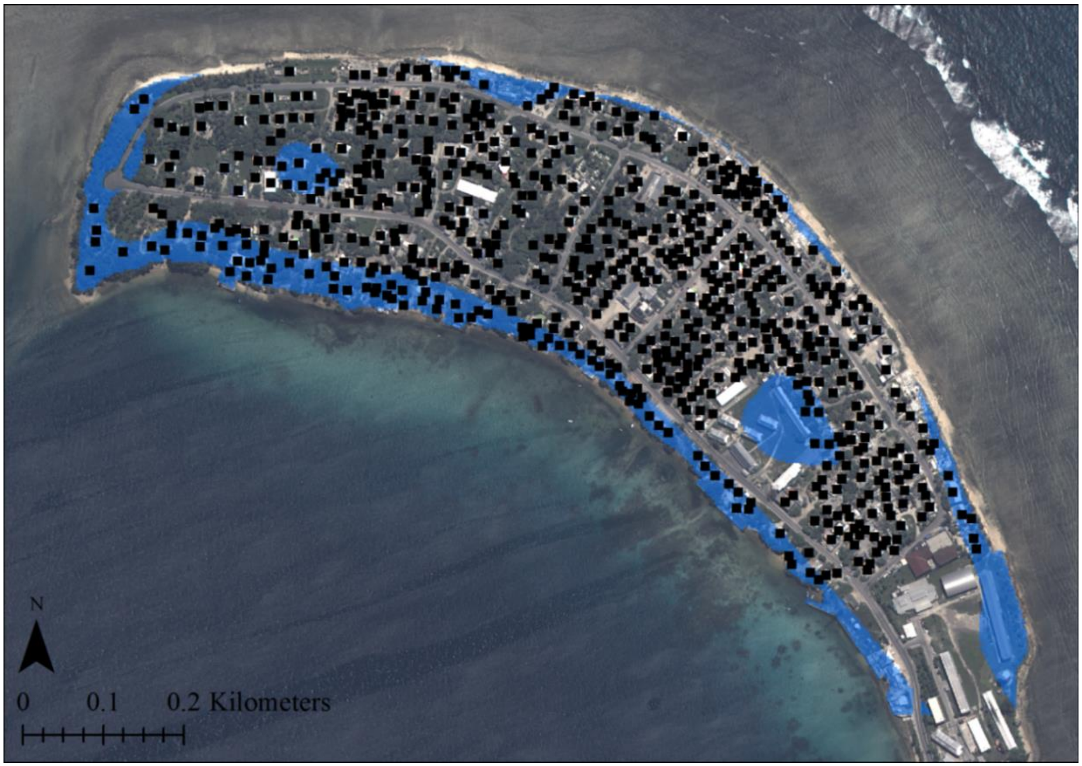
Figure 4.1: Scenario Model RCP 2.6: Year 2030



RCP 2.6: Year 2050

The RCP 2.6 Scenario in the year 2050 has a predicted median sea-level rise of 0.23 meters with respect to the global mean sea level of 1996-2005. This is an additional .10 meters of rise from 2030. As can be seen in Figure 4.2, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and two depressions in the center of Rita Village are inundated. From the year 2030 to the year 2050, the additional number of houses impacted is 41, displacing an additional 275 people. This brings the total number of houses impacted to 123 by 2050. The total estimated number of people displaced by 2050 is 824. This represents 17% of the total population of Rita Village. An additional 0.03 km^2 of land is lost. This brings the total area of land inundated to 0.09 km^2, which represents 21% of the land in Rita Village. The road is not impacted in this scenario.

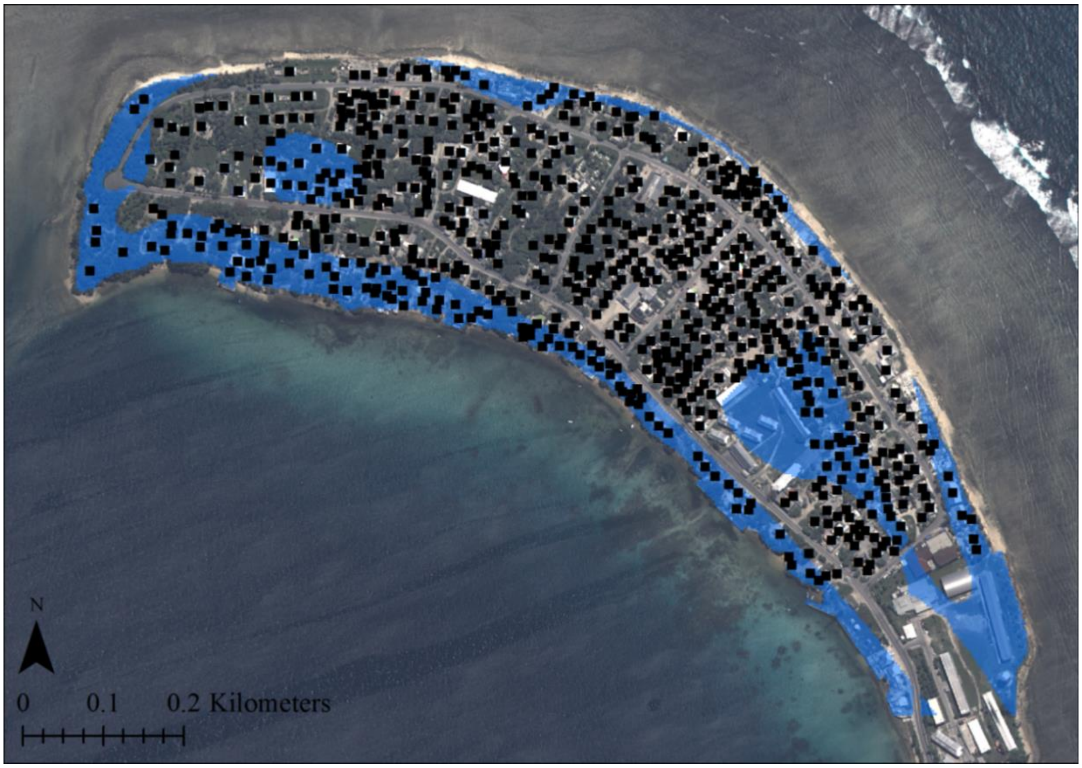
Figure 4.2: Scenario Model RCP 2.6: Year 2050



RCP 2.6: Year 2070

The RCP 2.6 Scenario in the year 2070 has a predicted median sea-level rise of 0.31 meters. This is an additional 0.08 meters of rise from 2050. As can be seen in Figure 4.3, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and two depressions in the center of Rita Village inundated. From 2050 to 2070, the additional number of houses inundated is 73, displacing an additional 489 people. This brings the total number of houses impacted in this scenario to 196. The total estimated number of people displaced is 1313 by 2070. This represents 28% of the total population of Rita Village. An additional 0.05 km^2 of land is lost. This brings the total area of land inundated to 0.14 km^2, which represents 33% of the land in Rita Village. Three small sections of the main road are impacted.

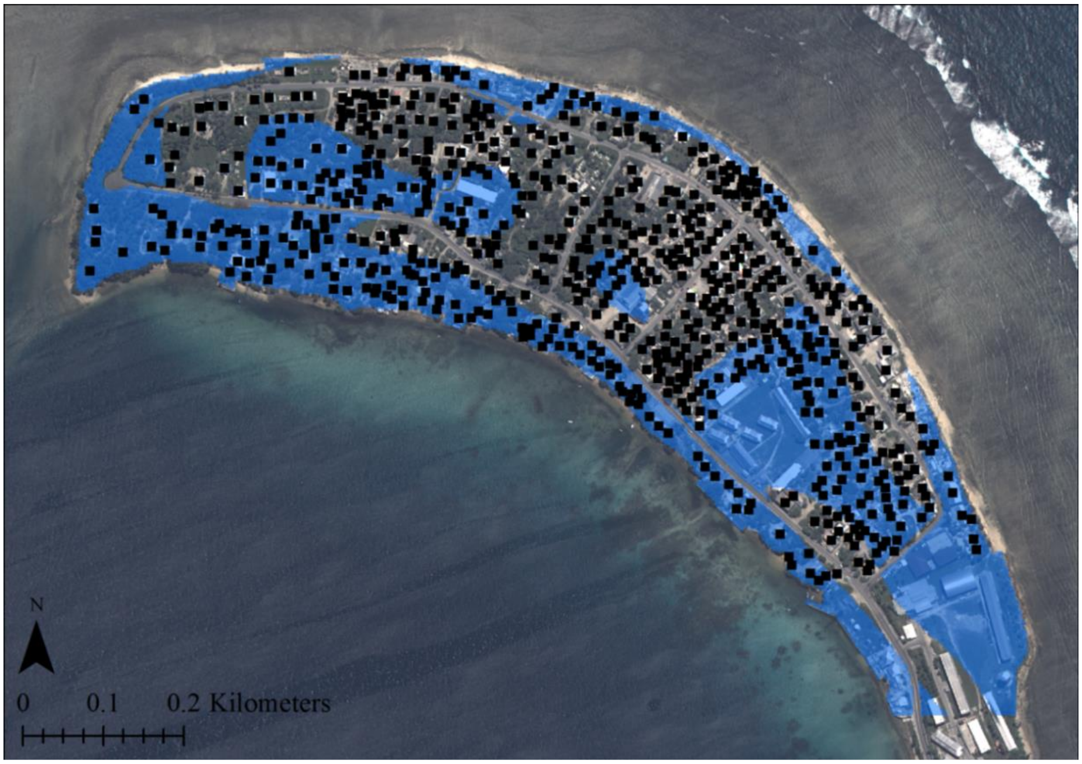
Figure 4.3: Scenario Model RCP 2.6: Year 2070



RCP 2.6: Year 2100

The RCP Scenario 2.6 in the year 2100 has a predicted median sea-level rise of 0.44 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.13 meters of rise from 2070. As can be seen in Figure 4.4, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and several large depressions in the center of Rita Village inundated. From 2070 to 2100, the additional number of houses inundated is 140, displacing an additional 938 people. The total number of houses impacted reaches 336 by 2100. The total estimated number of people displaced reaches 2251 by 2100. This represents 48% of the total population of Rita Village. An additional 0.09 km^2 of land is lost. This brings the total area of land inundated to 0.23 km^2, which is 55% of the land area of Rita Village. Large sections of the main road are impacted in this scenario.

Figure 4.4: Scenario Model RCP 2.6: Year 2100



Summary of Representative Concentration Pathway 2.6

This pathway, as a best case scenario, describes a future for Rita Village of steady, encroaching sea-level rise. With over half of the land area inundated and over half of the population displaced by 2100, this best case scenario is one in which a large portion of the population will be negatively impacted. The following section outlines the findings of the Representative Concentration Pathway 4.5, which is predicted to have a slightly higher magnitude of sea-level rise.

Representative Concentration Pathway 4.5 Inundation Scenarios: 2030, 2050, 2070 and 2100

This section presents the findings of the inundation models for Representative Concentration Pathway 4.5 for the years 2030, 2050, 2070 and 2100. While RCP 2.6 is the best case scenario, RCP 4.5 is the next best case scenario. RCP 4.5 is a pathway representative of scenarios that stabilize radiative forcing to 4.5 W/m^2 in the year 2100 (Thomson et al. 2011). The findings include sea-level rise projections, inundation results, a measure of houses impacted, the number of people displaced and the land area lost to inundation. The findings are presented both for the individual time period and as a cumulative measure from 2030 to 2100. Findings are first presented in table format followed by visual representation of the inundation models.

RCP 4.5 Summary Tables

As can be seen in table 4.3, sea-level rise for RCP 4.5 is 0.13 m by 2030, which inundates 0.06 km^2 of land, inundates 82 houses and displaces an estimated 549 people. By 2050, the predicted rate of sea-level rise is an additional 0.10 m, which inundates 0.03 km^2 of land, inundates an additional 41 houses and displaces an additional 275 people. By 2070, the predicted rate of sea-level rise is an additional 0.12 m, which inundates and additional 0.07 km^2 of land, inundates an additional 93 houses and displaces an additional 623 people. By 2100, the predicted rate of sea-level rise is an additional 0.18 m, which inundates an additional 0.15 km^2 of land, inundates an additional 225 houses and displaces an additional 1508 people.

Whereas Table 4.3 describes the impacts per time period, table 4.4 describes the cumulative impacts of sea-level rise to the year 2100. As can be seen in table 4.4, by the year 2030, sea-level is predicted to rise 0.13 m, inundating 0.06 km^2 of land (14% of the total land area), inundating 82 houses and displacing 549 people (12% of the total population). By 2050, cumulative sea-level rise is predicted to be 0.23 m, cumulative land loss is 0.09 km^2 (21% of the total land area), cumulative houses inundated by this point are 123 and the total displaced population rises to 824 (17% of the total population). By 2070, cumulative sea-level rise is predicted to be 0.35 m, cumulative land loss is 0.16 km^2 (38% of the total land area), cumulative houses inundated by this point are 216 and the total displaced population rises to 1447 (31% of the total population). By 2100, cumulative sea-level rise is predicted to be 0.53 m, cumulative land loss is 0.31 km^2 (74% of the total land area), cumulative houses inundated by this point are 441 and the total displaced population rises to 2955 (63% of the total population).

Table 4.3: RCP Scenario 4.5 Impacts for each Individual Time Period of Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters) per time period	**Area Inundated (km^2) per time period**	**Houses Inundated per time period**	**Estimated Number of People Displaced per time period**
Year 2030	0.13 m	0.06 km^2	82	549
Year 2050	0.10 m	0.03 km^2	41	275
Year 2070	0.12 m	0.07 km^2	93	623
Year 2100	0.18 m	0.15 km^2	225	1508

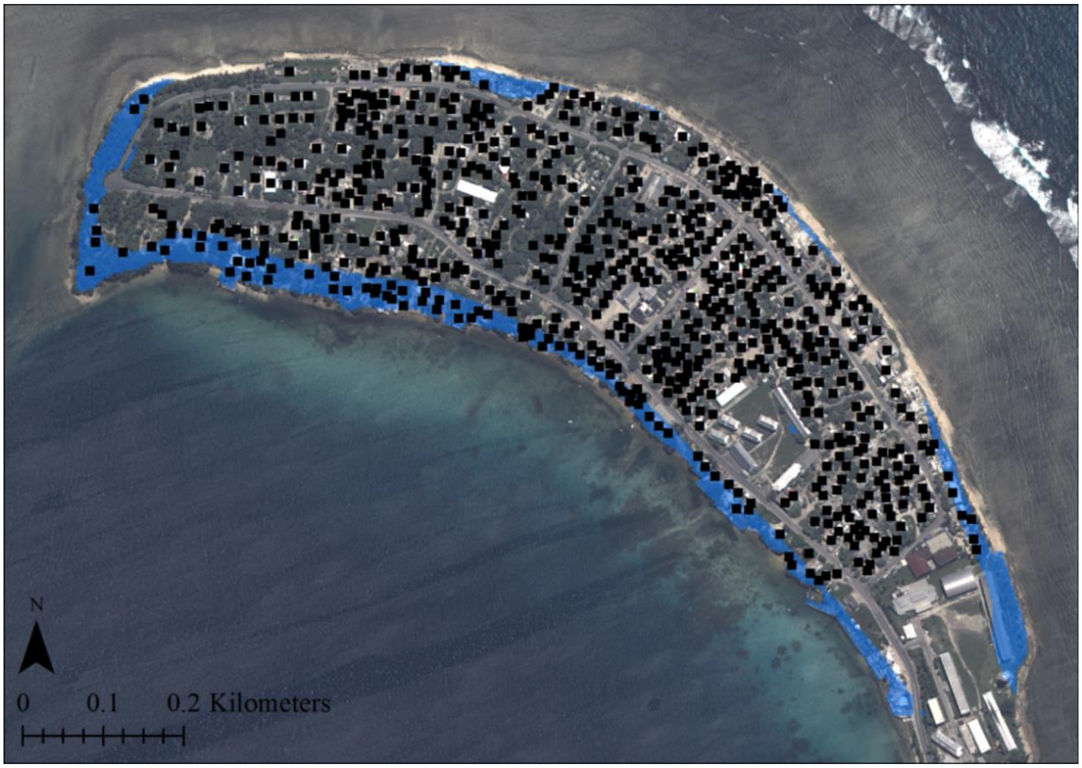
Table 4.4: RCP Scenario 4.5 Cumulative Impacts of Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters)	**Area Inundated (km^2)**	**% of Total Land Area**	**Houses Inundated**	**Estimated Number of People Displaced: Total**	**% of Total Rita Population**
Year 2030	0.13 m	0.06 km^2	14%	82	549	12%
Year 2050	0.23 m	0.09 km^2	21%	123	824	17%
Year 2070	0.35 m	0.16 km^2	38%	216	1447	31%
2100	0.53 m	0.31 km^2	74%	441	2955	63%

RCP 4.5: Year 2030

The RCP 4.5 Scenario in the year 2030 has a predicted median sea-level rise of 0.13 meters with respect to the global mean sea level of 1996-2005. As can be seen in Figure 4.5, the inundation model shows the entire south (lagoon) side, the far western side and a few areas on the northern and eastern ocean side of Rita Village with some level of inundation. The total number of households inundated is 82, including those that are fully or partially submerged. The estimated total number of people displaced is 549. This represents 12% of the total population of Rita Village. The area of land inundated is approximately .06 km^2, or 14% of the land in Rita.

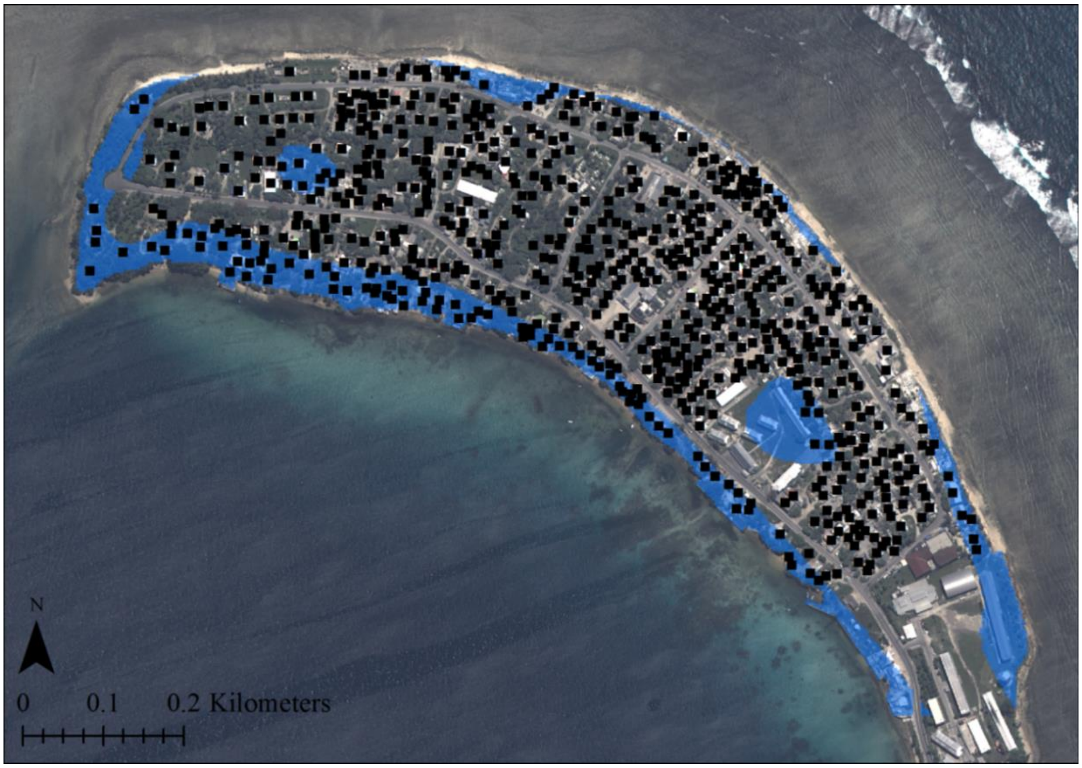
Figure 4.5: Scenario Model RCP 4.5: Year 2030



RCP 4.5: Year 2050

The RCP Scenario 4.5 in the year 2050 has a predicted median sea-level rise of 0.23 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.10 meters of rise from 2030. As can be seen in Figure 4.6, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and two small depressions in the center of Rita Village inundated. From 2030 to 2050, the additional number of houses inundated is 41, displacing an additional 275 people. The total number of houses impacted reaches 123 by 2050. The total estimated number of people displaced reaches 824 by 2050. This represents 17% of the total population of Rita Village. An additional 0.03 km^2 of land is lost. This brings the total area of land inundated to 0.09 km^2, which is 21% of the land area of Rita Village. The far western edge of the main road is impacted in this scenario.

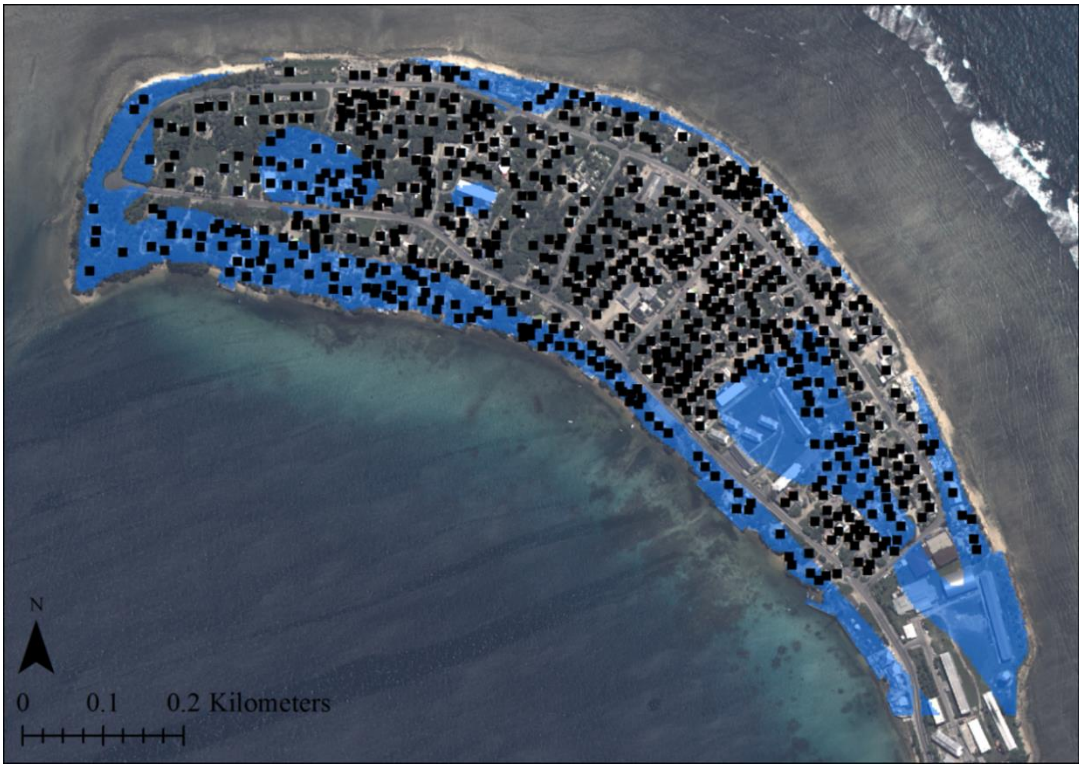
Figure 4.6: Scenario Model RCP 4.5: Year 2050



RCP 4.5: Year 2070

The RCP Scenario 4.5 in the year 2070 has a predicted median sea-level rise of 0.35 meters with respect to global mean sea level of 1996-2005. This is an additional 0.12 meters of rise from 2050. As can be seen in figure 4.7, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and a few small depressions in the center of Rita Village inundated. From 2050 to 2070, the additional number of houses inundated is 93, displacing an additional 623 people. The total number of houses impacted reaches 216 by 2070. The total estimated number of people displaced reaches 1447 by 2070. This represents 31% of the total population of Rita Village. An additional 0.07 km^2 of land is long. This brings the total area of land inundated to 0.16 km^2, which is 38% of the land area of Rita Village. A few sections of the main road are impacted.

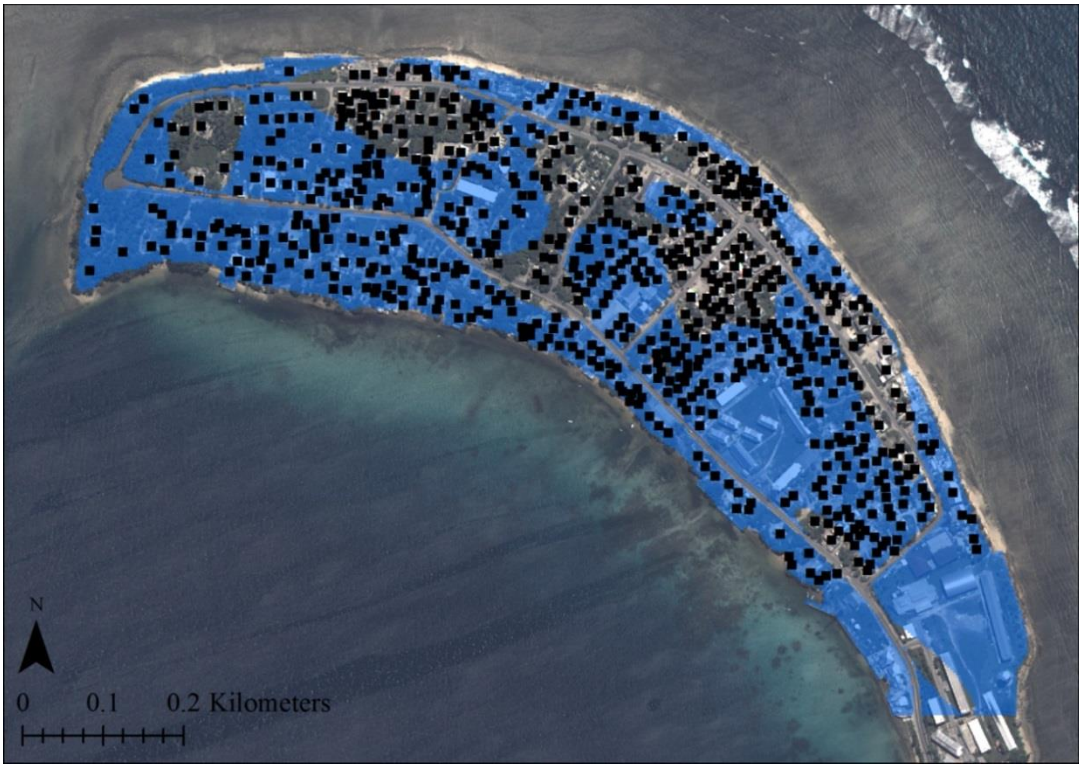
Figure 4.7: Scenario Model RCP 4.5: Year 2070



RCP 4.5: Year 2100

The RCP Scenario 4.5 in the year 2100 has a predicted median sea-level rise of 0.53 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.18 meters of rise from 2070. As can be seen in figure 4.8, the inundation model shows inundation on most of Rita Village, except for a few higher areas along the northern coastal area. From 2070 to 2100, the additional number of houses inundated is 225, displacing an additional 1508 people. The total number of houses impacted reaches 441 by 2100. The total estimated number of people displaced reaches 2955 by 2100. This represents 63% of the total population of Rita Village. An additional 0.15 km^2 of land is lost. This brings the total area of land inundated to 0.31 km^2, which is 74% of the land area of Rita Village. Large sections of the main road are impacted in this scenario.

Figure 4.8: Scenario Model RCP 4.5: Year 2100



Summary of Representative Concentration Pathway 4.5

This pathway, as a next best case scenario, describes a future for Rita Village of steady, encroaching sea-level rise of a higher magnitude than RCP 2.6. With over 70% of the land area inundated and 63% of the population displaced by 2100, this next best case scenario is one in which a large portion of the population will be negatively impacted. The following section outlines the findings of the Representative Concentration Pathway 6.0, which is predicted to have a slightly higher magnitude of sea-level rise.

Representative Concentration Pathway 6.0 Inundation Scenarios: 2030, 2050, 2070 and 2100

The purpose of this section is to present the finding of the inundation models for Representative Concentration Pathway 6.0 for the years 2030, 2050, 2070 and 2100. RCP 6.0 is a pathway that describes long-term trends in greenhouse gas emissions, short-lived species and changes in land use and land cover that stabilize radiative forcing to 6.0 W/m^2 by the year 2100 (Masui et al. 2011). The findings include sea-level rise projections, inundation results, a measure of houses impacted, the number of people displaced and the land area lost to inundation. The findings are presented both for the individual time period and as a cumulative measure from 2030 to 2100. Findings are first presented in table format followed by visual representation of the inundation models.

RCP 6.0 Summary Tables

As can be seen in table 4.5, sea-level rise for RCP 4.5 is 0.12 m by 2030, which inundates 0.06 km^2 of land, inundates 82 houses and displaces an estimated 549 people. By 2050, the predicted rate of sea-level rise is an additional 0.10 m, which inundates 0.03 km^2 of land, inundates an additional 41 houses and displaces an additional 275 people. By 2070, the predicted rate of sea-level rise is an additional 0.11 m, which inundates and additional 0.07 km^2 of land, inundates an additional 93 houses and displaces an additional 623 people. By 2100, the predicted rate of sea-level rise is an additional 0.22 m, which inundates an additional 0.15 km^2 of land, inundates an additional 260 houses and displaces an additional 1742 people.

Whereas Table 4.5 describes the impacts per time period, table 4.6 describes the cumulative impacts of sea-level rise to the year 2100. As can be seen in table 4.6, by the year 2030, sea-level is predicted to rise 0.12 m, inundating 0.06 km^2 of land (14% of the total land area), inundating 82 houses and displacing 549 people (12% of the total population). By 2050, cumulative sea-level rise is predicted to be 0.22 m, cumulative land loss is 0.09 km^2 (21% of the total land area), cumulative houses inundated by this point are 123 and the total displaced population rises to 824 (17% of the total population). By 2070, cumulative sea-level rise is predicted to be 0.33 m, cumulative land loss is 0.16 km^2 (38% of the total land area), cumulative houses inundated by this point are 216 and the total displaced population rises to 1447 (31% of the total population). By 2100, cumulative sea-level rise is predicted to be 0.55 m, cumulative land loss is 0.31 km^2 (74% of the total land area), cumulative houses inundated by this point are 476 and the total displaced population rises to 3189 (68% of the total population).

Table 4.5: RCP Scenario 6.0: Impacts for each Individual Time Period of Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters) per time period	Area Inundated (km^2) per time period	Houses Inundated per time period	Estimated Number of People Displaced per time period
Year 2030	0.12 m	0.06 km^2	82	549
Year 2050	0.10 m	0.03 km^2	41	275
Year 2070	0.11 m	0.07 km^2	93	623
Year 2100	0.22 m	0.15 km^2	260	1742

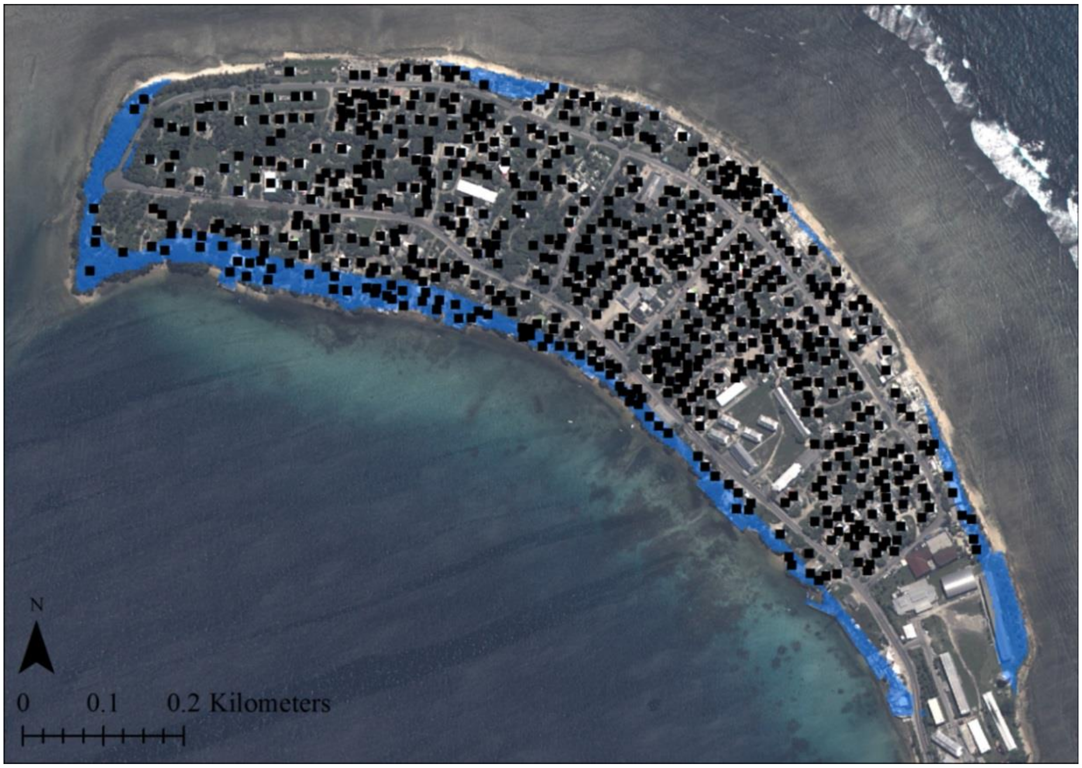
Table 4.6: RCP Scenario 6.0 Cumulative Impacts of Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters)	Area Inundated (km^2)	% of Total Land Area	Houses Inundated	Estimated Number of People Displaced: Total	% of Total Rita Population
Year 2030	0.12 m	0.06 km^2	14%	82	549	12%
Year 2050	0.22 m	0.09 km^2	21%	123	824	17%
Year 2070	0.33 m	0.16 km^2	38%	216	1447	31%
Year 2100	0.55 m	0.31 km^2	74%	476	3189	68%

RCP 6.0: Year 2030

The RCP Scenario 6.0 for the year 2030 has a predicted median sea-level rise of 0.12 meters with respect to the global mean sea level of 1996-2005. As can be seen in Figure 4.9, the inundation model shows the entire south (lagoon) side, the far western side and a few areas on the northern and eastern ocean side of Rita Village inundated. The total number of houses inundated is 82, including those that are fully or partially submerged. The estimated number of people displaced is 549. This represents 12% of the total population of Rita Village. The land area inundated is approximately 0.06 km^2, which represents 14% of the land in Rita Village.

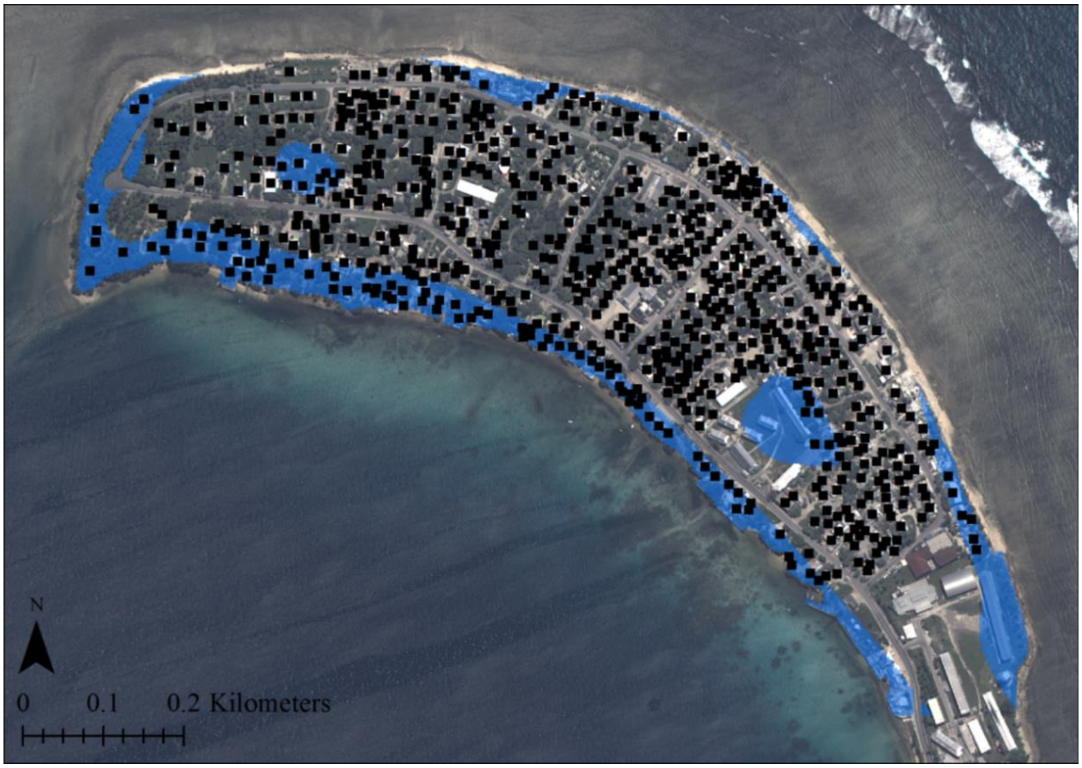
Figure 4.9: Scenario Model RCP 6.0: Year 2030



RCP 6.0: Year 2050

The RCP Scenario 6.0 in the year 2050 has a predicted median sea-level rise of 0.22 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.10 meters of rise from 2030. As can be seen in Figure 4.10, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and a few small depressions in the center of Rita Village inundated. From 2030 to 2050, the additional number of houses inundated is 41, displacing an additional 275 people. The total number of houses impacted reaches 123 by 2050. The total estimated number of people displaced reaches 824 by 2050. This represents 17% of the total population of Rita Village. An additional 0.03 km^2 of land is lost. This brings the total land inundated to 0.06 km^2, which is 21% of the total land area of Rita Village. No roads are impacted in this scenario.

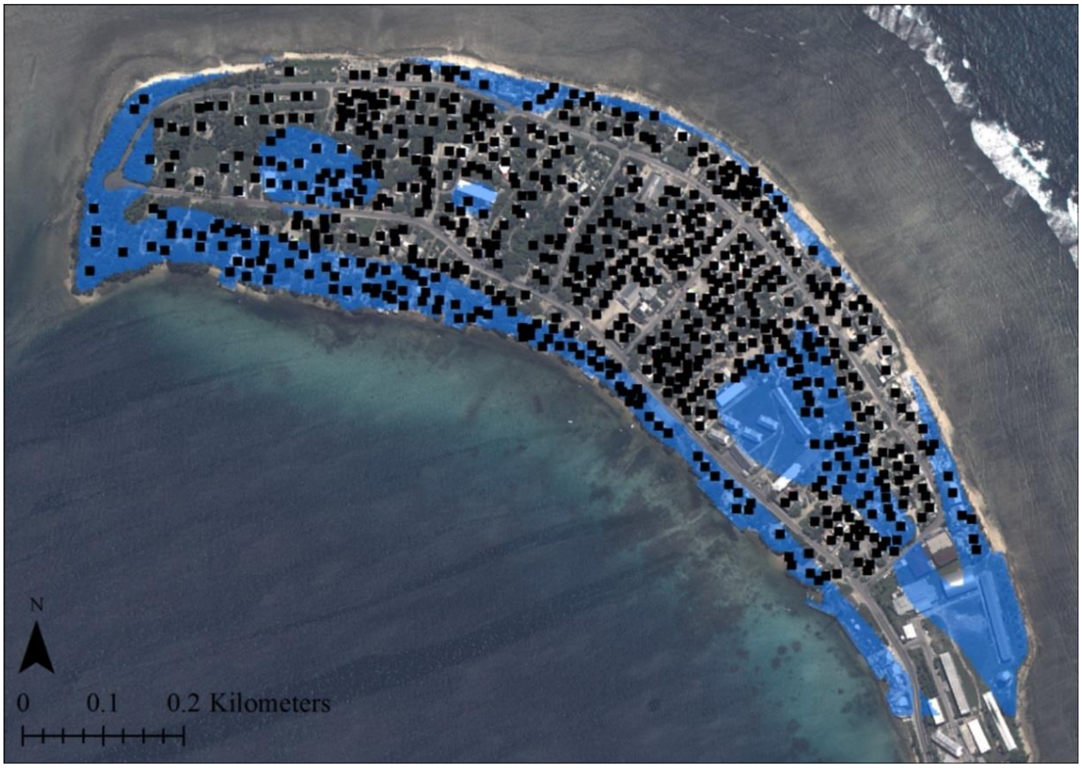
Figure 4.10: Scenario Model RCP 6.0: Year 2050



RCP 6.0: Year 2070

The RCP Scenario 6.0 for the year 2070 has a predicted median sea-level rise of 0.33 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.11 meters of rise from 2050. As can be seen in Figure 4.11, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and a few small depressions in the center of Rita Village inundated. From 2050 to 2070, the additional number of houses inundated is 93, displacing an additional 623 people. The total number of houses impacted reaches 216 by 2070. The total estimated number of people displaced reaches 1447 by 2070. This represents 31% of the total population of Rita Village. An additional 0.07 km^2 of land is lost. That brings the total area of land inundated to 0.16 km^2, which is 38% of the land area of Rita Village. A few small sections of the main road are impacted in this scenario.

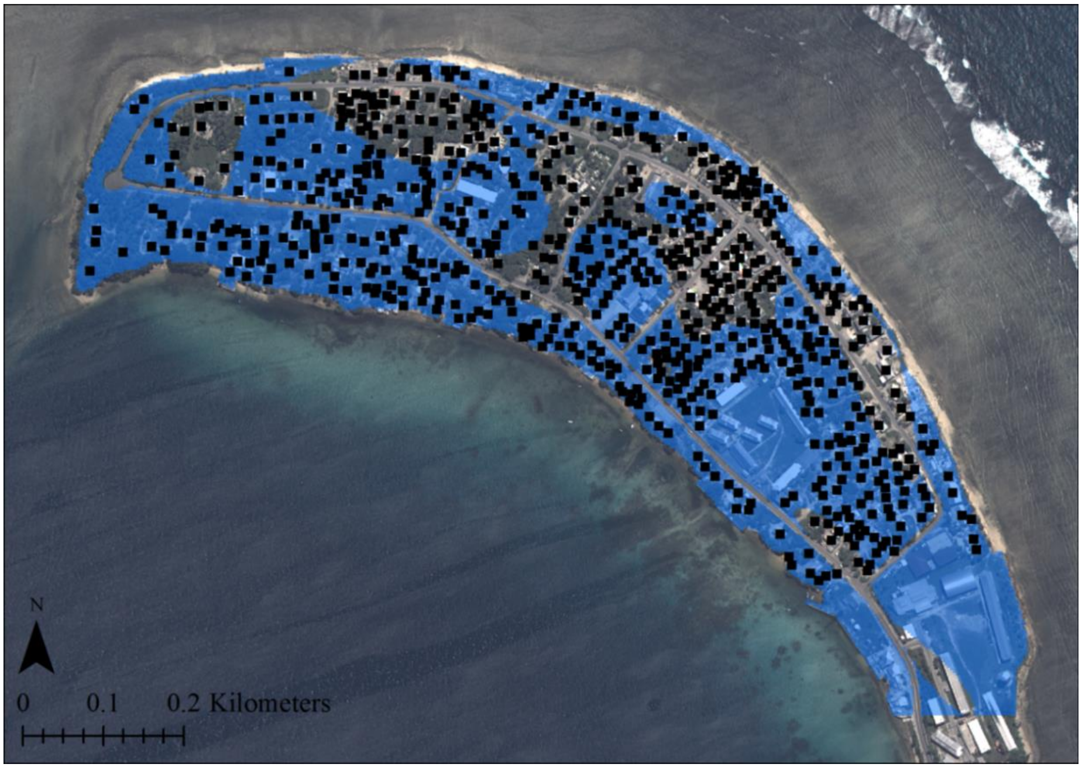
Figure 4.11: Scenario Model RCP 6.0: Year 2070



RCP 6.0: Year 2100

The RCP Scenario 6.0 in the year 2100 has a predicted median sea-level rise of 0.55 meters with respect to global mean sea level of 1996-2005. This is an additional 0.22 meters of rise from 2070. As can be seen in Figure 4.12, the inundation model shows large portions of Rita inundated, except for a few high spots along the northern coastal area. From 2070 to 2100, the additional number of houses impacted inundated is 260, displacing an additional 623 people. The total number of houses impacted reaches 476 by 2100. The total estimated number of people displaced reaches 3189 by 2100. This represents 68% of the total population of Rita Village. An additional 0.15 km^2 of land is lost. This brings the total area of land inundated to 0.31 km^2, which is 74% of the land area in Rita Village. Large sections of the main road are impacted in this scenario.

Figure 4.12: Scenario Model RCP 6.0: Year 2100



Summary of Representative Concentration Pathway 6.0

This pathway, as the next to worst case scenario, describes a future for Rita Village of increasingly high rates of encroaching sea-level rise with higher magnitude than RCP 4.5. With 74% of the land area inundated and nearly 3/4th of the population displaced by 2100, this next to worst case scenario is one in which a larger portion of the population will be negatively impacted. The following section outlines the findings of the Representative Concentration Pathway 6.0, which is predicted to have a slightly higher magnitude of sea-level rise.

Representative Concentration Pathway 8.5 Inundation Scenarios: 2030, 2050, 2070 and 2100

The purpose of this section is to present the finding of the inundation models for Representative Concentration Pathway 8.5 for the years 2030, 2050, 2070 and 2100. RCP 8.5 is the pathway with the highest greenhouse gas emissions to the year 2100 (IPCC 2013) and is considered the worst case scenario. The findings include sea-level rise projections, inundation results, a measure of houses impacted, the number of people displaced and the land area lost to inundation. The findings are presented both for the individual time period and as a cumulative measure from 2030 to 2100. Findings are first presented in table format followed by visual representation of the inundation models.

RCP 8.5 Summary Tables

As can be seen in table 4.7, sea-level rise for RCP 8.5 is 0.13 m by 2030, which inundates 0.06 km^2 of land, inundates 82 houses and displaces an estimated 549 people. By 2050, the predicted rate of sea-level rise is an additional 0.12 m, which inundates 0.04 km^2 of land, inundates an additional 50 houses and displaces an additional 335 people. By 2070, the predicted rate of sea-level rise is an additional 0.17 m, which inundates and additional 0.11 km^2 of land, inundates an additional 112 houses and displaces an additional 750 people. By 2100, the predicted rate of sea-level rise is an additional 0.32 m, which inundates an additional 0.20 km^2 of land, inundates an additional 426 houses and displaces an additional 2854 people.

Whereas Table 4.7 describes the impacts per time period, table 4.8 describes the cumulative impacts of sea-level rise to the year 2100. As can be seen in table 4.8, by the year 2030, sea-level is predicted to rise 0.13 m, inundating 0.06 km^2 of land (14% of the total land area), inundating 82 houses and displacing 549 people (12% of the total population). By 2050, cumulative sea-level rise is predicted to be 0.25 m, cumulative land loss is 0.10 km^2 (24% of the total land area), cumulative houses inundated by this point are 132 and the total displaced population rises to 884 (17% of the total population). By 2070, cumulative sea-level rise is predicted to be 0.42 m, cumulative land loss is 0.21 km^2 (50% of the total land area), cumulative houses inundated by this point are 244 and the total displaced population rises to 1634 (35% of the total population). By 2100, cumulative sea-level rise is predicted to be 0.74 m, cumulative land loss is 0.41 km^2 (98% of the total land area), cumulative houses inundated by this point are 670 and the total displaced population rises to 4488 (95% of the total population).

Table 4.7: RCP Scenario 8.5 Impacts for each Individual time period on Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters) per time period	Area Inundated (km^2) per time period	Houses Inundated per time period	Estimated Number of People Displaced per time period
Year 2030	0.13 m	0.06 km^2	82	549
Year 2050	0.12 m	0.04 km^2	50	335
Year 2070	0.17 m	0.11 km^2	112	750
Year 2100	0.32 m	0.20 km^2	426	2854

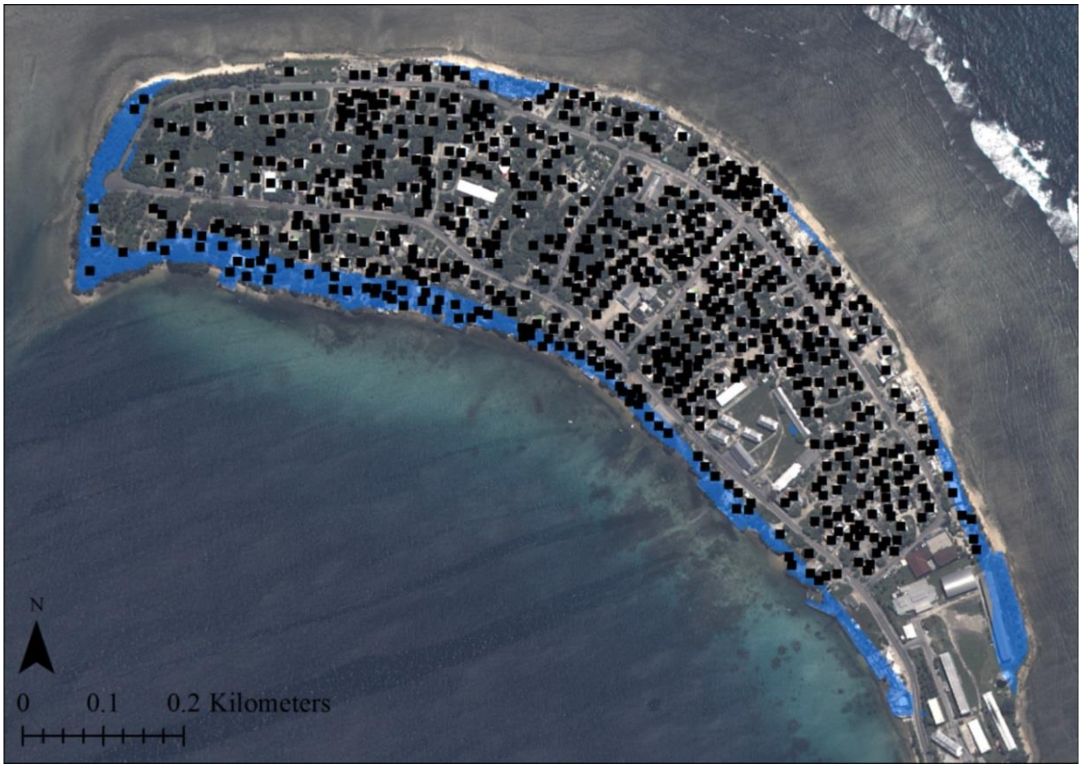
Table 4.8: RCP Scenario 8.5 Cumulative Impacts on Area Inundated, Houses Inundated and Estimated Number of People Displaced

	Sea-level rise (meters)	Area Inundated (km^2)	% of Total Land Area	Houses Inundated	Estimated Number of People Displaced: Total	% of Total Rita Population
Year 2030	0.13 m	0.06 km^2	14 %	82	549	12 %
Year 2050	0.25 m	0.10 km^2	24 %	132	884	17 %
Year 2070	0.42 m	0.21 km^2	50 %	244	1634	35 %
Year 2100	0.74 m	0.41 km^2	98 %	670	4488	95 %

RCP 8.5: Year 2030

The RCP Scenario 8.5 in the year 2030 has a predicted median sea-level rise of 0.13 meters with respect to the global mean sea level of 1996-2005. As can be seen in Figure 4.13, the inundation model shows the entire south (lagoon) side, the far western side and a few areas on the northern and eastern ocean side of Rita Village inundated. The total number of households inundated is 82, including those that are fully or partially submerged. The estimated total number of people displaced is 549. This represents 12% of the total population of Rita Village. The area of land inundated is approximately 0.06 km^2, which represents 14% of the land in Rita Village.

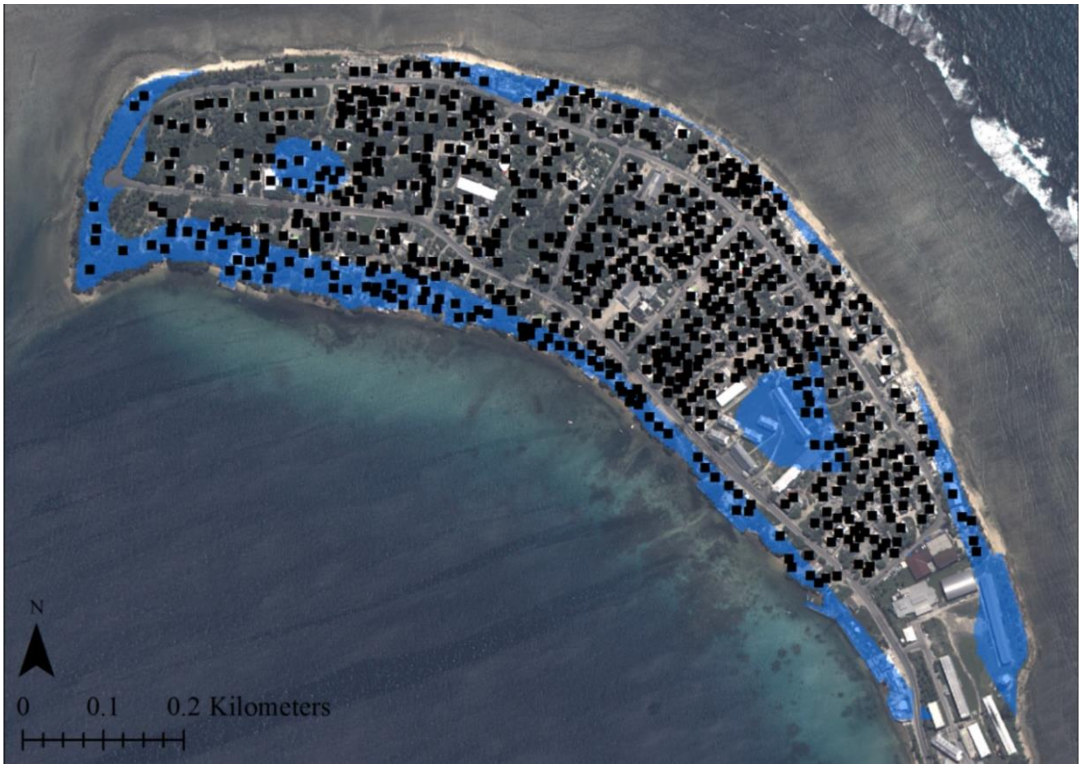
Figure 4.13: Scenario Model RCP 8.5: Year 2030



RCP 8.5: Year 2050

The RCP Scenario in the year 2050 has a predicted median sea-level rise of 0.25 meters with respect to global mean sea level of 1996-2005. This is an additional 0.12 meters of rise from 2030. As can be seen in Figure 4.14, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and two small depressions in the center of Rita Village inundated. From 2030 to 2050, the additional number of houses inundated is 50, displacing an additional 335 people. The total number of houses impacted reaches 132 by 2050. The total estimated number of people displaced reaches 884 by 2050. This represents 17% of the total population. An additional 0.04 km^2 of land is lost. This brings the total area of land inundated to 0.10 km^2, which is 24% of the land area of Rita Village. No roads are impacted.

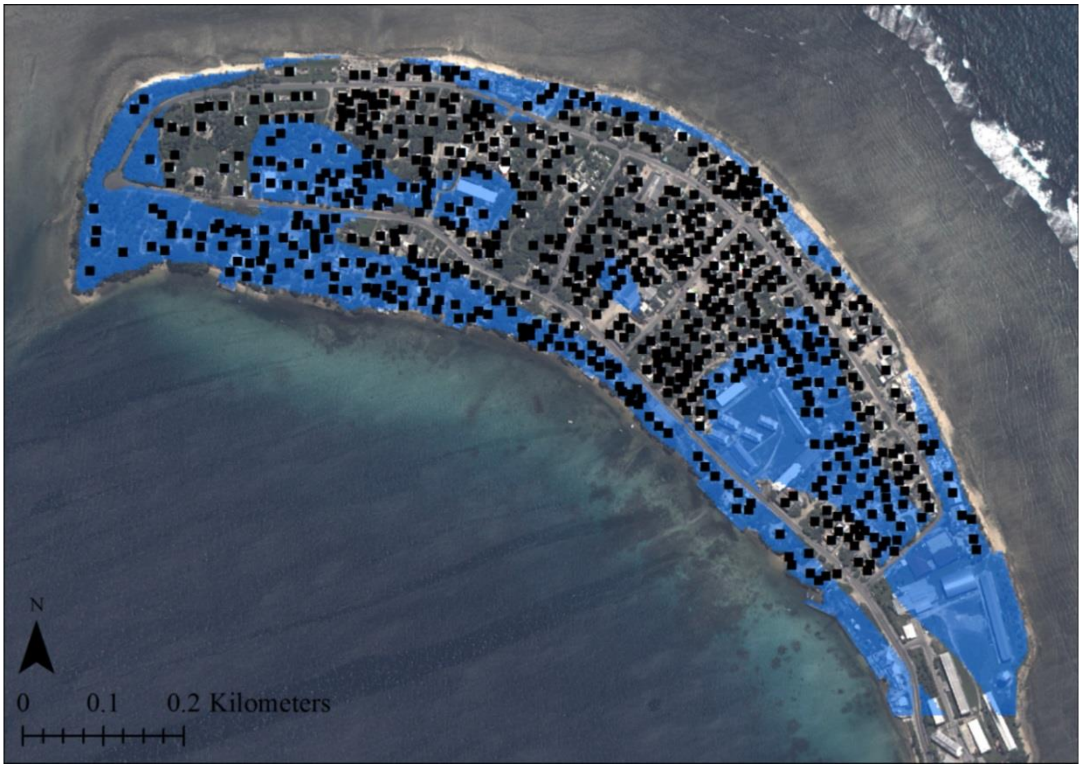
Figure 4.14: Scenario Model RCP 8.5: Year 2050



RCP 8.5: Year 2070

The RCP Scenario 8.5 in the year 2070 has a predicted median sea-level rise of 0.42 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.17 meters of rise from 2050. As can be seen in Figure 4.15, the inundation model shows the entire south (lagoon) side, the far western side, a few areas on the northern and eastern ocean side and a few small depressions in the center of Rita Village inundated. From 2050 to 2070, the additional number of houses inundated is 112, displacing an additional 750 people. The total number of houses impacted reaches 244 by 2070. The total estimated number of people displaced reaches 1634 by 2070. This represents 35% of the total population. An additional 0.11 km^2 of land is lost. This brings the total area of land inundated to 0.21 km^2, which is 50% of the land area of Rita Village. Several sections of the main road are impacted in this scenario.

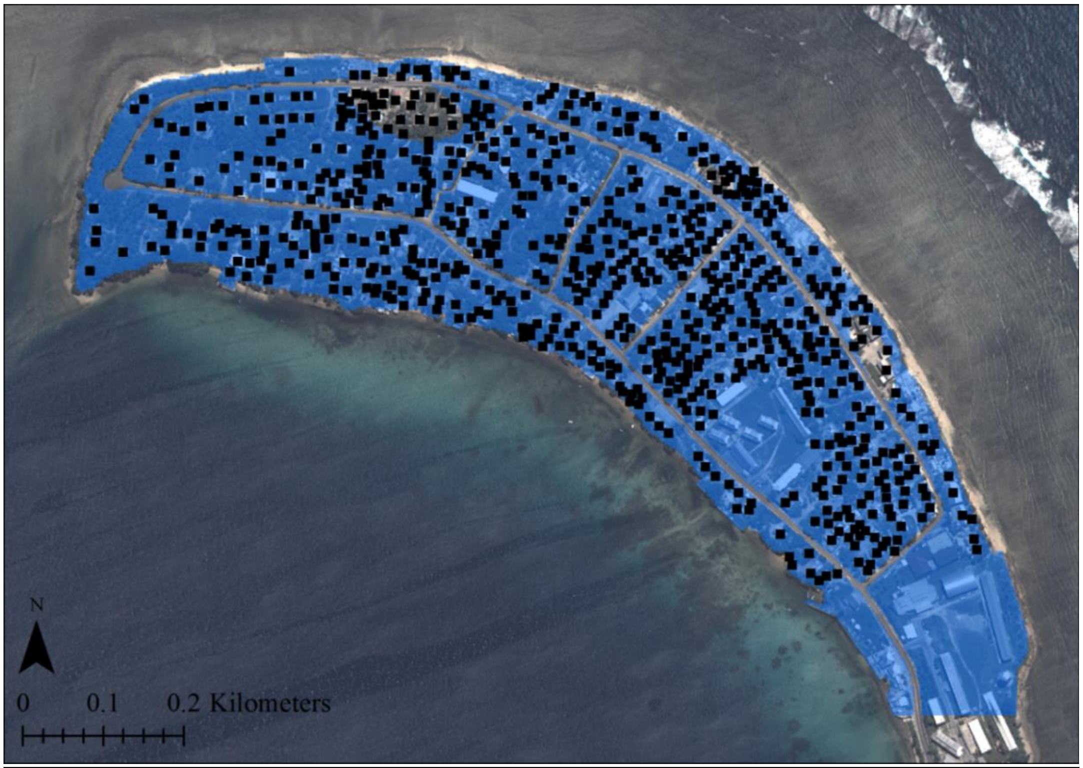
Figure 4.15: Scenario Model RCP 8.5: Year 2070



RCP 8.5: Year 2100

The RCP Scenario 8.5 in the year 2100 has a predicted median sea-level rise of 0.74 meters with respect to the global mean sea level of 1996-2005. This is an additional 0.32 meters of rise from 2070. As can be seen in Figure 4.16, the inundation model shows the entire land area of Rita Village inundated except for one very small high spot in the northern coastal area. From 2070 to 2100, the additional number of houses inundated is 426, displacing and additional 2854 people. The total number of houses impacted reaches 670 by 2100. The total estimated number of people displaced reaches 4488 by 2100. This represents 95% of the total population of Rita Village. An additional 0.20 km^2 of land is lost. This brings the total area of land inundated to 0.41 km^2, which is 98% of the land area of Rita Village. The entire main road is impacted in this scenario.

Figure 4.16: Scenario Model RCP 8.5: Year 2100



Summary of Representative Concentration Pathway 8.5

This pathway, as the worst case scenario, describes a future for Rita Village of considerably higher rates of encroaching sea-level rise than RCP 6.0. With 98% of the land area inundated and 95% of the population displaced by 2100, this worst case scenario is one in which the entire population will be negatively impacted. The following section outlines the findings of the migration scenarios.

Migration Scenarios

The purpose of this section is to present the findings of the migration scenarios in this research. The section is organized as follows. First, the migration scenario findings for Representative Concentration for the Representative Concentration Pathway 2.6 for the years 2030, 2050, 2070 and 2100 are presented. Second, the migration scenario findings for the Representative Concentration Pathway 4.5 for the years 2030, 2050, 2070 and 2100 are presented. Third, the migration scenario findings for Representative Concentration Pathway 6.0 for the years 2030, 2050, 2070 and 2100 are presented. Fourth, the migration scenario findings for the Representative Concentration Pathway 8.5 for the years 2030, 2050, 2070 and 2100 are presented. Finally, a summary of the findings is presented.

Migration Scenario: RCP 2.6

Based on the RCP Scenario 2.6 and as can be seen in Table 4.9, if all the estimated 549 displaced people in Rita Village emigrate as a result of their displacement by the year 2030, the network pull from Hawaii along with permanent displacement due to sea-level rise could influence the migration decisions of an estimated 181 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions an estimated 106 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of an estimated 54 people (9.8 %).

Of the additional 275 people potentially displaced between 2030 and 2050, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 91 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 53 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 27 people (9.8%).

Of the additional 489 people potentially displaced between 2050 and 2070, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 161 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 94 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 48 people (9.8%).

Of the additional 938 people potentially displaced between 2070 and 2100, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 310 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 181 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 92 people (9.8%).

By 2100, a total of 2251 people will potentially be permanently displaced from Rita Village, which is 48% of the total population of Rita Village. The Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 743 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 434 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 221 people (9.8%).

Scaling to the entire country by using Rita Village as a proxy, the total number of displaced people by 2100 is 25,516 people, which is 48% of the total population of the Marshall Islands. Of those displaced, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 8420 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 4925 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 2501 people (9.8%).

Figure 4.9: RCP Scenario 2.6 - Breakdown of Network Pull on Displaced Rita Population per Time Period

RCP 2.6	**Estimated Additional Number of Displaced People per Time Period**	**Number impacted by the Network Pull from Hawaii (33%)**	**Number impacted by the Network Pull from Arkansas (19.3%)**	**Number impacted by the Network Pull from Washington (9.8%)**
Year 2030	549	181	106	54
Year 2050	275	91	53	27
Year 2070	489	161	94	48
Year 2100	938	310	181	92
Total Displaced from Rita Village by 2100	2251 (48% of Rita Village)	743	434	221
Proxy Measure: Total Estimated Displaced by 2100 in the Marshall Islands based on Rita Findings	25,516 (48% of the Marshall Islands)	8420	4925	2501

Migration Scenario: RCP 4.5

Based on the RCP Scenario 4.5 and as can be seen in Table 4.10, if all the estimated 549 displaced people in Rita Village emigrate as a result of their displacement by the year 2030, the network pull from Hawaii along with permanent displacement due to sea-level rise could influence the migration decisions of an estimated 181 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions an estimated 106 people (19.3 %) and the Washington network pull along with permanent

displacement due to sea-level rise could influence the migration decisions of an estimated 54 people (9.8 %).

Of the additional 275 people potentially displaced between 2030 and 2050, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 91 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 53 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 27 people (9.8%).

Of the additional 623 people potentially displaced between 2050 and 2070, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 206 people (33%), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 120 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 148 people (9.8%).

Of the additional 1508 people potentially displaced between 2070 and 2100, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 498 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 291 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 148 people (9.8%).

By 2100, a total of 2955 people will potentially be permanently displaced from Rita Village, which is 63% of the entire population of Rita Village. The Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 975 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 570 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 290 people (9.8%).

Scaling to the entire country by using Rita Village as a proxy, the total number of displaced people by 2100 is 33490 people, which is 63% of the entire population of the Marshall Islands. Of those displaced, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 11051 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 6464 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 3282 people (9.8%).

Figure 4.10: RCP Scenario 4.5 - Breakdown of Network Pull on Displaced Rita Population per Time Period

RCP 4.5	**Estimated Additional Number of Displaced People per Time Period**	**Number impacted by the Network Pull from Hawaii (33%)**	**Number impacted by the Network Pull from Arkansas (19.3%)**	**Number impacted by the Network Pull from Washington (9.8%)**
Year 2030	549	181	106	54
Year 2050	275	91	53	27
Year 2070	623	206	120	61
Year 2100	1508	498	291	148
Total Displaced from Rita Village by 2100	2955 (63% of Rita Village)	975	570	290
Proxy Measure: Total Estimated Displaced by 2100 in the Marshall Islands based on Rita Findings	33490 (63% of the Marshall Islands)	11051	6464	3282

Migration Scenario: RCP 6.0

Based on the RCP Scenario 6.0 and as can be seen in Table 4.11, if all the estimated 549 displaced people in Rita Village emigrate as a result of their displacement by the year 2030, the network pull from Hawaii along with permanent displacement due to sea-level rise could influence the migration decisions of an estimated 181 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions an estimated 106 people (19.3 %) and the Washington network pull along with permanent

displacement due to sea-level rise could influence the migration decisions of an estimated 54 people (9.8 %).

Of the additional 275 people potentially displaced between 2030 and 2050, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 91 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 53 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 27 people (9.8%).

Of the additional 623 people potentially displaced between 2050 and 2070, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 206 people (33%), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 120 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 148 people (9.8%).

Of the additional 1742 people potentially displaced between 2070 and 2100, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 575 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 336 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 171 people (9.8%).

By 2100, a total of 3189 people will potentially be permanently displaced from Rita Village, which is 68% of the entire population of Rita Village. The Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of

1052 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 615 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 313 people (9.8%).

Scaling to the entire country by using Rita Village as a proxy, the total number of displaced people by 2100 is 36147 people, which is 68% of the entire population of the Marshall Islands. Of those displaced, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 11928 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 6976 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 3542 people (9.8%).

Figure 4.11: RCP Scenario 6.0 - Breakdown of Network Pull on Displaced Rita Population per Time Period

RCP 6.0	Estimated Additional Number of Displaced People per Time Period	Number impacted by the Network Pull from Hawaii (33%)	Number impacted by the Network Pull from Arkansas (19.3%)	Number impacted by the Network Pull from Washington (9.8%)
Year 2030	549	181	106	54
Year 2050	275	91	53	27
Year 2070	623	206	120	61
Year 2100	1742	575	336	171
Total Displaced from Rita Village by 2100	3189 (68% of Rita Village)	1052	615	313
Proxy Measure: Total Estimated Displaced by 2100 in the Marshall Islands based on Rita Findings	36147 (68% of the Marshall Islands)	11928	6976	3542

Migration Scenario: RCP 8.5

Based on the RCP Scenario 8.5 and as can be seen in Table 4.12, if all the estimated 549 displaced people in Rita Village emigrate as a result of their displacement by the year 2030, the network pull from Hawaii along with permanent displacement due to sea-level rise could influence the migration decisions of an estimated 181 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions an estimated 106 people (19.3 %) and the Washington network pull along with permanent

displacement due to sea-level rise could influence the migration decisions of an estimated 54 people (9.8 %).

Of the additional 335 people potentially displaced between 2030 and 2050, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 110 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 65 people (19.3 %) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 33 people (9.8%).

Of the additional 750 people potentially displaced between 2050 and 2070, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 248 people (33%), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 145 people (19.3%) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 74 people (9.8%).

Of the additional 2854 people potentially displaced between 2070 and 2100, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 942 people (33 %), the Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 551 people (19.3%) and the Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 280 people (9.8%).

By 2100, a total of 4488 people will potentially be permanently displaced from Rita Village, which is 95% of the entire population of Rita Village. The Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of

1481 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 866 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 440 people (9.8%).

Scaling to the entire country by using Rita Village as a proxy, the total number of displaced people by 2100 is 50500 people, which is 95% of the entire population of the Marshall Islands. Of those displaced, the Hawaii network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 16665 people (33%). The Arkansas network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 9747 people (19.3%). The Washington network pull along with permanent displacement due to sea-level rise could influence the migration decisions of 4949 people (9.8%).

Figure 4.12: RCP Scenario 8.5- Breakdown of Network Pull on Displaced Rita Population per Time Period

RCP 8.5	Estimated Additional Number of Displaced People per Time Period	Number impacted by the Network Pull from Hawaii (33%)	Number impacted by the Network Pull from Arkansas (19.3%)	Number impacted by the Network Pull from Washington (9.8%)
Year 2030	549	181	106	54
Year 2050	335	110	65	33
Year 2070	750	248	145	74
Year 2100	2854	942	551	280
Total Displaced from Rita Village by 2100	4488 (95% of Rita Village)	1481	866	440
Proxy Measure: Total Estimated Displaced by 2100 in the Marshall Islands based on Rita Findings	50500 (95% of the Marshall Islands)	16665	9747	4949

The purpose of this chapter was to present the findings of the research. The chapter was divided into two sections: the inundation scenarios and the migration scenarios. The organization of the inundation scenarios section was as follows. First, the findings of the inundation scenarios for Representative Concentration Pathway 2.6 were presented for the years 2030, 2050, 2070 and 2100. Second, the findings of the inundation scenarios for Representative Concentration Pathway 4.5 were presented for the years 2030, 2050, 2070 and 2100. Third, the findings of the inundation scenarios for Representative Concentration Pathway 6.0 were presented for the years 2030, 2050, 2070 and 2100. Fourth, the findings for the inundation scenarios for Representative

Concentration Pathway 8.5 were presented for the years 2030, 2050, 2070 and 2100. Findings presented included predicted sea-level rise, land area inundated, the percentage of total land represented by the inundated area, the number of houses inundated, the estimated number of people displaced and the percentage of the total population represented by the displaced count.

The purpose of this chapter was to present the findings of the research. The organization of the migration scenarios section was as follows. First, the findings of the migration scenarios for Representative Concentration Pathway 2.6 were presented for the years 2030, 2050, 2070 and 2100. Second, the findings of the migration scenario for Representative Concentration Pathway 4.5 were presented for the years 2030, 2050, 2070 and 2100. Second, the findings of the migration scenario for Representative Concentration Pathway 6.0 were presented for the years 2030, 2050, 2070 and 2100. Fourth, the findings of the migration scenario for Representative Concentration Pathway 8.5 were presented for the years 2030, 2050, 2070 and 2100. Findings presented included network pull from three destinations in the United States including Hawaii, Arkansas and Washington State. The following chapter will present the summary, conclusions and policy recommendations.

Chapter V

SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

The purpose of this chapter is to provide a brief summary of the research, draw broad based conclusions based on the findings, and place the findings into the context of community and policy. That chapter is organized as follows. First, a brief summary of the research results and conclusions are presented and interpreted in light of the full set of results, the theoretical foundation used and the limitations of the study. Finally, policy implications are addressed based on the findings of the research.

Summary and Conclusions

This research has been concerned with examining the relationship between sea-level rise and migration in Rita Village in the Marshall Islands. Due to the extremely low-lying topography and the predicted rates of sea-level rise in the coming decades, the Marshall Islands and the resident population are at the forefront of risks associated with permanent inundation due to sea-level rise. Due to the unique circumstance of this atoll nation in which there is no inland area in which to migrate as sea-level rises, serious concerns arise related to forced and permanent out migration. With no existing scholarship on impacts of sea-level rise on migration in this country, this research addresses that gap and provides a foundation for further research on sea-level rise-induced migration.

This research drew from the Cumulative Causation Theory of Migration, which argues that international migration sustains itself over time because each act of migration alters the social context through which others make their decisions to migrate, ultimately simplifying and stimulating the migratory process for subsequent migrants. This influence of social networks was one of two primary factors in how migration was examined in this research. The other primary factor was related to the impact of sea-level rise on the migratory decision. In order to examine how sea-level rise impacts migration, several assumptions were adopted in this research.

First, this research assumed that permanent inundation and lost land becomes an additional push factor in migration, along with existing socioeconomic push factors which currently sustain the robust stream of out migration from the Marshall Islands to the United States. Factoring in the influence of the environment on migration is a newly emerging field in migration research. This research posits that the likely and damaging impact of climate change on low-lying atoll nations requires the addition of environmental variables in migration research.

Secondly, this research defined the cumulative social network pull as a weighted measure in which each Marshallese individual in the United States exerts the same amount of pull on a potential migrant in the Marshall Islands. The top three destinations for Marshallese were identified as Hawaii, Arkansas and Washington, and their pull factor was a function of the number of Marshallese each state had in relation to the total Marshallese population that has migrated to the United States. This measure is justified based on theoretical simply due to the lack of data on the existing network effect.

The research design employed data from the International Panel on Climate Change on projected rates of sea-level rise in four different scenarios. The Representative Concentration Pathway scenarios 2.6, 4.5, 6.0 and 8.5, were used as the foundation of the research design. Within these four scenarios, four time periods were adopted in order to examine sea-level rise on a temporal scale. Using geographic information systems and a digital elevation model of Rita Village in the Marshall Islands, sea-level rise was mapped for the four scenarios in the years 2030, 2050, 2070 and 2100.

Variables measured in these inundation scenarios included land lost, houses inundated and number of people displaced. From these measures, and under that assumption that permanent loss of home and land would result in migration, the network pull from Hawaii, Arkansas and Washington was calculated. The ensuing discussion is organized around each of the Representative Concentration Pathways.

Representative Concentration Pathway 2.6 is representative of scenarios leading to very low greenhouse gas concentration levels by 2100 (2.6 W/m^2) and is representative of the research on mitigation targeting a limit to the increase of the global mean temperature to 2°C (IPCC 2013). RCP 2.6 is considered the best-case scenario for limiting the negative impacts of climate change. The findings of this research support that supposition as the measured impacts of sea-level rise were the lowest in this scenario. However, the total rate of sea-level rise predicted under this scenario to the year 2100 is 0.44 meters, which would cover 55% of Rita Village and displace 48% of the population. This best case scenario is still extremely threatening to the low-lying country of the Marshall Islands. The assumption of this research is that if a country loses over half the land to inundation and nearly half the population is displaced, habitability is severely limited. This RCP scenario suggests that migration to Hawaii could exceed 700 additional people displaced by sea level by 2100; Arkansas could grow by over 400 new migrants by 2100 and Washington State by over 200 new migrants. Because the terrain is so similar across the atolls of the Marshall Islands, it is an assumption of this research that as Rita Village becomes inundated, so too will the remaining villages and atolls in the country. The consequences of this RCP Scenario on migration from the Marshall Islands are such that both the Marshallese population and the destinations of Hawaii, Arkansas and Washington have a responsibility to pay attention to the trends in sea-level rise and plan accordingly.

Representative Concentration Pathway 4.5 is a pathway representative of scenarios that stabilize radiative forcing to 4.5 W/m^2 in the year 2100 (Thomson et al. 2011). The success of this scenario is dependent on limiting emissions through changes in energy production including shifts to electricity, increased use of technology that lowers emissions including the incorporation of carbon capture and geologic storage to the global energy system (Thomson et al. 2011). RCP 4.5 does not differ greatly from RCP 2.6 up to the year 2070 and is considered the next best-case scenario. However, from 2070 to 2100, RCP 4.5 predicts a 0.22m increase in sea-level rise. Under this scenario, by 2100, 74% of the land is of low enough elevation to be inundated and 63% of the population displaced. Again, the assumption of this research is that if a country loses over half the land to inundation and over half the population is displaced, habitability is severely limited. This RCP scenario suggests that migration to Hawaii could exceed 950 additional people displaced by sea level by 2100; Arkansas could grow by over 500 new migrants by 2100 and Washington State by over 250 new migrants.

Representative Concentration Pathway 6.0 is a pathway that describes long-term trends in greenhouse gas emissions, short-lived species and changes in land use and land cover that stabilize radiative forcing to 6.0 W/m^2 by the year 2100 (Masui et al. 2011). In this scenario, emissions peak around 2060 and then wane the rest of the century (Masui et al. 2011). The findings of this pathway mirror the findings of RCP 4.5 scenarios, but diverge slightly between 2070 and 2100. The RCP 6.0 scenario predicts a slightly higher total sea-level rise of 0.55 meters for 2100. Under this scenario, 74% of the land could become fully inundated and 68% of the total Rita population faces permanent displacement. Again, with no inland area in which to migration, this may result in over 3000 people out migrating from Rita Village. Using the network pull figure, this would result in over a 1000 people migrating to Hawaii, over 600 to Arkansas and over 300 to Washington.

Representative Concentration Pathway 8.5 is the scenario with the highest greenhouse gas emissions to the year 2100. This scenario is based on assumptions of a lack of climate change policies, high global population growth to 12 billion by 2100, relatively slow economic growth and slow progress in energy efficiency technologies (Riahi et al. 2011). The results of modeling inundation and displacement in this scenario show similar rates of land loss and displacement as RCP 4.5 and 6.0 to the year 2070. However, by 2100, with a predicted rate of sea-level rise at 0.74 meters, 98% of the land of Rita Village would be inundated, effectively causing wholesale abandonment of the entire Village by the end of the century. The implications for migration as found in this research show an increase of migration to Hawaii of over 1400 people, 866 to Arkansas and 440 to Washington.

While the study area of this research was limited to a small village in the Marshall Islands, the results can be provide insight on sea level and migration to the entire country because atoll topography is consistently low-lying across the entire Marshall Islands. Sea-level rise impacts would likely be similar across the entire country. In light of this assumption, nearly half of the entire country could be permanently displaced by 2100 in the best case scenario of sea-level rise predictions. In the worst case scenario, nearly 100% of the entire population will be displaced. The results suggest that overall, the country of the Marshall Islands is highly vulnerable to sea-level rise and that wholesale abandonment of the country may become a necessity by the end of the century, perhaps sooner. The impact of sea-level rise on the decision to migrate could be substantial. It can be assumed that with a progressively rising sea, there will be attempts at mitigation and adaption measures which could prolong residency on the Islands.

However, if 95% of the land becomes inundated, several assumptions and conclusions can tentatively be made with regard to migration, theory, policy and practice.

In the face of total inundation and complete loss of the country by 2100, assumptions on migration are that wholesale abandonment is inevitable. To lose an entire country to sea-level rise is an unprecedented occurrence. Several key matters arise when speculating on issues that would arise in the face of wholesale abandonment.

First, although migration from the Marshall Islands is currently strong and shows no signs of decline in the coming years, there could come a point where those that leave their home country of the Marshall Islands are doing so against their will and under duress. There are potentially harmful psychological consequences with being permanently displaced including issues of losing your home, heritage, cultural landmarks and land rights.

Further, this research took a conservative stance on the rate of sea-level rise and did not explore the possibility of a catastrophic rate of sea-level rise that could arise in the face of collapsing ice sheets. An extreme climate event such as that could trigger mass out migration in a relatively short amount of time, creating a potential humanitarian crisis both for the Marshallese and the communities that would receive them. A more robust discussion of managed migration planning in the face of catastrophic and rapid sea-level rise would lead to a more proactive response if faced with this situation.

Additionally, the likelihood that those forced to migrate will move to Hawaii, Arkansas or Washington because of the cumulative pull of existing social networks is high. This creates the potential for issues to arise in these receiving communities. As these communities continue to grow with Marshallese residents over time, some level of integration may occur which alleviates the pressures on newly arriving migrants. However, if the receiving community is not prepared to take on a large number of displaced Marshallese, particularly if it is the result of rapid abandonment, there are potential issues that may arise. The civic, social, education, health and service sectors would feel the impact of a large number of Marshallese moving in. Without adequate preparation, these sectors could face difficulties serving the needs of the growing population.

From a conceptual standpoint, this research reiterates the need to create a more robust theoretical foundation for analyzing migration to include potential impacts of climate change. While the findings of this research suggest that by 2030 there will be migrants on the move due to sea level in the Marshall Islands, it can be assumed this pressure will be exerted on other coastal populations across the earth. If sea-levels rise to the predicted magnitude, migration as a result of environmental variables will likely be vast across the globe. While the theory of cumulative causation incorporates the vast majority of factors influencing migratory decisions, the environment will become a clear factor as well. The explicit integration of environmental variables at the conceptualization stage of research holds the promise of providing more robust insight into the antecedents as well as the continued drivers of patterns of migration.

Recommendations and Policy Implications

The current research provides heretofore unavailable estimates and projections of the direct impact of sea-level rise on out migration from the Marshall Islands. It is clear from this research that sea-level rise must be incorporated into any calculus related to the long term viability of communities in the Marshall Islands. As seen in the scenarios presented in the preceding chapters, there is a very real possibility the entirety of the country will be virtually uninhabitable.

If this occurs, receiving communities, particularly in Hawaii, Arkansas and Washington, could see a dramatic increase in the Marshallese population. Potential next steps for receiving communities to prepare for this influx include several options. The first is increasing capacity of service providers that deal directly with Marshallese. Ensuring adequate access to health care and education is a social obligation that must be taken on in order to ensure equality and to create a system capable of dealing with an increased demand. This is particularly salient as the Marshallese people have unique health problems associated with the nuclear testing by the United States. The second is increasing the prevalence of translated documents such as health care forms, school enrollment forms, driver’s license examinations and other relevant documentation is recommended as is increasing the number of interpreters available in the community. Finally, civic leadership should take a role in creating specific ordinances that increase social, civic and economic opportunities for incoming Marshallese to smooth the transition into the community. Facilitating integration of Marshallese and reducing barriers to integration will create a more sustainable community and reduce the risk of creating a permanent social and economic divide between current residents and incoming Marshallese.

On the policy side, the potential of permanent displacement of people requires a sober assessment of the mechanisms that are in place (or lacking) that allow for a just and orderly relocation. The challenges for the Marshall Islanders are many. For one, there are no international treaties protecting those who may become climate change refugees. The impetus for addressing this lack of policy is clear; people who have fled home for circumstances ranging from persecution, war and famine, protection by the international community is needed. Identifying clear opportunities for protections proactively will alleviate potentially difficult situations in the future, both for the displaced and those receiving them.

Additional protections through policy are required to protect the rights of the Marshall Islands to operate as a free and sovereign country. Again, without protocol on protecting the right to self-govern to a population without a home country or a centralized relocation, there are inherent difficulties that would arise. International and environmental laws do not currently have precedent for providing protection of governing rights. Additionally, there are no laws protecting rights to land and minerals that are permanently inundated. Although much more difficult to protect with policy, the potential loss of culture for the Marshallese is a clear problem that would be faced in light of permanent displacement, particularly for a society in which land rights are so vital.

Further, it is argued that due to extensive nuclear testing by the Marshall Islands by the United States, it is a social obligation and moral imperative that our government closely examines policies issues that create further barriers for the Marshallese in the United States. A first order of business would be a renegotiation of the Compact of Free Association with the Marshallese government to include reparation payments to all existing Marshallese residents in the United States and increase access to social services such as Medicare and Medicaid. The renegotiation should also include a clear pathway to citizenship so Marshallese people have option to become fully participatory civic citizens of the United States. As it stands, Marshallese citizens in the United States are ineligible to vote and have no representation at the local, state or national level.

It recommended is serious consideration by all heads of state in the world to consider the impact of carbon emissions on low-lying atoll nations such as the Marshall Islands. They are the canary in the coal mine with respect to negative impacts of climate change while contributing some of the lowest amounts of emissions globally. Capping carbon emissions could potentially keep the climate impacts relegated to the best case scenario predictions, thereby offering a chance for the Marshallese to adapt to rising seas in a way that allows a portion of the population to remain in the home country.

This research has laid the groundwork for assessing the relationship between sea-level rise and migration from the Marshall Islands. Suggestions for future research include the collection and generation of high-resolution digital elevation models for all low-lying atoll nations across the globe. With the reliability of existing predictions of sea-level rise, modeling those rates of rise on these low lying countries is imperative to begin planning for adaptive measures. Without these inundation models, there are no clear visuals for which areas will be impacted first and which areas may be safe havens for residents.

Additionally, new research on migration patterns from the Marshall Islands which include existing drivers of migration and existing decision-making processes for destination, would allow for a much more robust examination of how sea-level rise could impact these migration flows. The minimal existing data provided a baseline for ways to examine this relationship, however there is room for a more data-driven methodology and approach.

The final suggestion for further research lies in the collection and incorporation of more climate variables in the relationship between climate change and migration. While sea-level rise was isolated in this research as the factor that would permanently displace people over time, other climatic changes will impact habitability over time as well. These changes could precipitate migration flows sooner than sea-level rise will. A more complete picture provides evidence for sending and receiving communities of climate change migration, which would allow for useful adaptive planning at the community, national and global level.

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