Climate Action

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What do climate impacts, health, and migration reveal about vulnerability and adaptation in the Marshall Islands?

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Abstract

Climate change is impacting public health in the Republic of the Marshall Islands (RMI). Meanwhile, migration within the RMI and abroad is driven, in part, by access to better healthcare, and migration is also expected to be accelerated by climate change. Based on a survey of 199 RMI households, this study used logistic regression and hierarchical clustering to analyze the relationships between climate stressors, climate-related health impacts, and migration outcomes and identify vulnerable segments of the population. Climate stressors were experienced by all respondents but no significant correlations were found between stressors, health impacts, and expectation to migrate. When grouped according to the climate stressors they faced, however, one group was characterized by low stressors, high wealth, and a low expectation to migrate, whereas another experienced very high climate stressors, low wealth, and a high expectation to migrate. Only the first exhibited a statistically significant relationship between climate-related health impacts and migration; however, for the second, climate stressors were significantly related to proximate determinants of health, and there was no association with migration. To create equitable adaptation outcomes across diverse society, policies should expand economic and education prospects and reduce vulnerability to the direct and indirect health impacts of climate change.

Keywords: Climate change, Clustering, Health, Marshall Islands, Migration

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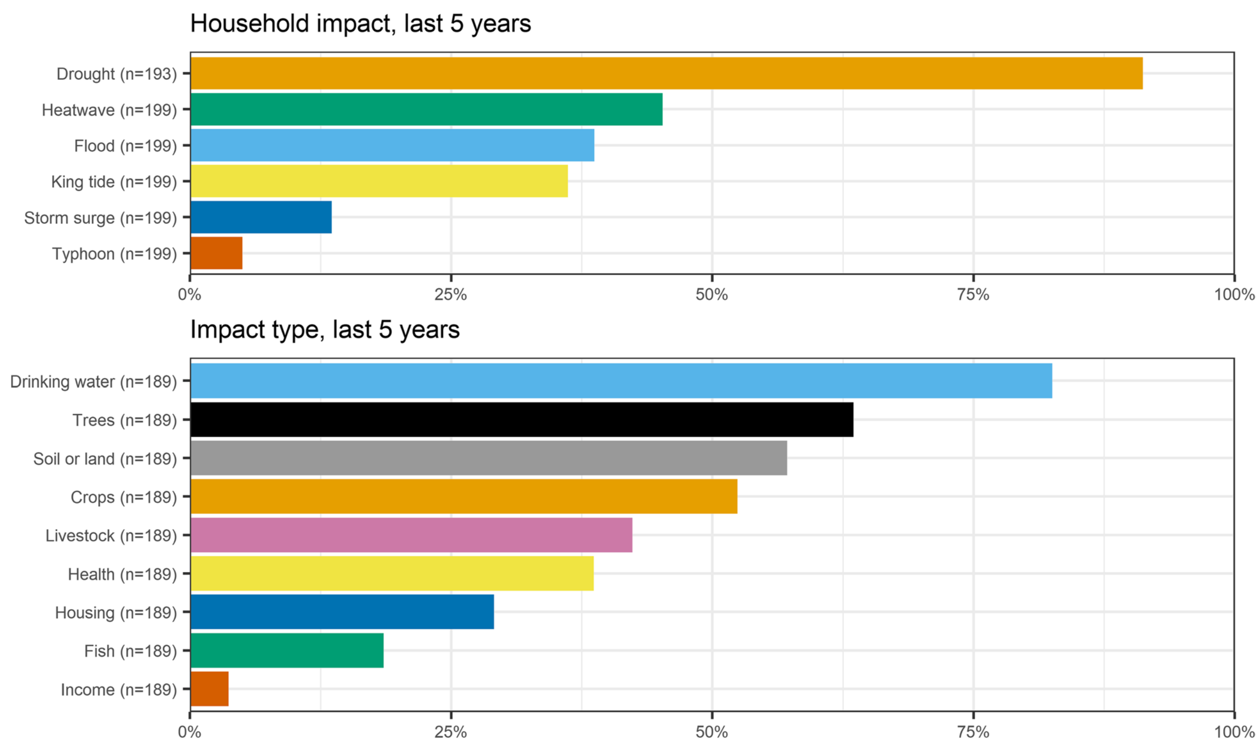
Graphical Abstract

Households that were surveyed in the Marshall Islands have experienced many climate stressors and direct impacts to health, as well as the determinants of health, in recent years.



Introduction

The interactions among climate change, health risks, and migration are complex and nuanced. Climate change progression in future years is expected to alter patterns of human migration, as has already been observed in some areas of the world (Campbell 2014; Upadhyay et al. 2015; Watts et al. 2018). Human health and associated climate exposure, risk, and access to social services are also both drivers of and outcomes from migration (Schwerdtle et al. 2018; Hunter et al. 2021). Understanding these interactions is further complicated by the fact it is difficult to isolate health impacts from environmental events or other determinants of people's mobility and migration patterns (Black et al. 2011; Beine and Parsons 2015; Hunter et al. 2021). Finally, the intersection of climate, migration, and health is "strongly heterogeneous," making it challenging to articulate a conceptual framework that is applicable across multiple cases (Schwerdtle et al. 2020; Hunter et al. 2021). Policy makers, in particular, require more nuanced information on the disparate experiences of climate stressors, health impacts, and how they affect people's migration decisions in order to address inequities and promote adaptive capacity in the face of climate change.

Climate stressors and change in Pacific Island communities have public health impacts that are direct—such as extreme events that cause injuries and loss of life and property; indirect—such as infectious, water-borne, and vector-borne disease outbreaks following flooding and drought events; or the disruption of food and water security; and diffuse—such as reduced physical activity and poor insulin regulation as a result of high temperatures and reduced food security (McMichael 2015; WHO 2015; McIver et al. 2016; Trtanj et al. 2016). The mental health impacts associated with climate stressors in the Pacific also cannot be ignored (WHO 2015) and include stress-related disorders and trauma following extreme events, stress and depression resulting from economic strain (Padhy et al. 2015), and *solastalgia*, the distress of watching one's home environment decline (Albrecht et al. 2007). As climate stressors intensify in their home islands and atolls, the migration of Pacific peoples throughout the region may be one way to ameliorate the risks associated with climate change, including health impacts (Locke 2009; Oakes et al. 2019; Brewington et al. 2021).

Previous research on climate-related migration in the Pacific Islands has focused on displacement (e.g., Burkett 2011; Weber 2015; Tabe 2019), risk and vulnerability (e.g., Campbell 2014; Milan et al. 2016; Oakes et al. 2016; Oakes et al. 2019), agency and decision-making (e.g., Roland and Curtis 2020; McMichael et al. 2021), and policy and adaptation mechanisms (e.g., Thomas and Benjamin 2018; Oakes 2019). Limited research has considered the relationships between climate stressors, health impacts, and migration in the region (e.g., Brewington et al. 2021), finding that migration decisions, like health impacts, are a composite of unique and place-based environmental, social, economic, demographic, and political factors, which may in turn be amplified by the impacts of a changing climate. Furthermore, empirical evidence is needed to understand these relationships in the broader social and economic context and the ability (or inability) to relocate (Hunter et al. 2021). This research contributes to the climate-migration literature by adding a health component to consider whether climate impacts on public health interact to influence migration in the Republic of the Marshall Islands (RMI) and identifies three population groups with distinct profiles of vulnerability to climate stressors, health impacts, and migration agency. The findings from this study can further inform policy interventions to expand education, healthcare, and livelihood opportunities in the RMI that reduce vulnerability and create more equitable adaptation outcomes in the face of climate change.

Study area and background

The RMI is a small Pacific Island nation composed of 29 low lying atolls with a resident population of about 53,000 (United Nations Population Division 2018) and, due to its status of Free Association with the USA, also has a sizeable US diaspora population of about 24,000

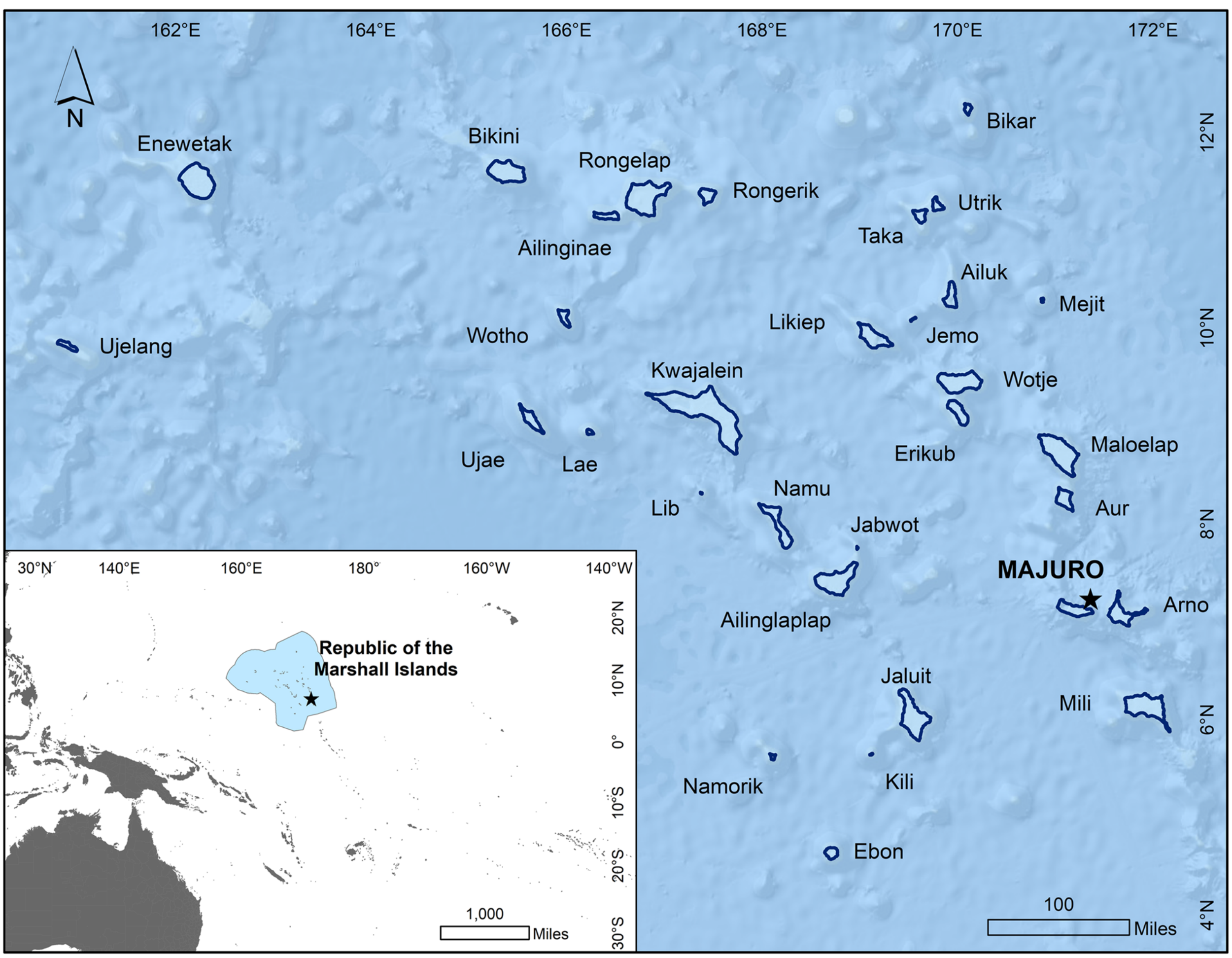


Fig. 1 Location of the RMI in the central tropical Pacific

(United States Census Bureau 2019; Fig. 1). Spread over an ocean area approximately the size of Mexico (800,000 square miles), but with a total land area of 70 square miles, the RMI is considered to be among the most vulnerable countries to the impacts of climate change (Woodward et al. 1998; Cocklin 1999; Owen et al. 2016; International Organization for Migration [IOM] 2017; Storlazzi et al. 2018). In addition to the threat of rising sea levels, the nation is vulnerable to droughts, wave-driven floods, and tropical storms that threaten homes, infrastructure, food and freshwater supplies, and livelihoods (Nurse et al. 2014; Marra and Kruk 2017; Storlazzi et al. 2018).

The RMI already faces significant risks to public health. Its limited natural resources have historically sustained a small population subsisting on fishing and small-scale agriculture. Agriculture is restricted due to a lack of arable land, overcrowding, limited fresh water, and salt spray from the ocean, and these effects are compounded by rising sea levels, flooding, droughts, and aquifer salinization and depletion (Barnett 2011). Drinking water supplies and essential infrastructure in the RMI are also inadequate and vulnerable to floods, droughts, and degraded aquifers (Burns 2003; Republic of the Marshall Islands [RMI] 2014). Sewage system failures and water contamination have been associated with disease outbreaks, which compound the risks associated with flooding (Beatty et al. 2004). Furthermore, challenges related to accessing adequate healthcare are prominent in the RMI and frequently require traveling to the nation's urban centers on Majuro and Kwajalein Atolls, or internationally. Although healthcare is government subsidized, it is not always easily accessible, and services on the more remote, outer atolls are limited (Saunders, pers comm 2021). The RMI has two hospitals located in densely-populated Majuro (the capital) and Ebeye (on Kwajalein); however, they generally lack the technology, infrastructure, and funding to manage chronic or serious conditions (Yamada et al. 2009; Duke 2014; International Organization for Migration [IOM] 2017).

Due to a variety of factors, internal (from outer islands to urban) and international migration is very common among the Marshallese population (Ahlgren et al. 2014; van der Geest et al. 2019a). The former President of the RMI, Hilda Heine, has cited healthcare, education and job opportunities, and threats of climate change as a few main drivers of this trend (Taibbi and Saltzman 2018). Under the Compact of Free Association (COFA), the USA provides financial assistance and compensation for damages to the RMI following decades of nuclear testing in the islands that resulted in the forced relocation of entire villages and severe, ongoing cancer risks (Land et al. 2010; Department of State 2021). In addition, Marshallese citizens can freely live and work in the USA, where many go to seek education, employment, and healthcare (International Organization for Migration [IOM] 2017; Yamada et al. 2017; van der Geest et al. 2019a). In Hawai'i, for example, healthcare is the leading driver of Marshallese in-migration (Pobutsky et al. 2009). Owing primarily to the stipulations in the COFA, of the nation's approximately 76,000 citizens in 2011, about 70% lived in the RMI with the remainder residing largely in Hawai'i, the US Territory of Guam, and the continental USA (Republic of the Marshall Islands [RMI] 2012), and the out-migration rate appears to only be increasing (Taibbi and Saltzman 2018; Johnson 2021). The current COFA expires in 2023, however, and many anticipate serious negative economic effects if its financial support mechanisms were discontinued, including a recent report by the Asia Development Bank that predicts further increases in out-migration (Asian Development Bank [ADB] 2022).

To explore how climate stressors, health impacts, and migration intersect in the RMI, this study analyzed household survey data that was collected in the RMI in 2017 (van der Geest et al. 2019b). Researchers surveyed 199 households on three islands (Majuro, Maloelap, and Mejit) about their experiences and expectations of migration in the context of climate change. Questions highlighted environmental, social, and economic factors that were hypothesized to influence migration decision-making. As van der Geest et al. (2019b, 2019c) reported, there were very high climate stressors and impacts experienced across the survey population. Few respondents indicated that climate or environmental stressors were a direct reason for migrating, however, and most said that they had migrated for health, work, education, and family visits.

Given that we know that large numbers of people in the RMI migrate for health reasons, this study sought to better understand whether climate stressors were related to people's health impacts and their associated decisions to migrate. "Health impacts" in this study refers the negative direct, indirect, or diffuse impacts of climate stressors on health, or proximate determinants of health (e.g., food and water, land, crops, housing, and safety). Consistent with research in the field (e.g., McLeman 2014) and in other Pacific Island nations (e.g., Campbell et al. 2016; Milan et al. 2016; Oakes et al. 2016), we hypothesized that cascading climate stressors may act as the "cause of the cause" of migration in the RMI, such that although one may not state that they migrated because of climate change, it may indirectly influence migration decisions. Furthermore, we posited that that people's experiences of climate stressors and impacts are not homogeneous throughout the RMI population, and may be linked with different health impacts and expectations to migrate, reflecting disparities in vulnerability and agency.

The present study focused on the following main questions: To what extent are climate stressors and health impacts related to migration outcomes in the RMI? Are there differential climate vulnerabilities, health impacts, and migration outcomes across the survey respondents? The research and findings aim to help shape policy interventions that can reduce vulnerability to climate stressors and create more equitable adaptation outcomes across diverse Pacific populations.

Methods

This secondary analysis of household survey data expanded on a prior case study conducted in the RMI in 2017 (van der Geest et al. 2019b, 2019c, 2020). The multi-part survey instrument was developed by researchers at the University of Hawai'i and the Marshall Islands Conservation Society and translated from English into Marshallese. Questions asked participants to rank the problems their household experienced in the RMI, such as poor healthcare, lack of job opportunities, poor education, food and water insecurity, and climate threats. Climate stressors (drought, heatwaves, storm surge, typhoons, king tides) and their direct and indirect impacts on household health (food, water, land, crops, housing, safety, disease, injury) were identified, along with whether participants believed stressors had been increasing or decreasing in severity over time. Participants were also asked to describe their household's migration history and expectations for the future, with multiple options (financial, health, education, employment, climate) to explain why they would/would not migrate.

The RMI household survey included a total of 199 respondents from the islands of Majuro ($n = 99$), Maloelap ($n = 50$), and Mejit ($n = 50$). Survey sites were selected to represent the RMI's unique geographies and population densities: one densely-populated urban area (Majuro) and two rural outer islands, including an atoll (Maloelap) and a raised coral island (Mejit). On Majuro, a random sample of 100 households were selected from a geo-coded list of 2398 eligible households located on the eastern side of the atoll, where the majority of the population resides. If a household was abandoned or unavailable, another household was randomly selected. On the outer islands, the research team surveyed all available households on Mejit and on two of the five inhabited islands of Maloelap. The team was led by a local Marshallese investigator with well-established contacts and a high level of trust in each study site. Surveys were conducted in Marshallese and English with translation provided by bilingual co-researchers. One respondent was removed from the sample due to incomplete data and the overall response rate was greater than 90%. Whereas previous analyses of this survey data focused on descriptive statistics and correlations between climate impacts and respondents' household migration experiences (van der Geest et al. 2019b, 2019c, 2020), the present analysis related climate stressors, health impacts, and migration outcomes using a two-part approach of logistic regression and hierarchical clustering.

Logistic regression

We first selected survey questions related to climate stressors to analyze associations between those variables and respondents' expectations that they or a member of their household would migrate in the future. The dependent variable, "expectation to migrate" was a binary 0/1 outcome derived from responses of "Yes" or "Maybe" (1) or "No" (0) in response to the question "Do you think that you or one of your household members will migrate (in RMI or abroad) within the next 10 years?". Logistic regression modeling was then used to evaluate whether climate stressors and health impacts (the independent variables) were associated with expectation to migrate. We also used regression modeling to assess the associations among variables related to climate stressors and health impacts, as well as demographic variables.

Hierarchical clustering

We further explored potential non-linearities and variance within the dataset using a hierarchical clustering method. Hierarchical clustering is a method of grouping respondents together so that the within-group variance in means for each clustering variable is minimized and the between-group variance is maximized (Johnson 1967). Because we hypothesized that people's experiences of climate stressors were not homogeneous throughout the RMI population, the clusters were constructed using variables related to whether a household had experienced climate stressors, respondents' perceptions of the state and trend in natural resources and ecosystem services, and ranking of problems associated with climate stressors and the environment. Analysis of variance (ANOVA) was used to compare the group means of each clustering variable and respondents were then grouped using only the variables that differed significantly between the groups. This step was repeated until all the clustering variables maintained significant differences in group means. This produced a stable and good-fitting solution that was limited to only the variables that most strongly distinguished the clusters from one another. The final, optimized three-cluster solution was validated using statistical fit indices and conceptual assessments by collaborators and subject matter experts.

Next, group means were compared using ANOVA and Tukey's Honestly Significant Difference test (Tukey 1949) for all additional study variables to describe the unique characteristics of each cluster and compare how health impacts and expectations to migrate differed between them. We explored the unique within-cluster associations between health impacts and migration outcomes by running logistic regressions with one independent variable at a time and using dummy variables for cluster membership as interaction terms. Descriptive statistics were produced for clustering and non-clustering variables to explore shared experiences and perspectives between and within clusters. Finally, quotes from the survey write-in responses were used qualitatively compare the different ways that members of each cluster experienced and responded to climate stressors, including their health outcomes and migration expectations.

Table 1 Descriptive statistics for selected participant demographic variables

	n	Mean/percent[a]
Household income	181	$5,818
Income source: agriculture	198	49.49%
Income source: fishing	198	50.51%
Income source: government salary	198	44.44%
Income source: private sector salary	198	33.33%
Education completed: high school	195	45.13%
Education completed: university	195	1.54%
Education completed: graduate school	195	1.03%
Household owns house	199	91.96%
Household owns land that house is on	199	63.82%
Household owns land on outer islands or elsewhere	197	87.82%
Total amount of remittances received in past year	69	$771
Years lived in current location	111	19.70

[a] Percentages are reported for binary variables

Results

The mean age of the survey respondents was 40 (standard deviation [SD] = 13.0) made up of 68% men and 32% women. Household mean income at the time of survey administration was around USD$5800 (SD = $6400; Table 1). Thirty-three percent of respondents earned income from the private sector, 44% from government, 49% from agriculture, and 51% from fishing. Although the survey questionnaire did not include options for income earned from copra (dried coconut to be exported for coconut oil production) and handicrafts, these were commonly written in by respondents as income from "other" sources. About 45% of respondents completed high school and about 2.5% completed further post-secondary education. There were broadly high rates of home and land ownership: over 90% of respondents owned a house, 64% owned the land their house was on, and almost 90% owned land elsewhere. Around $770 in remittances, non-commercial financial transfers from a relative or community member overseas, were received annually by about a third of respondent households.

Most respondents reported experiencing various climate stressors in recent years. The most prevalent stressor was drought, which had impacted 91% of respondents within the past five years (Fig. 2). Heatwave (45%), flood (39%), and king tide (36%) events were the next most common. Storm surge (14%) and typhoon (5%) events were less commonly reported. The most prominent household climate impacts related to determinants of health were on drinking water (84%), trees (63%), soil/land (57%), and crops (52%). In addition, about 38% of respondents had experienced a direct climate-related impact to their health in the form of heat stress or personal injury.

Respondents also generally reported that climate stressors had been increasing in severity over the past 10 to 20 years (Table 2). On a scale from −1 (decreasing) to 1 (increasing), drought, king tide, and heatwave events were all perceived to be increasing in severity with mean scores of 0.87, 0.55, and 0.49, respectively. Storm surges (0.13) and typhoons (0.01) were perceived to be mildly increasing in severity or about the same. Respondents were also provided a list of 12 climate and non-climate-related problems that households in the RMI might face and were asked to rank their top five from 1 (least serious) to 5 (most serious). Problems that were not in the top five were given a ranking of 0. On average, lack of jobs (2.4), poor education (2.0), and drought (2.0) were the highest ranked problems, followed by sea level rise (1.7) and poor healthcare services (1.4). Electricity/power cuts (0.2), lack of fish (0.3), and

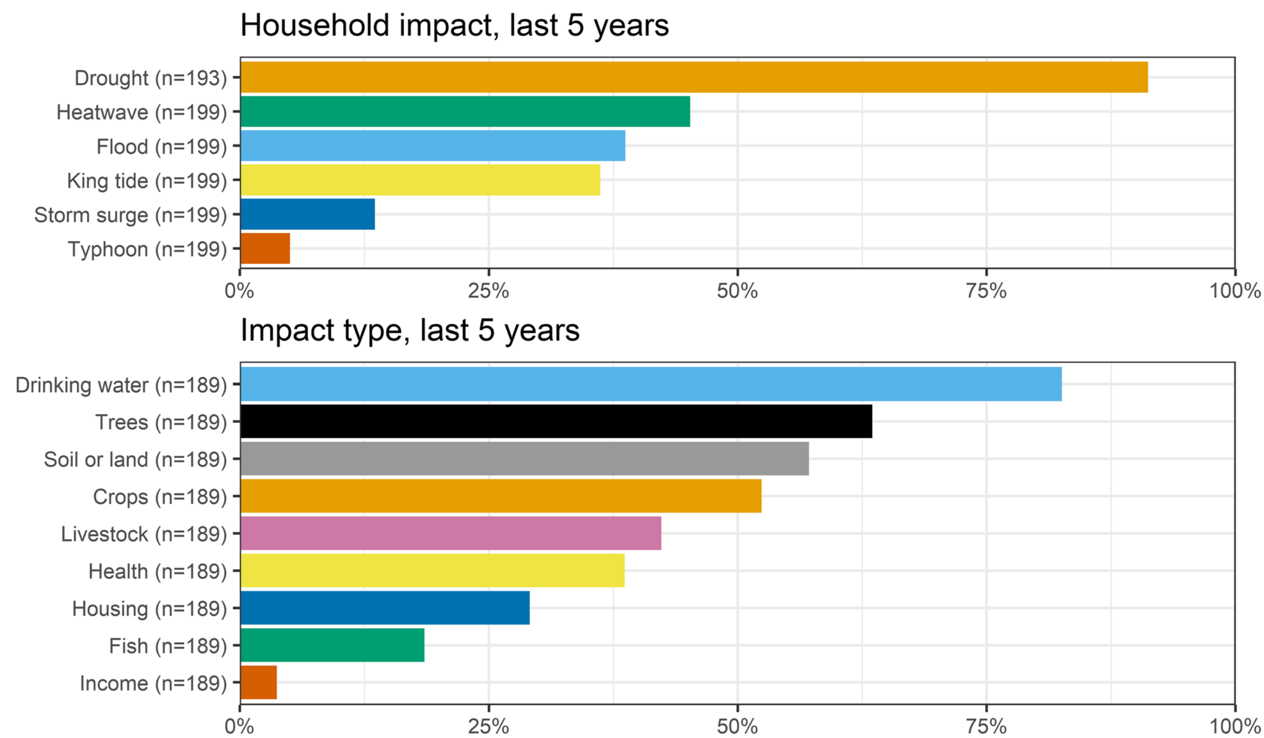


Fig. 2 Climate stressors and health impacts that were experienced by households in the last 5 years. "Impacts" include both direct health outcomes as well as determinants of health (food, water, land, housing, safety, etc.)

Table 2 Perceptions of climate impact severity trends and rankings of problems facing the household. Green shading indicates decreasing severity/lower problem rankings; orange indicates stable severity/medium problem rankings; red indicates increasing severity/highest problem rankings

		n	mean	Values
Climate impact severity trend	Drought	190	0.87	-1 (decreasing) 0 (stable) 1 (increasing)
	Heatwave	182	0.49	
	King tide	178	0.55	
	Storm surge	146	0.13	
	Typhoon	151	0.01	
Problem ranking	Lack of jobs	196	2.38	0 (not among top 5) 1 (lowest ranked problem) 5 (top problem)
	Not enough fresh water	199	2.21	
	Poor education	196	2.05	
	Drought	199	1.98	
	Sea level rise	199	1.73	
	Poor healthcare services	199	1.39	
	Overcrowding	196	0.97	
	Poor transport facilities	196	0.90	
	Out migration	196	0.52	
	Littering and illegal dumping	196	0.28	
	Not enough fish	199	0.27	
	No electricity or power cuts	196	0.21	

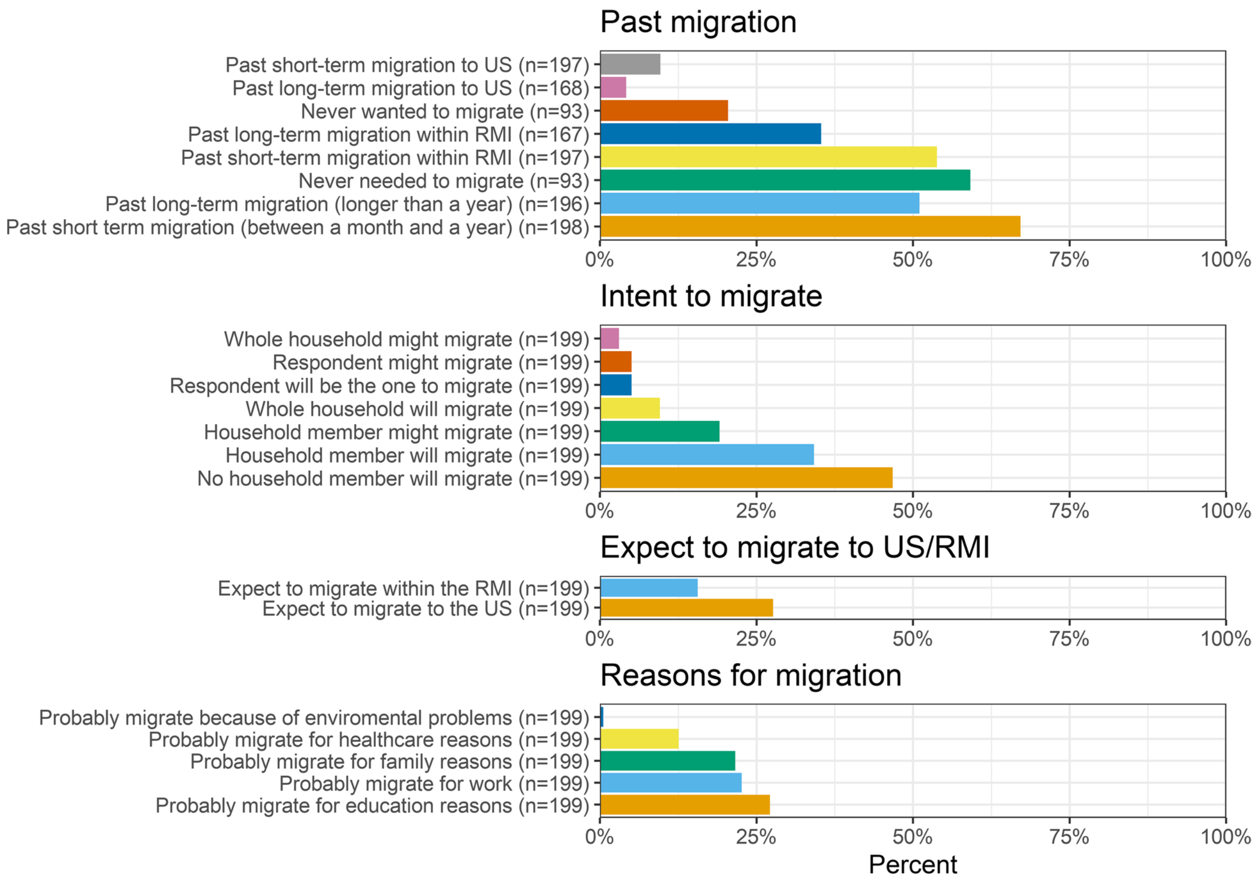


Fig. 3 Details about household past migrations, intentions to migrate, migration destinations, and reasons for migration

illegal dumping (0.3) ranked lowest among respondents' concerns.

Generally the expectation to migrate was very common in the RMI, with 34% of respondents answering "Yes" when asked "Do you think that you or one of your household members will migrate (in RMI or abroad) within the next 10 years?," and another 19% answering "Maybe," indicating that over half of those surveyed saw migration as a possible or likely outcome in the future (Fig. 3). About 5% of respondents expected that they themselves would be the one to migrate and another 5% answered that they might migrate. When asked where they would move, 16% of respondents indicated that they would migrate within the RMI and 28% planned to migrate to the USA. Respondents had also commonly migrated in the past with 67% having migrated short-term (between a month and a year) and 51% having migrated elsewhere within RMI (40%) or to the USA (10%) for over a year.

The extent to which climate stressors were reported as a reason to migrate was relatively low: only one participant said that they might migrate in the future because of climate or environment-related problems. Comparatively, over 25% said they would likely move for education, and around 20% of respondents said they would likely migrate for work or family reasons. Thirteen percent responded that healthcare was a reason they would migrate in the future, and 9% of respondents indicated that health was a reason for at least one past move. Across the full survey population, however, the logistic regression model results linking expectation to migrate with potential climate stressors or climate-related health impacts produced highly inconsistent correlation patters and very high variance. Controlling for income, education, home ownership, island of residence, and location of residence on island did not improve the fit, and a set of independent variables or controls could not be identified that was significantly associated with an increased expectation to

Table 3 List of variables used for clustering and how they compare across the clusters. Green shading indicates lowest impacts/problem rankings compared to the other clusters; orange indicates moderate impacts/problem rankings; red indicates highest impacts/problem rankings

	Cluster 1 mean (SE) (*n* = 86)	Cluster 2 mean (SE) (*n* = 91)	Cluster 3 mean (SE) (*n* = 22)	Values
Household impact last 5 years: typhoon**	0.00 (0.00)	0.11 (0.03)	0.00 (0.00)	0 (no) 1 (yes)
Household impact last 5 years: storm surge***	0.02 (0.02)	0.28 (0.05)	0.00 (0.00)	
Household impact last 5 years: king tide***	0.06 (0.03)	0.71 (0.05)	0.09 (0.06)	
Household impact last 5 years: flood***	0.07 (0.03)	0.76 (0.05)	0.09 (0.06)	
Impact type, last 5 years: crops***	0.38 (0.06)	0.70 (0.05)	0.27 (0.10)	0 (no) 1 (yes)
Impact type, last 5 years: fish***	0.07 (0.03)	0.32 (0.05)	0.05 (0.05)	
Impact type, last 5 years: trees***	0.42 (0.06)	0.75 (0.05)	0.91 (0.06)	
Impact type, last 5 years: soil/land***	0.33 (0.05)	0.73 (0.05)	0.77 (0.09)	
Impact type, last 5 years: income*	0.08 (0.03)	0.01 (0.01)	0.00 (0.00)	
Impact type, last 5 years: food prices**	0.11 (0.04)	0.01 (0.01)	0.00 (0.00)	
Impact type, last 5 years: housing***	0.11 (0.04)	0.52 (0.05)	0.00 (0.00)	
Impact type, last 5 years: properties***	0.09 (0.03)	0.54 (0.05)	0.05 (0.05)	
Not enough freshwater problem ranking***	1.06 (0.16)	2.87 (0.20)	3.95 (0.24)	0 (not among top 5) 1 (lowest ranked problem) 5 (top problem)
Sea level rise problem ranking***	1.33 (0.17)	1.74 (0.18)	3.32 (0.25)	
Not enough fish problem ranking***	0.15 (0.08)	0.15 (0.07)	1.18 (0.28)	
Heatwave severity trend**	0.35 (0.05)	0.62 (0.05)	0.50 (0.12)	-1 (decreasing) 0 (stable) 1 (increasing)
Weighted state of provision of food***	-0.22 (0.10)	-0.26 (0.11)	0.82 (0.29)	-3 (worst) to 3 (best)
Weighted state of provision of fuelwood***	0.17 (0.20)	0.94 (0.19)	2.86 (0.14)	
Weighted trend in provision of water***	-0.69 (0.19)	-1.11 (0.23)	-2.17 (0.33)	
Weighted trend in provision of fuelwood***	-0.42 (0.18)	-0.11 (0.18)	2.05 (0.33)	
Weighted trend in provision of safety***	-0.02 (0.16)	-0.90 (0.17)	-0.53 (0.26)	

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

migrate. Respondents' assessments of climate stressors and trends, state of ecosystems and social services, and migration outcomes were not linearly correlated, and there was a high degree of heterogeneity among them. We therefore attempted to control for the high variance and inconsistencies by grouping respondents according to the climate stressors and health impacts they faced, and then exploring correlations with migration outcomes.

Clustering analysis

The hierarchical cluster analysis grouped households into three distinct clusters based on the 21 climate stressor-related variables that most significantly differed between them (AC = 0.908; Table 3). Tukey's Honestly Significance Difference testing was used to further characterize the cluster mean comparisons (Table 7 in Appendix). Each cluster was characterized by unique climate-related impacts on health and determinants of health. Members of the first cluster ("Cluster 1", $n = 86$) had experienced the lowest typhoon, king tide, and flood impacts in recent years, with low to moderate impacts to their properties, access to natural resources, and other assets except for income and food prices. They were the least likely to report that limited freshwater supplies, sea level rise, and a lack of fish were a problem for them.

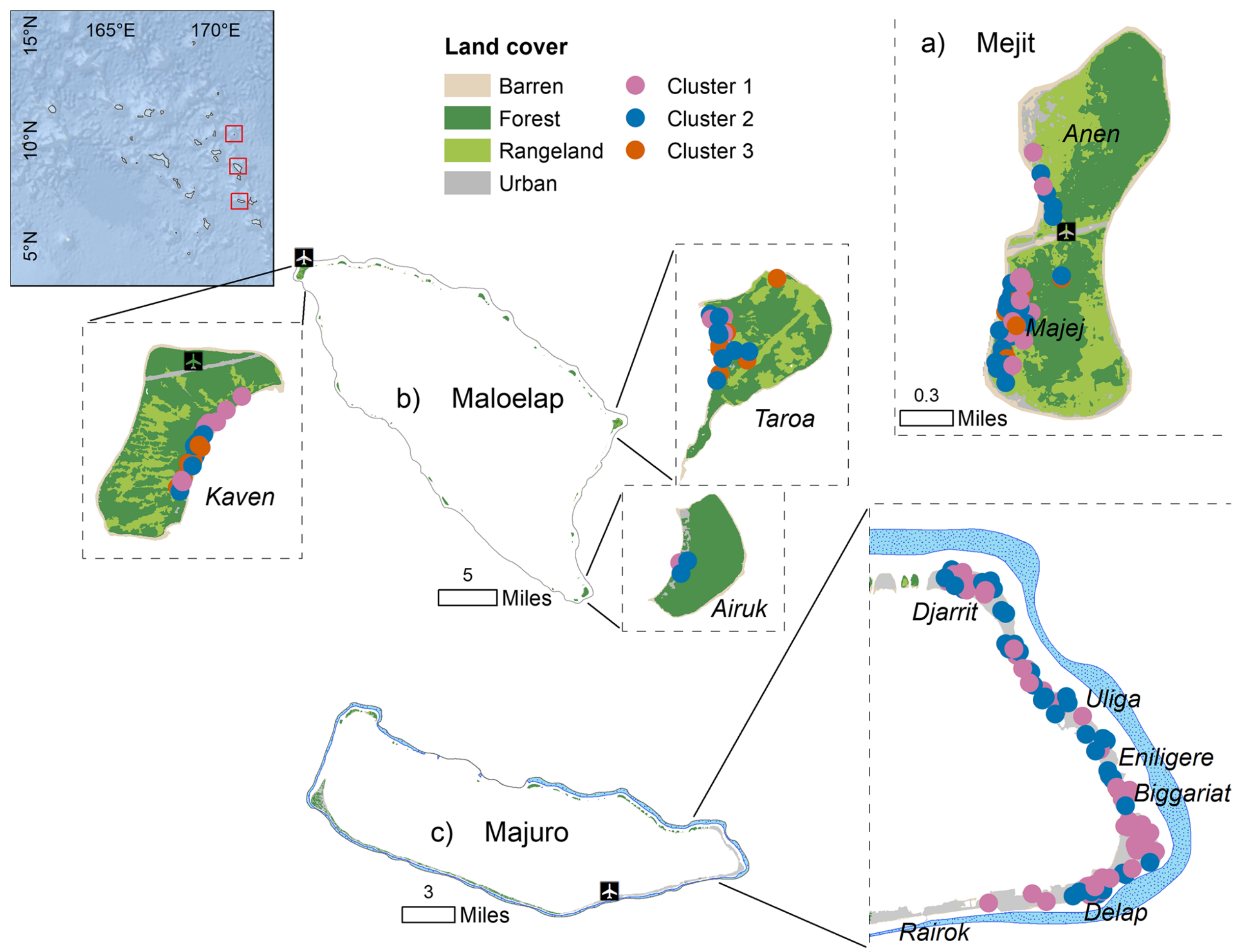


Fig. 4 The locations of members of each cluster on **a** Mejit, **b** Maloelap, and **c** Majuro, with land cover classes for each island. Red boxes in the upper left inset indicate the locations of the three study areas in the RMI

Members of Cluster 2 ($n = 92$) experienced the most climate events with some of the highest impacts to their homes and property, as well as crops and fish. They also reported the strongest declining trend in safety. Cluster 3 ($n = 22$) was a small cluster whose climate stressors were only slightly more severe than those in Cluster 1, except for the impacts on soil and trees, which were the highest of any cluster. They were generally satisfied with the state and trend of food and fuelwood provision but declines in water supplies were the most severe for this group. Across all clusters, respondents reported an increasing trend in heatwave severity, as well as declines in the provision of water supplies and perceptions of safety or protection from their environments.

The spatial distributions of the members of each cluster across the three survey locations of Majuro, Maloelap, and Mejit are shown in Fig. 4. Cluster 1 was a primarily urban cluster that made up of respondents who mostly resided on Majuro, especially near the southeastern and relatively more affluent neighborhood of Delap. Members of Cluster 1 on Maloelap tended to live farther north on Kaven and Taroa. Cluster 2 members lived nearer to the coasts than those in Cluster 1 with larger concentrations on the outer islands of Maloelap and Mejit than on Majuro. Members of Cluster 3 lived almost exclusively on Maloelap and Mejit, with only one respondent on Majuro.

The clusters also differed significantly in characteristics beyond the set of variables used to create them, including their migration expectations. Select variable means are shown in Table 4,

Table 4 List of select variables not used for clustering that differed significantly across the clusters. Green shading indicates lowest impacts/problem rankings, or higher assets like income and home or land ownership, compared to the other clusters; orange indicates moderate impacts/rankings or assets; red indicates highest impacts/problem rankings, or lowest assets

	Cluster 1 mean (SE) (*n* = 86)	Cluster 2 mean (SE) (*n* = 91)	Cluster 3 mean (SE) (*n* = 22)	Values
Household member will or might migrate**	0.50 (0.05)	0.64 (0.05)	0.23 (0.09)	0 (no) 1 (yes)
Household owns land that house is on**	0.56 (0.05)	0.64 (0.05)	0.96 (0.05)	
Household owns land on outer islands or elsewhere*	0.93 (0.03)	0.87 (0.04)	0.73(0.10)	
Lived in current location since birth*	0.15 (0.05)	0.04 (0.03)	0.33 (0.13)	
Household impact last 5 years: heat wave*	0.35 (0.05)	0.56 (0.05)	0.41 (0.11)	0 (no) 1 (yes)
Impact type, last 5 years: livestock***	0.26 (0.05)	0.56 (0.05)	0.41 (0.11)	
King tide trend severity***	0.46 (0.06)	0.70 (0.05)	0.13 (0.09)	-1 (decreasing) 0 (stable) 1 (increasing)
Storm surge trend severity**	0.03 (0.02)	0.24 (0.05)	0.08 (0.08)	
Drought problem ranking***	1.53 (0.16)	2.00 (0.18)	3.68 (0.30)	0 (not among top 5) 1 (lowest ranked problem) 5 (top problem)
Poor education problem ranking***	2.69 (0.24)	1.92 (0.23)	0.09 (0.09)	
Poor healthcare services problem ranking***	1.97 (0.21)	1.09 (0.17)	0.41 (0.18)	
Lack of jobs problem ranking***	2.85 (0.17)	2.32 (0.18)	0.82 (0.25)	
Perception that house is riskier than neighbors***	0.01 (0.06)	-0.56 (0.07)	-0.23 (0.11)	-1 (worse) 0 (same) 1 (better)
Level of education**	3.43 (0.19)	3.56 (0.16)	2.27 (0.33)	0 (no formal education) 8 (graduate school)
Household income***	$8,250 (735)	$4,730 (700)	$1,360 (240)	US Dollars
Remittances received in past year***	$544 (72.0)	$741 (119.0)	$4,650 (4,350)	
Income source: agriculture***	0.34 (0.05)	0.54 (0.05)	0.91 (0.06)	0 (no) 1 (yes)
Income source: fishing**	0.40 (0.05)	0.53 (0.05)	0.82 (0.08)	
Income source: government salary***	0.61 (0.05)	0.35 (0.05)	0.18 (0.08)	
Income source: sector salary***	0.46 (0.05)	0.29 (0.05)	0.05 (0.05)	

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

and Tukey's Honestly Significance Difference test results for all variables not used for clustering that differed significantly across the clusters are found in Table 8 in Appendix. Cluster 1 was comprised of respondents with relatively higher incomes, primarily from private sector and government sources. They were more highly educated, tended to own land more frequently, and reported feeling safer in their homes than the other two clusters. They were also moderately likely to expect to migrate. Members of Cluster 2 had lower incomes from a mix of employment and agriculture/fishing, and received limited remittances from family and friends overseas. They appeared to be more transient, with few having lived in their current locations their whole lives. They perceived their housing to be risky and reported the lowest access to natural resources. This cluster experienced the most direct climate stressors and was also the most likely to expect to migrate. Members of Cluster 3 had the lowest incomes and were much more dependent on natural resources and agriculture, rarely earning incomes from government or private sector sources and receiving more remittances than members of the other clusters. Almost all members of this cluster wrote in copra and/or handicrafts as income sources. They were the most likely to own the home where they lived and the least likely to expect to migrate, compared to Clusters 1 and 2.

Logistic regressions using cluster membership as an interaction term revealed cluster-specific associations between the independent variables related to climate stressors and health impacts and the dependent variable "expectation to migrate" (Table 5). For members of Cluster 1, living at a higher elevation was associated with an *increased* expectation to migrate, and the opposite was true for members of Cluster 2. Although elevations in RMI vary little (the maximum elevation across the three study areas is 10 feet), members of Cluster 2 living at lower elevations may have fewer means to reduce their exposure to impacts like king tides and flooding than Cluster 1 and be more likely to expect to migrate as a result. This may also reflect that more affluent households (Cluster 1) tended to be situated at higher elevations, especially on Majuro. Among members of Cluster 2, the perception that drought and king tides were increasing in severity was associated with a *decreased* expectation to migrate, whereas experiencing heatwave impacts was associated with an *increase* among members of Cluster 1. For members of Cluster 1 alone, having experienced a negative health outcome as a result of climate stressors in the last five years was significantly associated with an *increased* expectation to migrate. No variables were significantly associated with expectation to migrate among members of Cluster 3.

We repeated the analysis to identify variables that were significantly associated with the likelihood of experiencing a health impact as a result of climate stressors (Table 6). For members of Custer 1, having a larger household size and private sector income increased the likelihood of a health impact, along with overcrowding problem ranking and getting drinking water from government sources. For Cluster 2 members, living on the lagoon (interior) side of the island, having income from agriculture and fishing, poor education problem ranking, relying on the environment for food, and climate impacts to livestock increased the likelihood of a health impact. In fact, there were opposite directions of association between Clusters 1 and 2 for all seven of the significant factors that they shared. Among members of Cluster 3, only living on the lagoon (interior) side of the island increased the likelihood of a health impact.

These findings confirmed that the survey respondents faced very different sets of climate stressors and associated health impacts that were in turn associated with unique migration expectations. Although there were significant correlations between climate stressors and determinants of health and impacts in each cluster, only among members of Cluster 1 was the likelihood

Table 5 Logistic regression results showing factors significantly associated with expectation to migrate, by cluster. Orange shading indicates an associated increase in the dependent variable; blue indicates an associated decrease

	Cluster 1 [β (SE)] *(n=86)*	Cluster 2 [β (SE)] *(n=91)*	Cluster 3 [β (SE)] *(n=22)*
Expectation that a household member will or might migrate	Higher elevation [0.62 (0.21)]	Higher elevation [-0.63 (0.30)]	
		Increasing drought trend severity [-2.50 (1.24)]	
		Increasing king tide trend severity [-2.26 (0.91)]	
	Impact last 5 years: heat wave [1.05 (0.27)]		
	Impact type, last 5 years: health [0.97 (0.49)]		
	Income source: government [-1.16 (0.47)]		
		Lack of jobs problem ranking [0.46 (0.2)]	
		Poor education problem ranking [0.32 (0.15)]	
		Owning a boat [-2.06 (0.75)]	

Table 6 Logistic regression results showing factors significantly associated with the likelihood that a household member will experience a health impact, by cluster. Orange shading indicates an associated increase in the dependent variable; blue indicates an associated decrease

	Cluster 1 [β (SE)] *(n=86)*	Cluster 2 [β (SE)] *(n=91)*	Cluster 3 [β (SE)] *(n=22)*
Likelihood that a household member will experience a health impact	Living on lagoon side [-1.54 (0.64)]	Living on lagoon side [1.79 (0.80)]	Living on lagoon side [2.89 (1.41)]
		Living on ocean side [-2.75 (1.34)]	
	Larger household size [0.26 (0.10)]	Larger household size [-0.35(0.12)]	
	Income source: agriculture [-1.52 (0.55)]	Income source: agriculture [2.56 (0.70)]	
	Income source: fishing [-1.08 (0.50)]	Income source: fishing [2.19 (0.67)]	
	Income source: private sector [1.72 (0.51)]	Income source: private sector [-2.38 (0.71)]	
	Poor education problem ranking [-0.51 (0.13)]	Poor education problem ranking [0.51 (0.16)]	
	More food from local environment [-2.84 (1.10)]	More food from local environment [4.34 (1.42)]	
	Overcrowding problem ranking [0.27 (0.29)]		
		Livestock impacts [1.84 (0.27)]	
	Drinking water source: government supply [1.23 (0.55)]		
		Impact type, last 5 years: trees [1.57 (0.76)]	

of experiencing a negative health impact due to climate stressors significantly correlated with an increased expectation to migrate. Meanwhile, climate stressors on the determinants of health, particularly food sources, significantly increased the likelihood of experiencing a health impact only among members of Cluster 2.

Qualitative representations of vulnerability

Representative quotes from the survey write-in responses further contextualized the different ways that members of each cluster experienced and responded to climate stressors. Members of Cluster 1 were comparatively wealthier and faced less severe climate stressors than the other two clusters (Table 4). Impacts to the determinants of health (limited freshwater supplies, sea level rise, and a lack of fish) were also less of a problem for them, likely because they had lower vulnerability given their more affluent, urban status (Table 3). One Cluster 1 respondent referred to their ability to buy purified water and an air conditioning unit in response to drought and heat impacts: "We needed to buy drinking water when our tank ran out during droughts. Also very hot because of all the surrounding houses. So I bought an air con which means I pay more for electricity." They appeared to feel less vulnerable and were moderately likely to expect to migrate.

In contrast, members of Cluster 2 had lower incomes and faced more prevalent climate stressors related to storms and the ocean, as well as similar (but slightly lower) impacts of heat waves, droughts, and access to fresh water (Table 3). They reported a worse state of natural resources and felt much less safe, particularly with respect to their housing situation. "Our house is very close to the shore," said a member of Cluster 2. "If another king tide comes it will be washed away because the first time when [the] last king tide came, water ran straight into my house and everything in it [was] damaged." This group also reported some of the most severe climate impacts on other determinants of health, such as food and water, and was the most likely to expect to migrate (Table 4).

The relatively small Cluster 3 consisted mostly of people with comparatively very low incomes who were the least likely to expect to migrate (Table 4). They seemed to have sufficient access to natural resources, especially food, but the most prevalent climate stressors for this group were related to heat and drought, which impacted their access to drinking water (Table 3). One member of Cluster 3 mentioned feeling shame associated with running out of water during a drought: "We have only one water catchment, it ran out so we had to drink from our neighbor´s catchment which was a shameful thing for us to do." Despite being strongly impacted by heat waves and water shortages, however, they seemed to feel somewhat neutral about their risk and safety compared to their more urban counterparts in Cluster 2. Overall, Cluster 2 may be the most vulnerable group because they appeared to be facing heat and drought challenges similar to Cluster 3 but with additional storm and ocean-related stressors, and less resources available to them to blunt the impacts of climate change.

Discussion

The climate, health, and migration nexus—implications for policy

The results of this study, and the clustering analysis in particular, underscored the fact that the nexus of climate, health, and migration in the RMI is characterized by both direct and indirect relationships that are not homogeneous, with implications for policy interventions that could reduce vulnerability and promote more equitable adaptation outcomes among certain groups. Members of cluster 1, with their higher cash incomes, land ownership, and access to natural resources, likely had greater overall agency in migration decision making, including when migrating in response to health impacts. Accordingly, Cluster 1 displayed more consistent patterns of association between the climate stressors, health impacts, and expectations to migrate than Clusters 2 and 3, which are more commonly understood as "push" and "pull" factors (e.g., Massey et al. 1993; European Communities 2000). Drawing on Hunter et al.'s (Fig. 1 in Hunter et al. 2021) conceptualization of the relationship between climate vulnerability and migration, this group likely had higher "voluntary mobility" and "voluntary immobility" with an ability to adapt to climate stressors through migration or taking measures to adapt in place. Conversely, members of Cluster 2 with lower incomes may have considered migration as less of a possibility, even when facing the same stressors, if they did not have adequate resources to do so. They may have also had less capacity to adapt to climate stressors and health impacts than members of Cluster 1. As such, they could be considered to be involuntarily mobile or immobile. Among members of Cluster 3, respondents' low expectations to migrate may have simply been related to other drivers or barriers not captured in the survey, yet reflected overall greater voluntary immobility compared to the other two clusters. Clearly, more information is needed about this group of mostly outer island residents.

In addition, the inequities surrounding this nexus in the RMI may become further complicated and exacerbated as climate change progresses. Elsewhere in the Pacific and in other regions—such as Latin America—that are experiencing resource scarcity or weakened infrastructure, disparities in representation and interventions mean that those with greater financial capital and agency benefit more from migration or other adaptation and mitigation efforts, while the most vulnerable do not see the same benefits (Marino and Ribot 2012). Further engagement in the RMI across its diverse society is needed to reduce unequal vulnerability to climate stressors and identify optimal adaptation strategies that protect health and well-being, as well as the proximate determinants of health (e.g., food, water, land, safety). Equity concerns are currently top of mind for the RMI International Office for Migration, which acknowledges that some of the most vulnerable groups (e.g., members of Clusters 2 and 3 in this study) are absent from policy conversations around environmental and social adaptation (Saunders, pers comm 2021). The RMI Climate Change Directorate is also developing the country's first National Adaptation Plan (NAP) that addresses climate mitigation as well as critical aspects of climate adaptation across multiple sectors, including health (Wase-Jacklick, pers comm 2021).

Lastly, this and future research on the subject must acknowledge and consider the outsize role the USA plays with respect to foreign assistance, economic opportunities, and migration in the RMI. A recent analysis by the Asian Development Bank evaluating different COFA renewal scenarios between the RMI and the USA found that the economic impacts of non-renewal would reduce GDP by 4.4% with an associated increase in out-migration of 6.4% over current rates. A "better results" scenario, on the other hand, projects an overall decline in migration out of the RMI alongside economic growth in the public and private sectors (Asian Development Bank [ADB] 2022). As negotiations continue ahead of the 2023 expiration deadline, the inequities and challenges to long-term sustainability identified in this research must also be addressed in the face of climate change, in order to meaningfully reduce migration pressure.

Conclusions

There are profoundly concerning impacts of climate change facing the RMI, which exacerbate existing inequities and are occurring in the context of a population that is in motion. In this study, we analyzed survey data from 199 households across three representative islands in the RMI. Whereas previous analyses of this data focused on descriptive statistics and correlations between climate impacts and respondents' household migration experiences (van der Geest et al. 2019b, 2019c, 2020), we used logistic regression to evaluate whether climate stressors and associated direct and indirect health impacts (the independent variables) were associated with expectation to migrate. We then used a hierarchical clustering approach to identify three unique profiles of climate vulnerability, health outcomes, and migration agency. Our key findings are summarized below.

First, the surveyed households experienced very high levels of climate stressors and impacts to the proximate determinants of health, especially related to drought, heatwave, flooding, and king tide events, which mainly impacted household drinking water supplies, trees, soils, and crops. Furthermore, the severity of these stressors has been increasing in recent decades. When asked to rank the top problems their household was facing, respondents' top issues were a mix of climate stressors, livelihood concerns, and social services. A lack of available jobs, poor education, and drought were the highest ranked problems, followed by sea level rise and poor healthcare services.

Second, the expectation to migrate was very high across the survey population. Overall, more than 50% of respondents said they or a member of their household would or might migrate in the coming decade. Seeking healthcare was also one of the top drivers of both past and potential future migrations, whereas climate impacts and environmental factors were rarely cited as direct migration motivations. However, there were climate-related factors that were indirectly related to migration decisions for the survey population (such as heat waves and impacts to food and water resources).

Third, the clustering exercise revealed how people facing different sets of climate stressors and health impacts had significantly different circumstances and associated expectations to migrate. Although members of Clusters 1 and 2 were generally likely to expect to migrate, for example, only among members of Cluster 1 was experiencing a direct health impact due to climate stressors associated with an increased expectation to migrate. In Cluster 2, on the other hand, climate impacts to the proximate determinants of health were significantly associated with negative health outcomes, but this group's very high expectations to migrate were unrelated to health impacts, and increasing drought and king tide severity were even associated with a *decreased* expectation to migrate. For Cluster 3, no variables were significantly associated with expectation to migrate and only one variable was associated with experiencing a negative health impact; consequently, these results are difficult to interpret without further information.

Finally, the proximate determinants of health, including land ownership, access to food and water, and wealth were strong differentiators between the clusters that were correlated with climate stressors and migration agency. The group with the highest incomes, land ownership, and education (Cluster 1) reported some of the least climate impacts and intentions to migrate, perhaps because they possessed adaptation options (for example, the ability to buy an air conditioning unit or make improvements to their homes) that were not available to other groups. Members of Cluster 1 were also the least likely to experience a direct climate impact to their health. Conversely, members of Cluster 2 experienced climate stressors more strongly, had riskier or less secure housing, and were overall more likely to expect to migrate. Although the third group, Cluster 3, had lower cash incomes and experienced more heat and drought stressors than Clusters 1 and 2, they were generally more satisfied with the state of natural resources and less likely to expect to migrate.

This analysis offers empirical evidence in support of policy concerns in the RMI surrounding equity, vulnerability to climate impacts and adaptive capacity, and abilities and desires to migrate (Saunders, pers comm 2021). The findings from this study are also in agreement with Hezel and Levin's (1990) assessment from over 30 years ago, that increasing equitable opportunities for residents of the RMI to achieve what may be seen as achievable only through migration would provide greater decision-making agency, as well as the potential for return migration. Expanding healthcare, education, and livelihood prospects through the NAP process and COFA renewal, with attention to long-term sustainability in the face of climate change, could meaningfully reduce migration pressure. If, on the other hand, certain members of the population feel forced to migrate in the context of climate change, the disparities that exist today will only grow.

Appendix

Tables 7 and 8

Table 7 Tukey's Honestly Significant Difference test results for variables used for clustering. Blue shading indicates a significant (p < 0.05) positive difference between clusters; orange indicates a significant negative difference

		Cluster contrast		
		2-1	3-1	3-2
	aov.p	Estimate (p)	Estimate (p)	Estimate (p)
Household impact last 5 years: typhoon	0.002	0.110 (0.002)	0.000 (1.000)	-0.110 (0.079)
Household impact last 5 years: storm surge	0.000	0.251 (0.000)	-0.023 (0.950)	-0.275 (0.001)
Household impact last 5 years king tide	0.000	0.656 (0.000)	0.033 (0.922)	-0.623 (0.000)
Household impact last 5 years: flood	0.000	0.688 (0.000)	0.021 (0.965)	-0.667 (0.000)
Heatwave trend severity	0.002	0.269 (0.002)	0.150 (0.467)	-0.119 (0.615)
Impact type, last 5 years: crops	0.000	0.322 (0.000)	-0.109 (0.607)	-0.431 (0.000)
Impact type, last 5 years: fish	0.000	0.253 (0.000)	-0.020 (0.972)	-0.273 (0.006)
Impact type, last 5 years: trees	0.000	0.326 (0.000)	0.488 (0.000)	0.162 (0.286)
Impact type, last 5 years: soil/land	0.000	0.396 (0.000)	0.444 (0.000)	0.048 (0.900)
Impact type, last 5 years: income	0.042	-0.068 (0.053)	-0.079 (0.192)	-0.011 (0.967)
Impact type, last 5 years: food prices	0.009	-0.094 (0.012)	-0.105 (0.097)	-0.011 (0.973)
Impact type, last 5 years: housing	0.000	0.411 (0.000)	-0.105 (0.525)	-0.516 (0.000)
Impact type, last 5 years: properties	0.000	0.446 (0.000)	-0.047 (0.881)	-0.493 (0.000)
Not enough freshwater problem ranking	0.000	1.810 (0.000)	2.900 (0.000)	1.090 (0.017)
Sea level rise problem ranking	0.000	0.411 (0.202)	1.990 (0.000)	1.580 (0.000)
Not enough fish problem ranking	0.000	0.003 (1.000)	1.030 (0.000)	1.030 (0.000)
Weighted state of provision of food	0.000	-0.032 (0.977)	1.040 (0.000)	1.070 (0.000)
Weighted state of provision of fuelwood	0.000	0.779 (0.007)	2.700 (0.000)	1.920 (0.000)
Weighted trend in provision of water	0.010	-0.424 (0.310)	-1.480 (0.008)	-1.050 (0.079)
Weighted trend in provision of fuelwood	0.000	0.307 (0.443)	2.470 (0.000)	2.160 (0.000)
Weighted trend in provision of safety	0.001	-0.873 (0.000)	-0.502 (0.378)	0.371 (0.581)

Table 8 Tukey's Honestly Significant Difference test results for variables not used for clustering that differed significantly between clusters. Blue shading indicates a significant ($p < 0.05$) positive difference between clusters; orange indicates a significant negative difference

		Cluster contrast		
		2-1	3-1	3-2
	aov.p	Estimate (p)	Estimate (p)	Estimate (p)
Household member will migrate	0.029	0.024 (0.938)	-0.270 (0.045)	-0.294 (0.025)
Household member will or might migrate	0.002	0.137 (0.148)	-0.273 (0.052)	-0.410 (0.001)
Past flood recorded	0.005	0.223 (0.004)	0.000 (1.000)	-0.223 (0.314)
Household impact last 5 years: heat wave	0.016	0.212 (0.013)	0.060 (0.865)	-0.151 (0.398)
King tide trend severity	0.000	0.241 (0.004)	-0.327 (0.040)	-0.568 (0.000)
Storm surge trend severity	0.002	0.205 (0.001)	0.053 (0.862)	-0.152 (0.297)
Impact type, last 5 years: livestock	0.000	0.297 (0.000)	0.146 (0.419)	-0.151 (0.379)
Drought problem ranking	0.000	0.465 (0.116)	2.150 (0.000)	1.680 (0.000)
Poor education problem ranking	0.000	-0.768 (0.039)	-2.600 (0.000)	-1.830 (0.001)
Overcrowding problem ranking	0.041	-0.633 (0.045)	-0.652 (0.262)	-0.018 (0.999)
Poor healthcare problem ranking	0.000	-0.877 (0.002)	-1.560 (0.000)	-0.679 (0.210)
Lack of jobs problem ranking	0.000	-0.523 (0.079)	-2.030 (0.000)	-1.500 (0.000)
Weighted state of provision of safety	0.028	-0.442 (0.084)	0.276 (0.669)	0.718 (0.069)
Perception that house is riskier than neighbors	0.000	-0.568 (0.000)	-0.239 (0.250)	0.328 (0.072)
Preventative measures: changed economic activities	0.004	-0.200 (0.010)	-0.300 (0.038)	-0.100 (0.672)
Preventative measures: earn outside income	0.013	0.160 (0.021)	-0.040 (0.925)	-0.200 (0.136)
Preventative measures: other	0.001	-0.180 (0.001)	0.002 (1.000)	0.182 (0.091)
Preventative measures: none	0.028	-0.173 (0.025)	-0.031 (0.954)	0.142 (0.359)
Location: Maloelap	0.000	0.079 (0.414)	0.474 (0.000)	0.395 (0.000)
Location: Majuro	0.000	-0.167 (0.050)	-0.594 (0.000)	-0.427 (0.001)
Household income	0.000	-3530 (0.001)	-6890 (0.000)	-3360 (0.055)
Income source: agriculture	0.000	0.197 (0.017)	0.568 (0.000)	0.371 (0.003)
Income source: fishing	0.002	0.127 (0.195)	0.418 (0.001)	0.291 (0.034)
Income source: government salary	0.000	-0.260 (0.001)	-0.430 (0.001)	-0.170 (0.293)
Income source: private sector salary	0.000	-0.173 (0.034)	-0.413 (0.001)	-0.240 (0.071)
Household income change, past 10 years	0.003	-0.348 (0.003)	-0.309 (0.169)	0.039 (0.971)
Level of education completed	0.003	0.122 (0.870)	-1.160 (0.008)	-1.280 (0.002)
Household owns land that house is on	0.002	0.079 (0.502)	0.396 (0.001)	0.317 (0.014)
Household owns land on outer islands or elsewhere	0.034	-0.060 (0.435)	-0.201 (0.027)	-0.141 (0.162)
Household eats local more than half of the time	0.018	0.025 (0.943)	0.341 (0.015)	0.316 (0.025)
Probably migrate for work	0.027	-0.003 (0.999)	-0.256 (0.028)	-0.253 (0.029)
Probably migrate for education	0.009	-0.017 (0.963)	-0.314 (0.008)	-0.297 (0.013)
Total amount of remittances received	0.000	197 (0.689)	4110 (0.000)	3910 (0.000)
Remittances used to pay hospital bills	0.010	0.117 (0.038)	-0.070 (0.623)	-0.187 (0.035)
Drinking water source: groundwater	0.000	-0.059 (0.290)	0.282 (0.000)	0.342 (0.000)
Drinking water source: rainwater bins	0.000	0.005 (0.994)	0.486 (0.000)	0.481 (0.000)
Drinking water source: government supply	0.001	-0.19 (0.001)	-0.165 (0.120)	0.025 (0.951)
Drinking water source: reverse osmosis	0.040	0.09 (0.327)	0.246 (0.038)	0.156 (0.259)
Drinking water source: shop	0.001	-0.153 (0.05)	-0.384 (0.001)	-0.231 (0.065)
Participant has lived in same location since birth	0.013	-0.107 (0.242)	0.182 (0.145)	0.290 (0.010)
Never needed to migrate	0.016	0.148 (0.369)	0.412 (0.012)	0.264 (0.162)
Participant location: inland	0.008	-0.268 (0.006)	-0.129 (0.562)	0.139 (0.491)
Participant location: ocean side	0.001	0.223 (0.003)	-0.038 (0.923)	-0.261 (0.020)
Participant location: coast	0.008	0.268 (0.006)	0.129 (0.562)	-0.139 (0.491)

Acknowledgements
The authors are grateful to the Republic of the Marshall Islands Ministry of Health and Human Services, the Climate Change Directorate, and the International Organization for Migration Majuro Office for their contributions to this research. They also thank members of the Hawai'i and Pacific Islands healthcare community who shared experiences, literature, and other resources. Lastly, Kees van der Geest provided survey data and a constructive analysis review. This research was supported by the National Oceanic and Atmospheric Administration's International Research and Applications Project, federal funding opportunity NOAA-OAR-CPO-2018-2005445.

Code availability
Not applicable.

Authors' contributions
L.B. conceived of the study. D.K. developed the analysis plan and carried out the computations. All authors interpreted the results and contributed equally to the writing. The authors read and approved the final manuscript.

Funding
This research was supported by the National Oceanic and Atmospheric Administration's International Research and Applications Project, federal funding opportunity NOAA-OAR-CPO-2018-2005445.

Availability of data and materials
Data may be available upon request. Please contact the corresponding author.

Declarations

Consent to publication
Not applicable.

Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 10 June 2022 Accepted: 11 August 2022
Published online: 09 September 2022

References
Ahlgren I, Yamada S, Wong A (2014) Rising oceans, climate change, food aid, and human rights in the Marshall Islands. Health Hum Rights 16(2):69–81
Albrecht G, Sartore GM, Connor L, Higginbotham N, Freeman S, Kelly B, Stain H, Tonna A, Pollard G (2007) Solastalgia: the distress caused by environmental change. Australas Psychiatry 15(Suppl 1):S95–S98. https://doi.org/10.1080/10398560701701288
Asian Development Bank [ADB] (2022) The economic impacts of the end of compact grant assistance in the freely associated states. Draft for discussion. Asia Development Bank, Manila Available via https://pitiviti.org/storage/dm/2022/05/adb-report-2022-final-digital-4-fix-20220506211212360.pdf
Barnett J (2011) Dangerous climate change in the Pacific Islands: food production and food security. Reg Environ Chang 11(1):229–237. https://doi.org/10.1007/s10113-010-0160-2
Beatty ME, Jack T, Sivapalasingam S, Yao SS, Paul I, Bibb B, Greene KD, Kubota K, Mintz ED, Brooks JT (2004) An outbreak of vibrio cholerae O1 infections on Ebeye Island, Republic of the Marshall Islands, associated with use of an adequately chlorinated water source. Clin Infect Dis 38(1):1–9. https://doi.org/10.1086/379713
Beine M, Parsons C (2015) Climatic factors as determinants of international migration. Scand J Econ 117:723–767. https://doi.org/10.1111/sjoe.12098
Black R, Adger WN, Arnell NW, Dercon S, Geddes A, Thomas D (2011) The effect of environmental change on human migration. Glob Environ Chang 21:S3–S11. https://doi.org/10.1016/j.gloenvcha.2011.10.001
Brewington L, Kokame K, Lewis N (2021) Climate change and its implications for health and migration in the Pacific: examples from the Marshall Islands. AsiaPacific Issues 149:1–8 Available via https://www.eastwestcenter.org/system/tdf/private/api149brewington.pdf?file=1&type=node&id=41036
Burkett M (2011) In search of refuge: Pacific Islands, climate-induce migration, and the legal frontier. AsiaPacific Issues 98:1–7 Available via https://www.eastwestcenter.org/system/tdf/private/api098.pdf?file=1&type=node&id=32472
Burns WCG (2003) Chapter 5: Pacific Island developing country water resources and climate change. In: Gleick P, Burns W, Chalecki E et al (eds) The World's water, 2002-2003: the biennial report on freshwater resources. Island Press, Washington, pp 113–131
Campbell J, Oakes R, Milan A (2016) Nauru: climate change and migration: relationships between household vulnerability, human mobility and climate change. UN University Institute for Environment and Human Security, Bonn
Campbell JR (2014) Climate-change migration in the Pacific. Contemp Pac 26:1–28. https://doi.org/10.1353/cp.2014.0023
Charles E, Land André, Bouville Iulian, Apostoaei Steven L, Simon (2010) Projected lifetime cancer risks from exposure to regional radioactive fallout in the marshall islands. Health Physics 99(2) 201–15. https://doi.org/10.1097/HP.0b013e3181dc4e84
Cocklin C (1999) Islands in the midst: environmental change, vulnerability, and security in the Pacific. In: Lonergan SC (ed) Environmental change, adaptation, and security. NATO/Kluwer, Washington, pp 141–159. https://doi.org/10.1007/978-94-011-4219-9_9
Department of State (2021) U.S. relations with Marshall Islands. Bilateral relations fact sheet. Department of State Bureau of East Asian and Pacific Affairs, Washington Available via https://www.state.gov/u-s-relations-with-marshall-islands/
Duke, M (2014) Marshall Islanders: Migration Patterns and Health-Care Challenges | migrationpolicy.org. Available via https://www.migrationpolicy.org/article/marshall-islanders-migration-patterns-and-health-care-challenges
European Communities (2000) Push and pull factors of international migration: a comparative report. Office for Official Publications of the European Communities Available via https://www.nidi.nl/shared/content/output/2000/eurostat-2000-theme1-pushpull.pdf
Hezel FX, Levin MJ (1990) Micronesian emigration: the brain drain in Palau, Marshalls and the federated states. In: Connell J (ed) Migration and development in the South Pacific. Australia National University, Canberra, pp 42–60
Hugh B, Roland Katherine J, Curtis (2020) The differential influence of geographic isolation on environmental migration: a study of internal migration amidst degrading conditions in the central Pacific. Population and Environment 42(2) 161-182. https://doi.org/10.1007/s11111-020-00357-3
Hunter LM, Koning S, Fussell E, King B, Rishworth A, Merdjanoff A, Muttarak R, Riosmena F, Simon DH, Skop E, Van Den Hoek J (2021) Scales and sensitivities in climate vulnerability, displacement, and health. Popul Environ 43:61–81. https://doi.org/10.1007/s11111-021-00377-7
International Organization for Migration [IOM] (2017) Republic of Marshall Islands country strategy 2017–2020. Majuro, International Organization for Migration Available via https://publications.iom.int/books/republic-marshall-islands-iom-country-strategy-2017-2020
Johnson G (2021) Abandoning RMI. Marshall Islands J:1–4
Johnson SC (1967) Hierarchical clustering schemes. Psychometrika 32(3):241–254. https://doi.org/10.1007/BF02289588
Locke JT (2009) Climate change-induced migration in the Pacific region: sudden crisis and long-term developments. Geogr J 175:171–180. https://doi.org/10.1111/j.1475-4959.2008.00317.x
Marino E, Ribot J (2012) Adding insult to injury: climate change and the inequities of climate intervention. Glob Environ Chang 22(2):323–328. https://doi.org/10.1016/j.gloenvcha.2012.03.001
Marra JJ, Kruk M (2017) State of environmental conditions in Hawaii and the U.S. Affiliated Pacific Islands under a changing climate: 2017. NOAA NESDIS National Centers for Environmental Information, Honolulu
Massey DS, Arango J, Hugo G, Kouaouci A, Pellegrino A, Taylor JE (1993) Theories of international migration: a review and appraisal. Popul Dev Rev 19(3):431–466

McLeman RA (2014) Climate and human migration: past experiences, future challenges. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781139136938
McIver L, Kim R, Woodward A, Hales S, Spickett J, Katscherian D, Hashizume M, Honda Y, Kim H, Iddings S, Naicker J, Bambrick H, McMichael AJ, Ebi KL. Health Impacts of Climate Change in Pacific Island Countries: A Regional Assessment of Vulnerabilities and Adaptation Priorities. Environ Health Perspect. 2016 ;124(11):1707-14. https://doi.org/10.1289/ehp.1509756
McMichael AJ (2015) Extreme weather events and infectious disease outbreaks. Virulence 6(6):543–547. https://doi.org/10.4161/21505594.2014.975022
McMichael C, Farbotko C, Piggott-McKellar A, Powell T, Kitara M (2021) Rising seas, immobilities, and translocality in small island states: case studies from Fiji and Tuvalu. Popul Environ 43:82–107. https://doi.org/10.1007/s11111-021-00378-6
Milan A, Oakes R, Campbell J (2016) Tuvalu: climate change and migration: relationships between household vulnerability, human mobility and climate change. UN University Institute for Environment and Human Security, Bonn
Nurse LA, McLean RF, Agard J, Briguglio LP, Duvat-Magnan V, Pelesikoti N, Tompkins E, Webb A (2014) Small islands. In: Barros VR, Field CB, Dokken DK et al (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1613–1654
Oakes R (2019) Culture, climate change and mobility decisions in Pacific Small Island developing states. Popul Environ 40:480–503. https://doi.org/10.1007/s11111-019-00321-w
Oakes R, Banerjee S, Warner K (2019) Human mobility and adaptation to environmental change. In: McAuliffe M, Khadria B (eds) World migration report 2020. International Organization for Migration, pp 253–270 https://publications.iom.int/system/files/pdf/wmr_2020.pdf
Oakes R, Milan A, Campbell J (2016) Kiribati: climate change and migration: relationships between household vulnerability, human mobility and climate change. University Institute for Environment and Human Security, Bonn
Owen SD, Kench PS, Ford M (2016) Improving understanding of the spatial dimensions of biophysical change in atoll island countries and implications for island communities: a Marshall Islands' case study. Appl Geogr 72:55–64. https://doi.org/10.1016/j.apgeog.2016.05.004
Padhy SK, Sarkar S, Panigrahi M, Paul S (2015) Mental health effects of climate change. Indian J Occup Environ Med 19:3–7. https://doi.org/10.4103/0019-5278.156997
Pobutsky AM, Krupitsky D, Yamada S (2009) Micronesian migrant health issues in Hawaii: part 2: an assessment of health, language and key social determinants of health. Calif. J Health Promot 7(2):25. https://doi.org/10.32398/cjhp.v7i2.2013
Republic of the Marshall Islands [RMI] (2012) 2011 census report. Secretariat of the Pacific Community Statistics for Development Programme, and the Republic of the Marshall Islands Economic Policy, Planning, and Statistics Office. Available via, Noumea https://sdd.spc.int/digital_library/republic-marshall-islands-2011-census-report
Republic of the Marshall Islands [RMI] (2014) National water and sanitation policy Available via https://www.theprif.org/sites/default/files/2020-08/Marshall%20Islands%20Water%20Sanitation%20Policy.pdf
Saunders, A (2021) Personal communication, Majuro
Schwerdtle P, Bowen K, McMichael C (2018) The health impacts of climate-related migration. BMC Med 16:1. https://doi.org/10.1186/s12916-017-0981-7
Schwerdtle PN, McMichael C, Mank I, Sauerborn R, Danquah I, Bowen K (2020) Health and migration in the context of a changing climate: a systematic literature assessment. Environ Res Lett 15:103006. https://doi.org/10.1088/1748-9326/ab9ece
Storlazzi CD, Gingerich SB, Dongeren AV, Cheriton OM, Swarzenski PW, Quataert E, Voss CI, Field DW, Annamalai H, Piniak GA, McCall R (2018) Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding. Sci Adv 4(4):1–9. https://doi.org/10.1126/sciadv.aap9741
Tabe T (2019) Climate change migration and displacement: learning from past relocations in the Pacific. Sociol Sci 8(7):218. https://doi.org/10.3390/socsci8070218
Taibbi M, Saltzman M (2018) "Marshall Islands: a third of the nation has left for the U.S." PBS NewsHour weekend. December 16, 2018 https://www.pbs.org/newshour/show/marshall-islands-a-third-of-the-nation-has-left-for-the-us
Thomas A, Benjamin L (2018) Policies and mechanisms to address climate-induced migration and displacement in Pacific and Caribbean small island developing states. Int J Climate Change Strat Manag 10(1):86–104. https://doi.org/10.1108/IJCCSM-03-2017-0055
Trtanj J, Jantarasami L, Brunkard J, Collier T, Jacobs J, Lipp E, McLellan S, Moore S, Paerl H, Ravenscroft J, Sengco M, Thurston J (2016) Ch 6: climate impacts on water-related illness. In: Crimmins A, Balbus J, Gamble JL et al (eds) The impacts of climate change on human health in the United States: a scientific assessment. U.S. Global Change Research Program, Washington, pp 157–188. https://doi.org/10.7930/J03F4MH4
Tukey J (1949) Comparing individual means in the analysis of variance. Biometrics 5(2):99–114
United Nations Population Division (2018) World population prospects: the 2018 revision. United Nations, Department of Economic and Social Affairs, Population Division, Brussels
United States Census Bureau (2019) 2014-2018 American community survey 5-year estimates [CSV data file] https://factfinder.census.gov
Upadhyay H, Kelman I, Lingaraj GJ, Mishra A, Shreve C, Stojanov R (2015) Conceptualizing and contextualizing research and policy for links between climate change and migration. Int J Climate Change Strat Manag 7:394–417. https://doi.org/10.1108/IJCCSM-05-2014-0058
van der Geest K, Burkett M, Fitzpatrick J, Stege M, Wheeler B (2019a) Climate-induced migration and the compact of free association (COFA): limitations and opportunities for the citizens of the Republic of the Marshall Islands. IOM policy brief series 1(5), International Organization for Migration, Majuro Available via https://static1.squarespace.com/static/596d5a162e69cf240a0f043b/t/5e3cfc7fb5004465df14d6c9/1581055113094/MICMP2019_COFAPolicyBrief.pdf
van der Geest K, Burkett M, Fitzpatrick J, Stege M, Wheeler B (2019b) Marshallese migration: the role of climate change and ecosystem services. University Of Hawai'i At Mānoa, Honolulu Available via https://static1.squarespace.com/static/596d5a162e69cf240a0f043b/t/5f467533693e5f6ebae88c1c/1598453060819/marshall-islands-case-study-report-web-v5_compressed.pdf
van der Geest K, Burkett M, Fitzpatrick J, Stege M, Wheeler B (2019c) Marshallese perspectives on migration in the context of climate change. University Of Hawai'i At Mānoa, Honolulu Available via https://static1.squarespace.com/static/596d5a162e69cf240a0f043b/t/5e31192b4c3c06486ad9b6f6/1580276022123/MICMP2019_MarshallesePerspectives.pdf
van der Geest K, Burkett M, Fitzpatrick J, Stege M, Wheeler B (2020) Climate change, ecosystem services and migration in the Marshall Islands: are they related? Clim Chang 161(1):109–127. https://doi.org/10.1007/s10584-019-02648-7
Wase-Jacklick F (2021) Personal communication, Majuro
Watts N, Amann M, Ayeb-Karlsson S, Belesova K, Bouley T, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Chambers J, Cox PM, Daly M, Dasandi N, Davies M, Depledge M, Depoux A, Dominguez-Salas P, Drummond P, Ekins P, Flahault A et al (2018) The lancet countdown on health and climate change: from 25 years of inaction to a global transformation for public health. Lancet 391:581–630. https://doi.org/10.1016/S0140-6736(17)32464-9
Weber E (2015) The Pacific solution – a catastrophe for the Pacific!? Environ. Ecol Res 3:96–107. https://doi.org/10.13189/eer.2015.030404
Woodward A, Hales S, Weinstein P (1998) Climate change and human health in the Asia Pacific region: who will be most vulnerable. Clim Res 11:31–38. https://doi.org/10.3354/cr011031
Yamada S, Burkett M, Maskarinec GG (2017) Sea-level rise and the Marshallese diaspora. Environ Justice 10(4):93–97. https://doi.org/10.1089/env.2016.0038
World Health Organization [WHO] (2015) Human health and climate change in Pacific Island countries. World Health Organization Regional Office for the Western Pacific, Suva
Yamada S, Pobutsky A, Krupitsky D (2009) Micronesian migrant health issues in Hawaii: part 1: background, home island data, and clinical evidence. Calif. J Health Promot 7:16–31. https://doi.org/10.32398/cjhp.v7i2.2012

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