NIDEA

National Institute of Demographic and Economic Analysis

NIDEA WORKING PAPERS

No 4 July 2013

The Demographic Implications of Climate Change for Aotearoa New Zealand: A Review

Michael P. Cameron

National Institute of Demographic and Economic Analysis
Te Rūnanga Tātari Tatauranga
THE UNIVERSITY OF WAIKATO

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

NIDEA Working Papers are intended as a forum for the publication of selected papers on research produced within the Institute, for discussion and comment among the research community and policy analysts prior to more formal refereeing and publication.

The National Institute of Demographic and Economic Analysis (NIDEA) links together a virtual and evolving community of national and international researchers whose research focus is the interaction of demographic, social and economic processes. Initially founded through collaboration between the University of Waikato's Population Studies Centre, Waikato Management School, and Wellington-based Motu Economic and Public Policy Research Trust, the Institute's primary goal is to help inform choices and responses to the demographic, social and economic interactions that are shaping New Zealand's future. Reflecting this objective, NIDEA's research programme comprises five interconnected themes, and is supported and sustained by a strong capacity-building programme.

Disclaimer

The demographic implications of climate change for Aotearoa New Zealand: A review

Michael P. Cameron [a,b]

[a] Department of Economics, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand; email: mcam@waikato.ac.nz

[b] National Institute of Demographic and Economic Analysis, University of Waikato

Te Rūnanga Tātari Tatauranga | National Institute of Demographic and Economic Analysis

Te Whare Wānanga o Waikato | The University of Waikato

Private Bag 3105 | Hamilton 3240 | Waikato, New Zealand

Email: tahuk@waikato.ac.nz | visit us at: www.waikato.ac.nz/nidea/

ISSN 2230-441X (Print)

ISSN 2230-4428 (Online)

Referencing information:

Cameron, M.P. (2013). *The demographic implications of climate change for Aotearoa New Zealand: A review, NIDEA Working Papers No. 5*, University of Waikato, National Institute of Demographic and Economic Analysis

Acknowledgements: This research was funded by the Ministry of Business, Innovation and Employment as part of the Climate Change Impacts and Implications project (Contract C01X1225), led by Andrew Tait (NIWA) and Daniel Rutledge (Landcare Research). The author is grateful to Paul O'Neil for his research assistance in the initial stages of this review, and to Gemma Piercy and attendees at the New Zealand Climate Change Conference in Palmerston North in June 2013 for comments on earlier drafts of the paper.

Table of Contents

Abstract

Despite near universal recognition of the importance of climate change impacts on future generations, to date there has been no dedicated research on the effects of climate change on the population distribution in Aotearoa New Zealand. This paper reports on a review of international literature on the demographic impacts of climate change, with a particular focus on the likely implications for New Zealand. The paper argues that the greatest impacts are likely to be felt in terms of internal migration changes, with smaller but still significant effects on international migration and mortality rates.

Introduction

"*We are facing a global climate crisis. It is deepening. We are entering a period of consequences*" (Al Gore, speech at National Sierra Club Convention, September 9, 2005).

Advocates raising awareness on global climate change almost universally warn of dire consequences for future generations should action not begin now to mitigate the effects of global climate change (see for example Stern, 2007; Garnaut, 2011). However, climate change and its population impacts are not a new phenomenon. Climate has affected human population growth and distribution since prehistoric times (Diamond, 1997). The key difference is that current patterns of global climate change, i.e. those occurring since the industrial revolution, are different from those observed in the past, and are generally accepted as caused by human activity (Hegerl et al., 2007). For instance, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) notes that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007, p.30). The capacity of the earth to deal with such sudden anthropogenic climate change has been questioned (Rockström et al., 2009).

The consequences of global climate change are substantial, and will severely constrain human activity. Agricultural productivity is expected to decline on average (Mendelsohn and Dinar, 2009), leading to increasing global food insecurity (Schmidhuber and Tubeillo, 2007; Hanjra and Qureshi, 2010). Freshwater availability will decline, particularly in glacier- or snowmelt-fed river basins (Kundzewicz et al, 2007; Alcamo et al,. 2007; Hanjra and Qureshi, 2010). Desertification and frequency of drought are expected to increase (Burke et al., 2006; Lioubimtseva and Adams, 2004). At the other extreme, increasing rainfall intensity will lead to more frequent and widespread flood events (Nicholls et al., 2007; Pall et al., 2011), while sea level rise will inundate low lying coastal areas, and increase coastal erosion and salinisation of groundwater (Kundzewicz et al, 2007).

Inevitably, these changes will make some areas less suitable for human habitation, while other areas become relatively more suitable, with consequent impacts on demographic change. However, despite the obvious implications for human systems, to date there has been no dedicated research on the effects of climate change on the population distribution in Aotearoa New Zealand. In 2012, the Ministry of Business, Innovation and Employment (MBIE) contracted NIWA and Landcare Research to undertake a wide-ranging assessment of the impacts of climate change on New Zealand (Rutledge and Tait, 2013). As part of that project, a climate-calibrated regional demographic model of New Zealand is under development. The model will specifically address the lack of quantitative evidence on the demographic impacts of climate change in New Zealand. This paper reports on a review of the international literature on the demographic impacts of climate change, undertaken as part of that research project, with a particular focus on the likely implications for New Zealand. The paper begins by briefly reviewing the expected effects of climate change on Aotearoa New Zealand, and how climate affects population processes, before looking in turn at possible impacts on fertility, mortality, and migration (internal and international) for Aotearoa New Zealand.

Climate change in Aotearoa New Zealand

Mullan et al. (2008) identified and mapped the likely future effects of climate change across Aotearoa New Zealand. Their results were based on General Circulation Model simulations prepared for the IPCC Fourth Assessment (Meehl et al., 2007). Specifically, the results from twelve global climate models were statistically downscaled (Mullan et al., 2001) to provide local spatial detail for New Zealand, along with initial analyses from NIWA's regional climate models. The results demonstrate that New Zealand temperatures on average are expected to increase by about 1°C by 2040, and by about 2°C by 2090. However, these average changes mask significant differences in temperature change at the local level. The greatest increases in average summer temperature are expected to occur in the North Island (and in particular in the central and west of the North Island), while the greatest increases in average winter temperature are expected to occur in the central South Island (Mullan et al., 2008).

The models demonstrate a marked increase in the seasonality of rainfall and wind patterns, with increased westerlies in winter and spring, but decreased frequency of westerlies in summer and autumn. Rainfall is expected to increase during winter and spring in the west of both the North and the South Islands, with lower rainfall in the east and north. Conversely, in summer and autumn, there is expected to be drier conditions in the west of the North Island and rainfall increases in the east (Mullan et al., 2008). They also projected increases in the incidence of extreme weather including high temperatures, extreme rainfall, and strong winds, but decreases in frost incidence and snow cover.

Climate change and population processes

The changes in local climate outlined in the previous section, as well as the wider changes in global climate, are expected to impact the demographic future for Aotearoa New Zealand. If we want to understand the impacts of climate change on the size and distribution of the future population, we need to recognise the effects climate change will have on population processes. In the simplest sense, the future population relies on three key factors, each of which interacts to determine future population: (1) fertility rates; (2) mortality rates; and (3) net migration (international and internal). Thus, to understand the impact of climate change on future population, we must first understand its likely impact on each of these three factors.

However, before we consider directly the potential impacts of climate change on the factors that determine future population, we must first consider two broader issues. First, climate change is an ongoing and long run process, which leads to an identification problem. For instance, when considering population data it might not be possible to empirically separate the proportion of changes in fertility, mortality, or migration that occurs as a result of changing climate, from changes resulting from other long-run processes such as demographic fertility transitions (particularly in developing countries), increases in life expectancy due to improved infant and youth health or life extension at older ages, or migration due to economic or other factors. Thus, while it may be intuitively appealing to attempt to empirically determine the incremental contribution of climate change to future demographic change, there is likely to be a significant amount of statistical error associated with any such estimates based on past data. These errors will then transfer into projections of demographic parameters that are based on past data and used to project future population.

A second, and related, issue is that of uncertainty more generally. Population projections are known to be subject to a great deal of uncertainty (Lutz and Goldstein, 2007), particularly at smaller geographical scales (Cameron and Poot, 2011; Wilson, 2013). Added to this, models of climate change are also subject to a great deal of uncertainty. This uncertainty arises because of uncertainty about future greenhouse gas emissions, the extent and intensity of mitigation efforts, and the impact of new technologies, as well as uncertainty about the effects of emissions on future climate (so-called climate sensitivity) (Visser et al, 2000; Stainforth et al., 2005). Uncertainty about future population will therefore combine uncertainty from both demographic and climate change sources.

While these two issues (identification and uncertainty) might give pause for concern about developing population projections, I argue that neither issue is particularly problematic for demographers. In terms of the identification issue, traditional modelling of future fertility, mortality, and migration based on past trends might be sufficient to account for most of the climate-related variation in the near future, since it is likely that climate change is impacting on population change already. Longer-term projections can use projections of demographic parameters that are calibrated to climatic conditions, particularly for sub-national projections. The second issue is also not problematic. The uncertainty in climate projections can be modelled and explicitly described. Thus this uncertainty can be incorporated into population projections in the same way as demographic uncertainty is – by using probabilistic or stochastic projection techniques (Tuljapurkar, 1992; Cameron and Poot, 2011).

Fertility and mortality

The international literature reveals little about changes in fertility as a result of climate change. While global fertility clearly has large implications for future population growth and therefore flow-on effects on carbon emissions and climate change, there is to date no evidence of effects of climate change on the total fertility rate. Philibert et al. (2013) found that climate change influenced conception/birth seasonality in the Kayes region of Mali through changes in rainfall affecting rates of foetal loss (following patterns of change in malaria incidence among pregnant women) and changes in agricultural cycles that affect energy balance and sexual behaviour. In a developed country like New Zealand, where food security for the majority of the population is not associated with agricultural cycles, it seems unlikely that fertility will be affected through these mechanisms. Thus, we can be fairly sure that fertility rates will not be directly affected by climate change. However, if international migration changes the ethnic mix of the population (see below), in-migration of ethnic groups of traditionally higher (or lower) fertility than the current population on average may cause indirect changes in age-specific fertility rates.

There are a number of mechanisms through which climate change will affect mortality globally, including cardiovascular and respiratory problems associated with extreme heat (Kalkstein and Greene, 1997), altered transmission of (particularly tropical) infectious diseases (Semenza and Menne, 2009; de Souza et al., 2012), and malnutrition associated with changes in agricultural cycles and food insecurity (Battisti and Naylor, 2009).

Heat-related mortality has been shown to follow a J-curve (McMichael et al., 1996), with temperatures at both extremes (hot and cold) are associated with increased morbidity and mortality (Curriero et al., 2002), but with mortality at its highest at high temperatures. The European summer of 2003 provides a recent example that demonstrates the potent effect of extreme heat, as temperatures were approximately 3.5°C higher than average. The extreme heat resulted in as many as 70,000 heat-related deaths (Robine et al., 2008). Notwithstanding the large absolute number of deaths associated with the heatwave, the crude excess mortality was less than 1.6 deaths per 10,000 population, compared with an underlying crude death rate of about 99 per 10,000 population in 2002 (Eurostat, 2005). This equates to an increase in death rates of about 2 percent. As noted earlier in this paper, the average temperature in New Zealand is expected to rise by about 2°C by 2090. It is likely that there will be many years in the future where the increase in temperature above the current average will be similar or greater in magnitude to that of the European heatwave in 2003, and so modestly increased mortality rates are likely in those years. However, there also is evidence to suggest that the positive relationship between heat and mortality is declining over time due to adaptation through the use of technology such as air conditioning (Barreca et al., 2012). Thus, we can probably expect a small increase in heat-related deaths to be associated with climate change in New Zealand (see also

Woodward et al., 2001), but the effect on the overall mortality rate is likely to be small. However, age-specific mortality rates will be differentially affected, with heat-related deaths likely to be concentrated among older New Zealanders, particularly older women (Stafoggia et al., 2006), but even these effects may be small.

Increased temperatures and rainfall (particularly in spring and summer) are associated with increased reproduction and survival rates of protozoa, bacteria, viruses, and their associated vectors such as mosquitos (Gubler et al., 2001). The incidence of vector-borne diseases, such as malaria (Parham and Michael, 2010), dengue fever (Hopp and Foley, 2003), and Ross River virus (Woodruff et al., 2003), have been shown to be related to changes in climate. These diseases are likely to further spread and increase in incidence through the Pacific due to climate change (Potter, 2008). Furthermore, there is evidence to suggest that food-borne infectious diseases such as salmonellosis (Kovats et al., 2004) and campylobacteriosis (Kovats et al., 2005) are related to temperature, and thus incidence of these diseases may also alter with changes in climate. New Zealand is projected to get both hotter and wetter in parts, increasing the suitability of the climate for vector-borne and other infectious diseases (Woodward et al., 2001). For instance, the Foundation for Research, Science and Technology-funded Health Analysis and Information for Action (HAIFA) project found that under the IPCC's A2 high emissions scenario for 2090, campylobacteriosis would increase by a maximum annual average percentage change of 23%, and seasonal influenza (with vaccination) would decrease by 27% (Baker et al., 2013). Despite relatively large increases in rates of incidence of infectious diseases, actual mortality from these diseases is likely to remain low (see for example Harley et al. (2001) on Ross River Virus). Thus, the impact on mortality rates in New Zealand from climate-induced increases in infectious diseases is also likely to be low, despite the potential for significant increases in morbidity.

Finally, as noted previously climate change is likely to affect agricultural productivity, and in aggregate global agricultural output is expected to fall. While New Zealand is currently a large net exporter of agricultural products, and this is expected not to change under even the most extreme climate scenarios (Tait et al., 2008), reductions in availability of food and growing global population are likely to significantly raise the price of food. The combination of rising food prices and decreasing food availability are likely to lead to food insecurity and malnutrition among the poorest in society. However, these factors will also likely lead to reductions in food waste (Godfray et al., 2010). The extent of future food insecurity in New Zealand is difficult to determine, but the implications for mortality rates in New Zealand are likely to be small as the number of deaths in New Zealand attributable to malnutrition is currently negligible,[1] and projections for the global burden of malnutrition due to climate change show no significant impact on developed countries at all (Campbell-Lendrum et al., 2003).

[1] To the extent that statistics on deaths attributed to ICD-10 codes E40-46 (malnutrition) are not reported by the Ministry of Health.

Migration (international and internal)

One of the most widely cited estimates of global climate-induced migration is the 200 million environmental refugees claimed by Myers (2002). Myers' paper itself provides little in the way of empirical support for this claim, and uses an extremely broad definition of environmental refugees, being "people who could no longer gain a secure livelihood in their homelands because of drought, soil erosion, desertification, deforestation and other environmental problems, together with the associated problems of population pressures and profound poverty" (Myers, 2002, 609). Leaving aside for a moment the problems associated with use of the term 'refugee', this definition draws no distinction between internally displaced people and those that migrate internationally, and neither does it distinguish between those who are permanently displaced and those that are temporarily displaced due to extreme weather events such as hurricanes or floods. However, a similar estimate on climate refugee numbers was recently obtained by Biermann and Boas (2010). Both estimates appear to be largely based on estimates of the population exposed to risk, rather than considering the number of people who would actually migrate (Kniveton et al., 2008). Myers' estimates in particular have been widely criticised (see for example Castles, 2002; Kolmannskog, 2008) and debated in the media and elsewhere, but the fact that they are often accepted at face value (see for example Stern, 2007; Brown, 2008) simply represents a lack of alternative systematic research into the number of climate-induced migrants. This demonstrates the importance of further quantitative research on the migration implications of climate change.

Gemenne (2011) reviewed the available estimates of people displaced by environmental change, and noted in particular a number of problems with Myers' estimates, including: (1) they are a stock, rather than a flow; (2) they do not distinguish between different types of environmental changes as migration drivers and assume that all people displaced in an area affected by environmental changes have been displaced solely because of these changes; and (3) they combine estimates from many other studies, which employ widely varying methods. Gemenne (2011, S48) concluded that existing estimates of people displaced by environmental change "lack robust methodological foundations, and are generally grounded in a deterministic perspective, assuming that all people impacted by environmental changes will move away from their homes." However, these methodological problems are being addressed in more recent quantitative evaluations (for example see Marchiori et al., 2012).

The debate outlined above raises a number of important issues, which must be considered before we can interpret the international literature and its implications for New Zealand. First, there is no commonly accepted definition for a climate-induced migrant, with terms such as 'environmental refugees', 'environmentally displaced people', and 'climate migrants', often used interchangeably. The identification of the excess migration that arises due to climate change is complicated by the multi-causal, complex nature of migration, wherein climate change is only one of many drivers of migration

(Black et al., 2011; Barnett and Chamberlain, 2010). Piguet (2010, 517) even goes as far as to claim that: "there is truly no such thing as a climate or environmental migrant in the narrow sense of a migrant exclusively moving for environmental reasons". Despite this assertion, it is likely that climate change will affect the migration decision-making process for a large number of people, both now and in the future, and climate change must therefore be taken into consideration when estimating future migration flows.

The issue of defining who is and who is not a climate-induced migrant is further complicated by the likelihood that climate change will affect existing drivers of migration, such as by changing agricultural profitability and employment opportunities in rural areas (Government Office for Science, 2011). Furthermore, while climate change might make individuals want to migrate, their ability to migrate may be constrained by legal, political, or economic reasons (Goldin, 2011). This means that the number of actual climate-induced migrants is likely to be significantly smaller than the number of potential climate-induced migrants, i.e. not all people affected by climate change will migrate and thus estimates of climate-induced migration based on exposure to climate change will significantly overstate the true degree of migration.

Second, most of the migration flows induced by climate change are likely to be internal (i.e. within national boundaries) rather than international. There are a number of reasons to support this. Currently, most of the world's migrants are internal rather than international – according to the International Organization for Migration (IOM) there were 214 million international migrants, compared with 740 million internal migrants in 2010 (IOM, 2011). It is unlikely that there will be a major re-balancing towards international migration in the future. Furthermore, the greatest impacts of climate change on human populations are likely to be felt in the world's poorest countries (Schneider et al., 2007; World Bank, 2010). In these countries, much of the population is unlikely to have the financial means to migrate internationally, and so international migration flows are likely to be small.

Obviously different factors affect climate change-induced international migration from the factors that affect internal migration. International migrants generally need greater financial means because of the larger distances involved, and typically require an established social network in the destination country in order to effectively settle (Carrington et al., 1996; Zhao, 2003). Furthermore, the direction and size of migration flows will likely be determined by prior migration ties between the sending and receiving countries (Adamo and de Sherbinin, 2011). In the New Zealand context, climate-induced international migrants are most likely to originate from low-lying Pacific atolls that are at risk of inundation by sea level rise, more frequent droughts, and tropical cyclones of greater frequency and intensity (Mimura et al., 2007), or similarly affected areas in the major river deltas of South and Southeast Asia such as Bangladesh and Vietnam (Cruz et al., 2007; Ericson et al., 2006).

For Pacific countries, New Zealand is an obvious destination choice due to its proximity and the dense social networks of expatriate Pacific Islanders, particularly in urban centres. However, it is unlikely that all affected Pacific Islanders would migrate to New Zealand. There are similar advantages to re-settlement in Australia, which also boasts large Pasifika communities, and Fiji has offered to re-settle affected Pacific populations (Bedford and Bedford, 2010). Furthermore, it is likely that climate-induced migration will first be accommodated within the islands, in the form of rural-urban migration, rather than international relocation (Campbell et al., 2005; Campbell, 2010). However, the capacity of the islands to accommodate increases in internal migration, particularly to urban centres, has been called into question (Locke, 2009; Hunt, 1996).

Currently, permanent and long term migration arrivals into New Zealand from Oceania (excluding Australia) make up about five percent of the total arrivals.[2] A substantial incremental increase in arrivals from the Pacific would be required in order to significantly affect the future population of Aotearoa New Zealand. However, this substantial increase may be possible because to date, most migration to New Zealand has been from smaller Pacific countries such as Samoa and Tonga while the migration flows from populous Melanesian countries such as Papua New Guinea have been much smaller. However, as the impacts of climate change are increasingly felt in these more populous countries, migration flows can be expected to increase (Moore and Smith, 1995). Thus, the numbers of international migrants from the Pacific to New Zealand in the future is likely to grow as a result of climate change, and may increase as a proportion of total in-migration if migration from Papua New Guinea (in particular) increases.

For non-Pacific-Island countries, distance and the associated cost of travel ensure that only relatively wealthy migrants will have the resources necessary to migrate to New Zealand. This includes large numbers of potentially environmentally displaced people in Asia. Despite the rhetoric that labels climate-induced migrants as 'environmental refugees' (e.g. see Myers, 2002), climate change is not recognised as one of the factors that defines a refugee under international agreements such as the United Nations Convention Relating to the Status of Refugees 1951 (United Nations High Commissioner for Refugees (UNHCR), 2008). Thus, New Zealand is not obliged under these agreements to accept 'environmental refugees' (Burson, 2010). Furthermore, New Zealand currently restricts the conditions under which potential migrants may gain residency (Burson, 2010). Thus without a lowering of the threshold for residency, the impacts of climate change outside of the Pacific Islands are unlikely to induce substantial additional migration flows into New Zealand.

Climate-induced international migration is likely to also affect other demographic characteristics of the New Zealand population. The countries most likely to contribute in-migrants to New Zealand as a result of climate change currently have both higher total fertility rates and higher mortality rates than

[2] Based on Statistics New Zealand permanent and long-term migration data, there were 87,778 permanent and long term arrivals in the year ended May 2013. Of these, 4207 (4.8%) originated from Oceania (excluding Australia). Similarly, arrivals from Oceania (excluding Australia) totalled 4309 of 83,789 (5.1%) in the year ended May 2012, and 4299 of 83,781 (5.1%) in the year ended May 2011.

New Zealand. These fertility and mortality differences between migrants and the current population have flow-on implications for the future New Zealand population. For example, it takes time for migrants to assimilate and adopt similar fertility patterns to the local population (Ford, 1990).

Internal migration is not affected by the legal barriers noted above, and is much less costly for potential migrants. The effects of climate change differ substantially between the North and South Islands, as noted earlier in this paper. Differences in small-area climate have been shown in international studies to affect internal migration flows (Barrios et al., 2006; Barbieri et al., 2010). For example, Poston et al. (2009) demonstrated that temperature, humidity, but not wind were related to inter-state migration rates in the United States between 1995 and 2000, and concluded that climate acts more as a pull factor than a push factor for migration. Thus, in addition to present long-term trends in population movement from the South Island to the North Island and from rural areas to urban centres, we can expect to see small but significant climate-induced internal migration effects as changes in local climate affect the relative attractiveness of the different regions.

As well as international and internal migration, at the small area level there is likely to be a redistribution of population away from vulnerable coastal and flood plain areas. According to McGranahan et al. (2007), about 13 percent of the population in New Zealand and Australia currently resides in vulnerable low elevation coastal zones. However, it seems likely that most of the population at risk of sea level rise will either adapt in situ, or migrate within the local area. Thus the impact of these changes is unlikely to be dramatic except at the localised level in coastal and low-lying areas.

Summary and future research directions

Climate change is likely to have profound impacts, both globally and locally in Aotearoa New Zealand. However, to date there has been no systematic evaluation of the likely impacts of climate change on demographic change in New Zealand. The review presented in this paper demonstrates that climate change is unlikely to greatly affect fertility rates, and will likely have a small but significant effect on mortality rates. The effect on international migration will largely depend on future government policy with respect to in-migration, but regardless migration from the Pacific will likely increase, both in absolute terms and as a proportion of total migration. Changes in the pattern of internal migration are also likely, as climate change will differentially affect the various regions in New Zealand.

As noted in the introduction, this paper marks the beginning of a four-year MBIE-funded project investigating the impacts and implications of climate change for New Zealand. As part of that project, a climate-calibrated regional demographic model is currently under development. The model is based on a standard cohort-component method, with parameters that are calibrated to account for past and future changes in climate variables, including both average and extreme climate variables (e.g. average daily temperature, and the number of days where temperature exceeds certain values). The relationship between all-cause mortality by region and climate variables is being investigated in order to better incorporate climate-related changes in mortality rates. Gravity models incorporating climate variables at both the inter-regional level (for internal migration) and international level (for international migration) are under development. The inclusion of climate-calibrated parameters in the demographic model addresses the identification issues noted earlier in this paper. The model can also be extended to a stochastic model, following Cameron and Poot (2011), to incorporate both climate and demographic uncertainty. The final model will be integrated into a coupled human-environmental systems model to determine the future impacts and implications of climate change for Aotearoa New Zealand (Rutledge and Tait, 2013).

Acknowledgments

This research was funded by the Ministry of Business, Innovation and Employment as part of the *Climate Change Impacts and Implications* project (Contract C01X1225), led by Andrew Tait (NIWA) and Daniel Rutledge (Landcare Research). The author is grateful to Paul O'Neil for his research assistance in the initial stages of this review, and to Gemma Piercy and attendees at the New Zealand Climate Change Conference in Palmerston North in June 2013 for comments on earlier drafts of the paper.

References

Adamo, S.B., and de Sherbinin, A. (2011). The impact of climate change on the spatial distribution of the population and on migration. In: United Nations Population Division, *Population distribution, urbanization, internal migration and development: An international perspective.* New York: United Nations.

Alcamo, J., Florke, M., and Märker, M. (2007). Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Sciences Journal* 52 (2), 247–275.

Baker, V., Winstanley, A., and Slaney, D. (2013). *Information and adaptation planning tools for climate change and human health impacts: To what extent can tools negotiate interlocking individual and institutional barriers?* Paper presented at the New Zealand Climate Change Conference, Palmerston North, 4-5 June.

Barbieri, A.F., Domingues, E., Queiroz, B.L., Ruiz, R.M., Rigotti, J.I., Carvalho, J.A.M., and Resende, M.F. (2010). Climate change and population migration in Brazil's Northeast: scenarios for 2025–2050. *Population and Environment* 31(5), 344-370.

Barnett, J., and Chamberlain, N. (2010). Migration as climate change adaptation: Implications for the Pacific. In: Burson, B. (Ed.), *Climate change and migration – South Pacific perspectives.* Wellington: Institute of Policy Studies.

Barreca, A.I., Clay, K., Deschenes, O., Greenstone, M., and Shapiro, J.S. (2012). Adapting to climate change: the remarkable decline in the U.S. temperature mortality relationship over the 20th century, *MIT Working Paper 12-29*. Cambridge, Ma.: MIT.

Barrios, S., Bertinelli, L., and Strobl, E. (2006). Climatic change and rural–urban migration: The case of sub-Saharan Africa. *Journal of Urban Economics* 60(3), 357-371.

Battisti, D.S., and Naylor, R.L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323(5911), 240-244.

Bedford, R., and Bedford, C. (2010). International migration and climate change: A post-Copenhagen perspective on options for Kiribati and Tuvalu. In: Burson, B. (Ed.), *Climate change and migration – South Pacific perspectives.* Wellington: Institute of Policy Studies.

Biermann, F., and Boas, I. (2010). Preparing for a warmer world: Towards a global governance system to protect climate refugees. *Global Environmental Politics* 10(1), 60-88.

Black, R., Bennett, R.G., Thomas, S., and Beddington, J.R. (2011). Climate change: Migration as adaptation. *Nature* 478(7370), 447-449.

Brown, O. (2008). Migration and Climate Change, *Migration Research Series No. 31*. Geneva: International Organization for Migration.

Burke, E.J., Brown, S.J., and Christidis, N. (2006). Modelling the recent evolution of global drought and projections for the 21st century with the Hadley Centre climate model. *Journal of Hydrometeorology* 7(5), 1113-1125.

Burson, B. (2010). Protecting the rights of people displaced by climate change: Global issues and regional perspectives. In: Burson, B. (Ed.), *Climate change and migration – South Pacific perspectives.* Wellington: Institute of Policy Studies.

Cameron, M.P., and Poot, J. (2011). Lessons from stochastic small-area population projections: The case of Waikato subregions in New Zealand, *Journal of Population Research* 28(2-3), 245-265.

Campbell, J. (2010). Climate change and population movement in Pacific Island countries. In: Burson, B. (Ed.), *Climate change and migration – South Pacific perspectives.* Wellington: Institute of Policy Studies.

Campbell, J., Goldsmith, M., and Koshy, K. (2005). *Community relocation as an option for adaptation to the effects of climate change and climate variability in Pacific Island Countries (PICs)*. Hamilton: Department of Geography, Tourism and Environmental Planning, University of Waikato.

Campbell-Lendrum, D.H., Corvalan, C.F., and Pruss-Ustun, A. (2003). How much disease could climate change cause? In: McMichael, A.J., Campbell-Lendrum, D.H., Corvalan, C.F., Ebi, K.L., Githeko, A.K., and Scheraga, J.S. (Eds.), *Climate change and health: Risks and responses.* Geneva: World Health Organization.

Carrington, W.J., Detragiache, E., and Vishwanath, T. (1996). Migration with endogenous moving costs, *American Economic Review* 86(4), 909-930.

Castles, S. (2002). Environmental change and forced migration: Making sense of the debate. *New Issues in Refugee Research No. 70*. Geneva: United Nations High Commissioner for Refugees.

Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., and Huu Ninh, N. (2007). Asia. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Curriero, F.C., Heiner, K., Zeger, S., Samet, J.M., and Patz, J.A. (2002). Temperature and mortality in 11 cities of the eastern United States. *American Journal of Epidemiology* 155(1), 80-87.

de Souza, D.K., Owusu, P.N., and Wilson, M.D. (2012). Impact of Climate Change on the Geographic Scope of Diseases. In Chhetri, N. (Ed.), *Human and social dimensions of climate change*. Rijeka, Croatia: InTech.

Diamond, J. (1997). *Guns, germs and steel – The fates of human societies*. New York: Norton.

Ericson, J.P., Vörösmarty, C.J., Dingman, S.L., Ward, L.G., and Meybeck, M. (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. *Global and Planetary Change* 50(1-2), 63-82.

Eurostat. (2005). *Health in Europe – 2005 edition*. Luxembourg: European Commission.

Ford, K. (1990). Duration of residence in the United States and the fertility of U.S. immigrants. *International Migration Review* 24(1), 34-68.

Garnaut, R. (2011). *The Garnaut review 2011: Australia in the global response to climate change*. Cambridge: Cambridge University Press.

Gemenne, F. (2011). Why the numbers don't add up: A review of estimates and predictions of people displaced by environmental changes. *Global Environmental Change* 21(Supplement 1), S41-S49.

Godfray, H.C.J., Beddington J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., and Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science* 327(5967), 812-818.

Goldin, I. (2011). *DR3: The future of global migration and the impact of environmental change*. London: Government Office for Science.

Government Office for Science. (2011). *Foresight: Migration and global environmental change final project report*. London: Government Office for Science.

Gubler, D.J, Reiter, P., Ebi, K.L., Yap, W., Nasci, R., and Patz, J.A. (2001). Climate variability and change in the United States: Potential impacts on vector- and rodent-borne diseases. *Environmental Health Perspectives* 109(Supplement 2), 223-233.

Hanjra, M.A., and Qureshi, M.E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy* 35(5), 365–377.

Harley, D., Sleigh, A., and Ritchie, S. (2001). Ross River Virus transmission, infection, and disease: A cross-disciplinary review. *Clinical Microbiology Reviews* 14(4), 909-932.

Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Marengo Orsini, J.A., Nicholls, N., Penner, J.E., and Stott, P.A. (2007). Understanding and Attributing Climate Change. In: Solomon, S., D.

Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.), *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Hopp, M.J., and Foley, J.A. (2003). Worldwide fluctuations in dengue fever cases related to climate variability. *Climate Research* 25, 85-94.

Hunt, C. (1996). Property rights and environmental management on Pacific atolls. *International Journal of Social Economics* 23(4-6), 221-234.

Intergovernmental Panel on Climate Change [IPCC]. (2007). *Climate change 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

International Organization for Migration [IOM]. (2011). *World migration report 2011*. Geneva: IOM.

Kalkstein, L.S., and Greene, J.S. (1997). An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environmental Health Perspectives* 105(1), 84-93.

Kniveton, D., Schmidt-Verkerk, K., Smith, C., and Black, R. (2008). Climate change and migration: Improving methodologies to estimate flows, *Migration Research Series No. 33*. Geneva: International Organization for Migration.

Kolmannskog, V.O. (2008). *Future floods of refugees. A comment on climate change, conflict and rorced migration*. Oslo: Norwegian Refugee Council.

Kovats, R.S, Edwards, S.J., Hajat, S., Armstrong, B.G., Ebi, K.L., Menne, B., and The Collaborating Group. (2004). The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. *Epidemiology and Infection* 132(3), 443-453.

Kovats, R.S, Edwards, S.J., Charron, D., Cowden, J., D'Souza, R.M., Ebi, K.L., Gauci, C., Gerner-Smidt, P., Hajat, S., Hales, S., Hernandez Pezzi, G., Kriz, B., Kutsar, K., McKeown, P., Mellou, K., Menne, B., O'Brien, S., van Pelt, W., and Schmid, H. (2005). Climate variability and campylobacter infection: An international study. *International Journal of Biometeorology* 49(4), 207-214.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z., and Shiklomanov, I.A. (2007). Freshwater resources and their management. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report* *of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Lioubimtseva, E., and Adams, J.M. (2004). Possible implications of increased carbon dioxide levels and climate change for desert ecosystems. *Environmental Management* 33(1), S388-S404.

Locke, J.T. (2009). Climate change-induced migration in the Pacific Region: Sudden crisis and long-term developments. *Geographical Journal* 175(3), 171-180.

Lutz, W., and Goldstein, J.R. (2007). Introduction: How to Deal with Uncertainty in Population Forecasting? *International Statistical Review* 72(1), 1-4.

Marchiori, L., Maystadt, J., and Schumacher, I. (2012). The impact of weather anomalies on migration in Sub-Saharan Africa. *Journal of Environmental Economics and Management* 63(3), 355-374.

McGranahan, G., Balk, D., and Anderson, B. (2007). The rising tide: Assessing the risks of climate change and human settlements in low elevation coastal zones, *Environment and Urbanization* 19(1), 17–37.

McMichael, A.J., Haines, A., Slooff, R., and Kovats, S. (Eds). (1996). *Climate change and human health*. Geneva: World Health Organization.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., and Zhao, Z.C. (2007). Global climate projections. In Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Eds.), *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Mendelsohn, R., and Dinar, A (2009). *Climate change and agriculture: An economic analysis of global impacts, adaptation and distributional effects*. Cheltenham: Edward Elgar.

Mimura, N., Nurse, L., McLean, R.F., Agard, J., Briguglio, L., Lefale, P., Payet, R., and Sem, G. (2007). Small islands. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Moore, E.J., and Smith, J.M. (1995). Climate change and migration from Oceania: Implications for Australia, New Zealand and the United States. *Population and Environment* 17(2), 105-122.

Mullan, B., Wratt, D., Dean, S., Hollis, M., Allan, S., Williams, T., and Kenny, G. (2008). *Climate change effects and impacts assessment: A guidance manual for local government in New Zealand, 2nd*

Edition. Wellington: Ministry for the Environment.

Mullan, A.B., Wratt, D.S., and Renwick, J.A. (2001). Transient model scenarios of climate changes for New Zealand. *Weather and Climate* 21, 3-34.

Myers, N. (2002). Environmental refugees: a growing phenomenon of the 21stcentury. *Philosophical Transactions of the Royal Society B: Biological Sciences* 357(1420), 609-613.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S., and Woodroffe, C.D. (2007). Coastal systems and low-lying areas. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D., and Allen, M.R. (2009). Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature* 470(7334), 382-385.

Parham, P.E., and Michael, E. (2010). Modeling the effects of weather and climate change on malaria transmission. *Environmental Health Perspectives* 118(5), 620-626.

Philibert, A., Tourigny, C., Coulibaly, A., and Fournier, P. (2013). Birth seasonality as a response to a changing rural environment (Kayes region, Mali), *Journal of Biosocial Science* 45(4), 547-565.

Piguet, E. (2010). Linking climate change, environmental degradation, and migration: A methodological overview. *Wiley Interdisciplinary Reviews: Climate Change* 1(4), 517-524.

Poston, D.L., Zhang, L., Gotcher, D.J., and Gu, Y. (2009). The effect of climate on migration: United States, 1995–2000. *Social Science Research* 38(3), 743-753.

Potter, S. (2008). *The sting of climate change: Malaria and dengue fever in maritime Southeast Asia and the Pacific Islands*. Sydney: Lowy Institute for International Policy.

Robine, J., Cheung, S.L.K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J., and Herrmann, F.R. (2008). Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies* 331(2), 171–178.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J.A. (2009). A safe operating space for humanity. *Nature* 461(7263), 472-475.

Rutledge, D., and Tait, A. (2013). *Climate change impacts and implications for New Zealand to 2100: A new 4-year MBIE funded project*. Paper presented at the New Zealand Climate Change Conference, Palmerston North, 4-5 June.

Schmidhuber, J., and Tubiello, F.N. (2007) Global food security under climate change. *Proceedings of the National Academy of Sciences* 104(50), 19703-19708.

Schneider, S.H., Semenov, S., Patwardhan, A., Burton, I., Magadza, C.H.D., Oppenheimer, M., Pittock, A.B., Rahman, A., Smith, J.B., Suarez, A., and Yamin, F. (2007). Assessing key vulnerabilities and the risk from climate change. In Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E. (Eds.). *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Semenza, J.C., and Menne, B. (2009). Climate change and infectious diseases in Europe. *Lancet Infectious Diseases* 9, 365-375.

Stafoggia, M., Forastiere, F., Agostini, D., Biggeri, A., Bisanti, L., Cadum, E., Caranci, N., de'Donato, F., De Lisio, S., De Maria, M., Michelozzi, P., Miglio, R., Pandolfi, P., Picciotto, S., Rognoni, M., Russo, A., Scarnato, C., and Perucci, C.A. (2006). Vulnerability to heat-related mortality: a multicity, population-based, case-crossover analysis. *Epidemiology* 17(3), 315-323.

Stainforth, D.A., Aina, T., Christensen, C., Collins, M., Faull, N., Frame, D.J., Kettleborough, J.A., Knight, S., Martin, A., Murphy, J.M., Piani, C., Sexton, D., Smith, L.A., Spicer, R.A., Thorpe, A.J., and Allen, M.R. (2005). Uncertainty in predictions of the climate response to rising levels of greenhouse gases. *Nature* 433(7024), 403-406.

Stern, N. (2007). *The economics of climate change – The Stern review*. Cambridge: Cambridge University Press.

Tait, A., Baisden, T., Wratt, D., Mullan, B., and Stroombergen, A. (2008). An initial assessment of the potential effects of climate change on New Zealand agriculture. *New Zealand Science Review* 65(3), 50-56.

Tuljapurkar, S. (1992). Stochastic population forecasts and their uses, *International Journal of Forecasting* 8(3), 385-391.

United Nations High Commissioner for Refugees [UNHCR]. (2008). *Climate change, natural disasters and human displacement: A UNHCR perspective*. Geneva: UNHCR.

Visser, H., Folkert, R.J.M., Hoekstra, J., and de Wolff, J.J. (2000). Identifying key sources of uncertainty in climate change projections, *Climatic Change* 45(3-4), 421-457.

Wilson, T. (2013). Quantifying the uncertainty of regional demographic forecasts, *Applied Geography* 42, 108-115.

Woodruff, R., Guest, C., Garner, G., Becker, N., and Lindsay, M.F. (2003). Weather and climate as early warning system indicators for epidemics of Ross River virus: a case study in south-west western Australia. *Epidemiology* 14(5), S94.

Woodward, A., Hales, S., and de Wet, N. (2001). *Climate change: Potential effects on human health in New Zealand*. Wellington: Ministry for the Environment.

World Bank. (2010). *World development report 2010: Development and climate change*. Washington, DC: World Bank.

Zhao, Y. (2003). The role of migrant networks in labor migration: The case of china, *Contemporary Economic Policy* 21(4), 500-511.