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**Number: 62**      **Rapid Integrated Assessment of Climate Change-  
Induced Disease Burdens under Uncertainty**

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# **RAPID INTEGRATED ASSESSMENT OF CLIMATE CHANGE-INDUCED DISEASE BURDENS UNDER UNCERTAINTY**

Corinne Baulcomb, Dominic Moran

## **ABSTRACT**

*This paper contributes to research on projecting and valuing the impacts of climate change on human health by proposing and implementing a methodology that allows for rapid integrated assessment of climate change-induced disease burdens to be used in environments characterized by cumulating uncertainty relating to data gaps and the accuracy of downscaled projections. The approach is important because the countries most vulnerable to the early effects of climate change need to start laying the foundations for their adaptation policies now, regardless of the quality of their national health and environmental data sets.*

*The methodology consists of a series of specifically delineated, iterative steps that helps to identify hierarchy of variables driving the quantitative results. The method also helps to identify key data gaps, thereby providing an important focus for subsequent research, monitoring, and data collection efforts.*

*The paper demonstrates this methodology by applying it to the projection and valuation of the excess disease burden in Montserrat and Saint Lucia for two climate change scenarios. We illustrate their utility in the context of adaptation planning. This paper also highlights that investment in data collection and information systems is a “no regrets” action that should be considered integral to national and regional adaptation efforts, particularly in instances where current data do not facilitate the implementation of best practice health impact assessment methods.*

**KEY WORDS:** Climate Change Health Impacts, Integrated Assessment, Disease Projection, Uncertainty, Nonmarket Valuation

## 1. INTRODUCTION

Climate change has the potential to affect disease and mortality incidence both directly and indirectly across a wide range of conditions the world over.<sup>1</sup> Disease incidence and mortality have significant economic and social relevance, and it is important to model, project, and value these health impacts.

Doing so can inform national and regional assessments of the overall impact of climate change, and by extension the investment needs for future adaptations..

A growing number of publications provide some guidance as to the more robust methods currently available for use in assessing the health impacts of climate change (Ebi, 2008a, 2008b; Ebi et al., 2008; Ebi et al., 2006; Kovats et al., 2003; Kuhn et al., 2005; McMichael et al., 2004; Murray et al., 2003; Sussman et al., 2008; Sutherst, 2004; WHO, 2003).

However, much of this guidance assumes good data availability and sufficient local research capacity to integrate information across different disciplines. Typically however in many countries that are most vulnerable to the impacts of climate change this is not the case. Funding for new, primary studies can be limited, and research efforts are unable to escape very significant levels of uncertainty. In this type of scenario, the methods discussed in these publications are difficult, if not impossible to use.

Accordingly, a simplified series of iterative steps is needed to help these countries lay the policy and administrative foundations for future adaptation efforts.

The purpose of this paper is to present one such methodology for integrated assessment efforts focused on projecting and valuing the health impacts of climate change. We apply the methodology in two small island states: Saint Lucia and Montserrat. The paper is structured as follows. We first present background on the two case study islands, and subsequent sections outline our methodology, results, discussion, and conclusions.

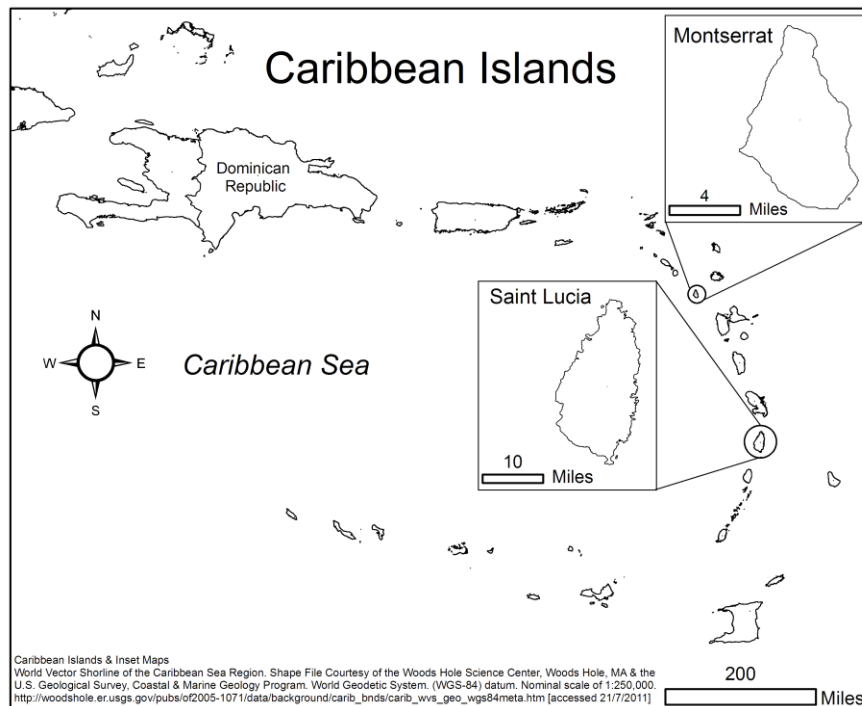
## 2. SITE BACKGROUND

Located in the Lesser Antilles (figure 1), St Lucia and Montserrat are ideal countries to use as case study sites for the following three reasons: 1) they are actively formulating climate change adaptation plans; 2) as small island developing states they are also extremely vulnerable to the impacts of climate change across a range of sectors; 3) the available disease incidence and mortality data for both these countries is of insufficient quantity and quality for the best practice analyses advocated by the WHO (see for example: Kovats et al., 2003; Kuhn et al., 2005; McMichael et al., 2004; WHO, 2003).

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<sup>1</sup> For a short overview of the pathways through which climate change can impact on vector-borne diseases, water and food-borne diseases, cardiovascular and respiratory diseases, and meningococcal meningitis, see supplementary information

Figure 1: Map of the Caribbean with Montserrat and Saint Lucia highlighted



Their vulnerability in terms of health impacts stems primarily from the fact that despite successful vector eradication efforts in the 1950s and early 1960s (Rawlins et al., 2008), and relatively good vaccine coverage (PAHO, 2010a, b) Saint Lucia and Montserrat, like many other Caribbean islands, experience a “dual” disease burden characterized by the presence of both environmentally-sensitive disease vectors and human populations with low birth rates, long life expectancies, and high rates of cardio-respiratory diseases (DCPP, 2006; PAHO, 2007a, b). Furthermore, although they are considered middle-income countries, both countries suffer from a shortage of trained staff within their respective health systems, and rely heavily on international support of their health care sectors (PAHO, 2010a, b), all of which may limit resilience of their health sectors to the effects of climate change.

### 3. METHODOLOGY

Suggested best practice approaches to projecting and valuing disease burdens are typically time and data intensive. Some of the important components of best practice analyses for integrated assessment include:

- Engaging with a range of national and international stakeholders
- Utilizing the combined expertise of a wide range of researchers and decision-makers
- Analyzing country-specific adaptive capacity
- Deriving time series-based, context-specific, and if possible spatially explicit epidemiological relationships between exposure and health responses that are age, sex, and location-specific
- Accounting for intra-population differences in terms of sensitivity and exposure to health risks.
- Controlling for the effects of population and socio-economic development in those study sites where these variables are deemed independent of climate change
- Analyzing site-specific data on the financial and social costs of diseases
- Conducting primary studies to value changes in the risk of disease contraction and death across a range of fatal and nonfatal conditions in the context of climate change adaptation.

These analyses require such substantial amounts of time and data, however, that despite their obvious desirability, they become unrealistic given the data availability in many locations around the world. Thus, a systematic and pragmatic approach is needed for those instances where best practice methods prove infeasible to implement.

Table 1 (and Annex Table 1), detail the methodological steps involved in developing an integrated assessment of health impacts in such a scenario, and illustrate how they were carried out for two case study sites. These steps are divided into stages relating to preliminary assumptions, baseline projections, climate change scenario projections and endpoint valuation. The preliminary assumptions relate to the choice of time periods for the study, global warming scenarios, target populations data and selected health endpoints. The baseline details relate the calculation of baseline or business as usual morbidity and mortality rates, which are then recalculated for comparison under the selected warming scenarios. The endpoint valuation stage details the approach to assign monetary values to cases of morbidity and mortality under the baseline and counterfactual warming scenarios. This stage also details the discounting assumptions required for reporting present values.

This application was undertaken as part of a regional UN initiative to derive a consistent cross-sector picture of warming impacts and adaptation priorities. Certain assumptions – e.g. on time periods, warming scenarios and discount rates were thus pre-specified.

Table 1: Details of the methodology and its implementation in this study. This table shows the general steps proposed, how they were implemented in this study, as well as generic formulas that link the steps together. For additional details on the equation variables, see the appendix.

Step Group	General Step	Implementation in This Study	Generic Formula
Preliminary	1. Define the baseline time period	1960-1990: Selected by ECLAC	
	2. Define the projection time period	2010-2050: Chosen to cover a medium-long term period	
	3. Pick the climate emission scenarios that will be utilized	SRES A2 & B2: Selected by ECLAC	
	4. Collect disease incidence and mortality data. Include data on the health impacts of environmentally-sensitive extreme events (droughts, floods, fires, cyclones, and other storms)  *Note: Some data may have to be inferred from other data	Montserrat: 1980-2009, Extreme Events 1960-2009 Saint Lucia: 1980-2009, Extreme Events 1960-2009  *Note: - Some mortality data was inferred from data showing zero incidence, or from regional mortality data apportioned by population - Gastroenteritis >5 baseline data was inferred using the ratio of <5 to >5 incidence data during the 1994-2000 period for Montserrat and the 1993-1999 period for Saint Lucia	
	5. Select diseases for inclusion in the study based on data from step 4 and broader climate change health literature	Malaria, Dengue Fever, Gastroenteritis, Schistosomiasis, Leptospirosis, Ciguatera Poisoning, Meningococcal Meningitis, Cardiovascular/Respiratory diseases	
	6. Collect climate model data for projection time period (step 2). Calculate the annual modeled climate anomaly time series.	Selected and Provided by ECLAC: ECHAM4 downscaled climate temperature and precipitation model	Projected Annual Data–Mean Baseline Data
	7. Search the literature for dose-response/exposure-response relationships connecting the step 6 climate variables to the step 5 diseases.	1. Consulted the following: (Ebi, 2008a; Ebi et al., 2008; Ebi et al., 2006; Kovats et al., 2003; Kuhn et al., 2005; McMichael et al., 2004; Murray et al., 2003; Sussman et al., 2008; Sutherst, 2004; WHO, 2003)  2. Conducted ISI Web of Knowledge and Ovid Medline searches for peer-reviewed, English-languages articles and reviews using the following search parameters:  "Ciguatera AND Sea Surface Temperature," "Ciguatera AND Caribbean," "Ciguatera AND Climate," "Cardiovascular Morbidity AND Climate," "Cardiovascular Mortality AND Climate," "Heat-related Morbidity AND Climate," "Temperature Morbidity AND Climate," "Heat-Related Mortality AND Climate," "Leptospirosis AND Temperature," "Leptospirosis AND Precipitation," "Leptospirosis AND Climate," "Respiratory Morbidity AND Climate," "Respiratory Mortality AND Climate" "Neisseria meningitidis AND Climate," "N. meningitidis AND Climate," "Meningococcal AND Climate," "Meningitis AND Climate," "Schistosomiasis AND Prediction," "Schistosomiasis AND Climate," "Gastroenteritis AND Forecast," "Gastroenteritis AND Climate," "Diarrh* AND Climate," "Dengue AND Climate," "Malaria AND Climate,"	

	8. Identify population projections for the scenarios from step 3	A2: Best match is UN Constant Fertility Variant (2008) B2: Best match is UN Medium Variant (2008)  *Note: Both were linearly interpolated between UN 5 year estimates	
Baseline/ Reference Projection	9. Collect census data covering the baseline-present period.	Montserrat & Saint Lucia: Total population: 1960-2010 Saint Lucia <5's: 1980-2010	
	10. Calculate the average baseline mortality and incidence rates for each of the step 5 diseases using the step 9 and step 4 data. Repeat for relevant extreme event data.	Calculated: $\overline{BIR}_x = \left( \frac{\sum BI_x}{\sum BPop_x} \right)$ $\overline{BMR}_x = \left( \frac{\sum BM_x}{\sum BPop_x} \right)$  *Note: - Baseline data summed over the 1980-1990 period (For extreme events, 1960-1990) - Only used years in the baseline interval where both health and population data existed - For Saint Lucia, 3 incidence rates were calculated for gastroenteritis: all, <5s, >5s -	For each step 5 disease, and any extreme event data, over the relevant baseline period, calculate:  $\Sigma \text{Step 4} / \Sigma \text{Step 9}$
	11. Calculate the yearly reference population projections for the step 2 time period using regressions on the step 9 data.  *Note: For countries that have a markedly changed population growth pattern, perform regressions on the recent trends	Regression Time period utilized: Montserrat & Saint Lucia: Total population: 2001-2010 Saint Lucia: >5's: 2006-2010 <5's: (Total pop) – (>5 pop) for each year 2010-2050	
Baseline/ Reference Projection	12. Project the reference incidence and mortality burden for each step 5 condition using steps 10 and 11 for each year in the step 2.	Calculated: $RIB_{st} = (\overline{BIR}_x) * (RPop_{st})$ $RMB_{st} = (\overline{BMR}_x) * (RPop_{st})$	For each step 2 year, and each step 5 disease, calculate:  Step 10*Step 11
Climate Change Scenario Projection	13. Create a time series of modified annual incidence and mortality rates covering the step 2 projection period and using the step 10 baselines rates for each step 3 scenario according to the step 7 dose-response relationships and the step 6 climate anomaly data.	Calculated: $PIR_{yxt} = (\overline{BIR}_x) * C$ $PMR_{yxt} = (\overline{BMR}_x) * C$	For each step 2 year, each step 3 scenario, and each disease with a step 7 dose-response relationship, calculate:  Step 10*(1+(Step 7*Step 6))
	14. Project the incidence and mortality disease burden for each step 3 scenario using the step 13 rates and the step 8 population projections.	Calculated: $PIB_{yxt} = (PIR_{yxt}) * (SPop_{yxt})$ $PMB_{yxt} = (PMR_{yxt}) * (SPop_{yxt})$	For each step 2 year, each step 3 scenario, and each disease with a step 7 dose-response relationship, calculate:  Step 13*Step 8
	15. Estimate the disease burden for diseases for which no dose-response relationship was found. Use the step 10 incidences and mortality rates and the step 3 population projections.  * Note: This will capture only the effect of population changes	Calculated: $EIB_{yxt} = (\overline{BIR}_x) * (SPop_{yxt})$ $EMB_{yxt} = (\overline{BMR}_x) * (SPop_{yxt})$	For each step 2 year, each step 3 scenario, and each step 5 disease without a dose-response function, calculate:  Step 10*Step 7
	16. Calculate the annual incidence and mortality anomalies for each step 3 scenario by subtracting the step 12 reference projections from the step 14/15 projections.	Calculated: $PIA_{yxt} = PIB_{yxt} - RIB_{st} \quad EIA_{yxt} = EIB_{yxt} - RIB_{st}$ $PMA_{yxt} = PMB_{yxt} - RMB_{st} \quad EMA_{yxt} = EMB_{yxt} - RMB_{st}$	For each step 2 year, each step 3 scenario, and each step 5 disease, calculate:  Step 14 - Step 12 & Step 15 - Step 12



Valuation	17. Based on the baseline data, pick valuation units.	A willingness-to-pay & benefits transfer-based value of statistical life (VSL) burden was used as the data was insufficient for disability adjusted life years (DALYs) derivation.	
	18. Collect recent PPP-adjusted GDP per capita data	Montserrat: US\$3,400 (2002) Saint Lucia: US\$10,900 (2009) (CIA World Factbook, 2010c)	
	19. Search for studies containing VSLs derived from environmental and/or health-focused studies	Selected mean US Health VSL: see Appendix 2 (Lindhjem et al., 2010): VSL <sub>2005</sub> =4,808,000 PPP-adjusted US\$	
	20. Collect the PPP-adjusted GDP per capita data for the step 19 reference country to match the years identified in step 18.	2002: US\$37,600 2009: US\$46,000 (CIA World Factbook, 2010c)	
	21. Inflate or deflate the step 19 VSL using the step 19 reference country consumer price index (CPI) data to match the years of the step 18 GDP data.	Utilized online calculator: <a href="http://www.bls.gov/data/inflation_calculator.htm">http://www.bls.gov/data/inflation_calculator.htm</a> VSL <sub>2002</sub> =\$4,428,874.55 VSL <sub>2009</sub> =\$5,281,586.77	For each year identified in steps 18 and 19, and using the step 19 VSL value, calculate: $VSL_{Step\ 19} * (CPI_{Step\ 18} / CPI_{Step\ 19})$
	22. Scale the step 21 VSLs to the income of the study sites using the information in steps 18, 20 and 21	Calculated: $VSL_{M\ 2002} = \frac{\$3,400}{\$37,600} * \$4,428,874.55 = \$400,483.34$ $VSL_{SL\ 2009} = \frac{\$10,900}{\$46,000} * \$5,281,586.77 = \$1,251,506.43$	For each study site, calculate: $(Step\ 18/Step\ 20)*Step\ 21$
	23. If necessary, scale the step 22 VSLs to match the initial step 2 projection year using CPI data	Utilized online calculator: <a href="http://www.bls.gov/data/inflation_calculator.htm">http://www.bls.gov/data/inflation_calculator.htm</a> $VSL_{M\ 2010} = \$485,323.51$ $VSL_{SL\ 2010} = \$1,271,772.09$	For each step 22 VSL, calculate: $Step\ 22 * (CPI_{Step\ 2} / CPI_{Step\ 22})$
	24. Define an inflation effect for the step 23 VSLs, and project a VSL time series through the step 2 projection period	Calculated 2% annual inflation: $VSL_i = VSL_{2010} * (1.02)^i$ $i : 0 (2010) - 40 (2050)$	For each step 23 VSL, inflationary rate, and year n, calculate: $Step\ 23 * (1+r)^n$
	25. Calculate the VSL mortality anomaly for each year in the step 2 projection period, and for each of the step 5 diseases included in step 16, using the step 24 VSL time series.	Calculated: $PVSL_{(M)\ yst} = VSL_i * PMA_{yst}$ $EVSL_{(M)\ yst} = VSL_i * EMA_{yst}$	For each step 2 year, and each step 5 disease with projected mortality data, calculate: $Step\ 24 * Step\ 16$
Valuation	26. Find the relevant average life span information	Montserrat: 72.76 years Saint Lucia: 76.45 years (CIA World Factbook, 2010a, b)	

<p>27. For each step 5 disease for which incidence data was projected, look up the average duration of the disease. Use this information to approximate what fraction of the step 26 average life span this duration constitutes. (Note: This approach was utilized both because no WTP-based studies focusing on morbidity from with these diseases were found, and because the data was insufficient to support a cost of illness approach).</p>	<p><b>Life Fractions</b></p> <table border="1"> <thead> <tr> <th></th> <th>Montserrat</th> <th>Saint Lucia</th> </tr> </thead> <tbody> <tr> <td>Gastroenteritis</td> <td></td> <td></td> </tr> <tr> <td>- Overall Pop</td> <td>0.000188</td> <td>0.000179</td> </tr> <tr> <td>- &lt;5</td> <td>0.000113</td> <td>0.000108</td> </tr> <tr> <td>- &gt;5</td> <td>0.000264</td> <td>0.000179</td> </tr> <tr> <td>Leptospirosis</td> <td>0.003436</td> <td>0.003270</td> </tr> <tr> <td>Ciguatera Poisoning</td> <td>0.006872</td> <td>0.006540</td> </tr> <tr> <td>Malaria (1 year of illness)</td> <td>0.013743</td> <td>0.013080</td> </tr> <tr> <td>Dengue Fever</td> <td>0.000377</td> <td>0.000358</td> </tr> <tr> <td>Schistosomiasis</td> <td>0.068719</td> <td>0.065402</td> </tr> <tr> <td>Respiratory Diseases (influenza)</td> <td>0.000188</td> <td>0.000179</td> </tr> <tr> <td>Extreme Events (1 month)</td> <td>0.001145</td> <td>0.001090</td> </tr> </tbody> </table> <p>(CDC, 2010; Every Day Health, 2009a, b; Fleming, 2010; Galea et al., 2005; <i>InteliHealth</i>, 2008; NHS, 2005; Tol, 2008)</p> <p><b>*Note:</b> This requires assuming that the statistical life burden of these non-fatal conditions always scales linearly to the life fraction constituted by each condition</p>		Montserrat	Saint Lucia	Gastroenteritis			- Overall Pop	0.000188	0.000179	- <5	0.000113	0.000108	- >5	0.000264	0.000179	Leptospirosis	0.003436	0.003270	Ciguatera Poisoning	0.006872	0.006540	Malaria (1 year of illness)	0.013743	0.013080	Dengue Fever	0.000377	0.000358	Schistosomiasis	0.068719	0.065402	Respiratory Diseases (influenza)	0.000188	0.000179	Extreme Events (1 month)	0.001145	0.001090	<p>For each step 5 disease with projected incidence data, calculate:</p> <p style="text-align: center;">Duration/Step 26</p>
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<p>28. Project the step 16 incidence anomaly VSL fractions for each step 2 year using steps 27 and 24.</p>	<p>Calculated:</p> $PVSL_{(t)_{y_{21}}} = VSL_i * LF_a * PIA_{y_{21}}$ $EVSL_{(t)_{y_{21}}} = VSL_i * LF_a * EIA_{y_{21}}$	<p>For each step 2 year and each step 5 disease with incidence anomaly data, calculate:</p> <p style="text-align: center;">Step 24*Step 17*Step 16</p>																																				
<p>29. For each projection year, sum the VSL data (incidence and mortality) across all diseases to generate a cumulative VSL burden time series for each study site. Discount this cumulative time series if desired/required.</p>	<p>Calculated:</p> $VSL_{(Total)_{y_{21}}} = VSL_{(I)_{y_{21}}} + VSL_{(M)_{y_{21}}}$ $VSL_{(Cumulative\ Total)_{y_{21}}} = \sum_i VSL_{(Total)_{y_{21}}}$ $PV_{y_{21}} = \frac{\sum_0^i VSL_{(Cumulative\ Total)_{y_{21}}}}{(1+r)^i}$	<p>Across all diseases within each year, <i>i</i>, calculate:</p> <p style="text-align: center;"><math>A_i = \text{Step 28} + \text{Step 25}</math> <math>\text{Sum}(A_i)/(1+r)^i</math></p>																																				

The two primary data collation stages and the three primary, non-methodological results of this study are presented below.<sup>2</sup>

## 4. DATA

### 4.1 Compilation of Baseline Health Data

The baseline health data was compiled for Saint Lucia and Montserrat from a variety of sources (CAREC, 2002-2009, 2005, 2008; EM-DAT, 2010; Fenton, 2010; PAHO, 1998a, b, 2007a, b, 2010a, b; Saint Lucia, 1998, 1999, 2002, 2006). Based on the climate change health impacts literature, and this baseline data, the following conditions were selected for inclusion in this study: malaria, dengue fever, gastroenteritis, schistosomiasis, leptospirosis, ciguatera poisoning, meningococcal meningitis, as well as both cardiovascular diseases and respiratory diseases. The number of people affected and killed by extreme events and malnutrition were also considered.

Health data was available for the period 1980–2009, meaning that only 10 years of data existed within the baseline window of 1960–1980. The data covered a variety of conditions and causes of mortality, but were inconsistently stratified by gender or age. Furthermore, many of the available datasets for these conditions were incomplete across the baseline time period, and for the majority of these conditions, the direct mortality data was virtually non-existent. Consequently, most of the mortality data had to be inferred from a combination of sources. For years in which no incidence of a disease was recorded, it was inferred that no deaths resulted from that disease either. In the case of deaths from dengue fever, meningococcal meningitis, malnutrition, cardiovascular diseases, and respiratory diseases, the baseline mortality data was at least partly inferred using baseline population data and regional mortality rates (CAREC, 2005).

### 4.2 Dose-Response Relationship Identification

The search effort described in section 3 returned a wide variety of dose-response relationships from the literature. However, only four were deemed suitable for transfer to this study. They pertained to malaria morbidity and mortality (Tol, 2008), gastroenteritis morbidity (Lloyd et al., 2007; Singh et al., 2001), and joint cardio-respiratory mortality (Hashizume et al., 2009). With the exception of the Lloyd et al. (2007) dose-response relationship, all of these relationships relied exclusively on temperature changes to project changes in disease incidence.

## 5. RESULTS

### 5.1 Disease Burden Projections

The total excess disease and mortality burden as of 2050 for Saint Lucia and Montserrat in each climate change scenario is shown in Table 2. For Montserrat, the cumulative excess disease burden resulting from the climate change scenarios is relatively small, with no more than 500 extra cases of, or 100 extra deaths from, any of the diseases considered. For Saint Lucia, however, the excess disease burden projected appears to be substantially more serious with tens of thousands of extra cases of disease over the projection period, and thousands of extra deaths. It is worth reiterating, however, that these numbers depend on the assumptions made throughout the steps shown in section 3, and are burdened by the uncertainties inherent in the data.

### 5.2 Statistical Life Burden Projections

As is explained in section 3, this study projects the statistical life burden resulting from

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<sup>2</sup> For further details on the data collection, see the supplementary information

climate change, rather than the DALY burden because of the baseline health data. At its most basic, the concept behind valuing a statistical life is that individuals (and whole societies) can and do place a value (both implicitly and explicitly) on changes to the statistical risk of death (or in some cases illness/injury) experienced in day-to-day settings. This happens both because health risks affect individual and social welfare, and because individuals and societies have to make economic trade offs due to income constraints (Lindhjem et al., 2010; Marquez, 2006).

Consideration of this type of trade off in the context of environment- or policy-driven changes to future health risks (like climate change and adaptation) often requires that stated preference methods be used, or as in this study, benefits transfer of stated preference study outcomes. It is worth noting that the value of a statistical life (VSL) derived from these stated preference studies is defined as the *rate* at which people are willing and able to trade income for a reduction in a statistical mortality risk without a decrease in welfare (Lindhjem et al., 2010). This definition is key because it emphasizes that the VSL in a given context does not actually represent the monetized *worth* of a human being, but rather is a measure of the rate at which real human beings will trade finite income for marginal statistical risk reductions in particular contexts. This allows real (but non-market) human preferences to be quantitatively considered in decision-making frameworks rather than implicitly excluded.

Table 2: The projected total excess disease burden 2010-2050. Values <1 show 2 decimal places. Values >1 are rounded. Unless otherwise indicated, the units are number of cases (morbidity) or deaths (mortality).

2010-2050 Total Mean Disease Burden Anomaly	Montserrat				Saint Lucia			
	Morb. Anomaly		Mort. Anomaly		Morb. Anomaly		Mort. Anomaly	
	A2	B2	A2	B2	A2	B2	A2	B2
Malaria (Years of disability, deaths)	0.76	0.76	2	2	4	4	52	52
Dengue Fever	0	0	0	0	209	168	3	3
Gastroenteritis	<5				24,237	19,180		
	>5				5,193	4,517		
	Total Pop	484	427					
Schistosomiasis					50	40		
Leptospirosis	0.50	0.37	0	0	0	0	0	0
Ciguatera Poisoning	17	14			0	0	0	0
Meningococcal Meningitis	0	0	0	0			29	23
Cardio. Diseases								
Respiratory Disease	253	203	70	62	12,279	9,894	4,306	3,623
Malnutrition			2	2	54	44	182	146
Extreme Events (# affected, deaths)	511	410	0.47	0.37	30,594	24,652	30	24

The transfer of a VSL from one country to another, as was done in this study, requires adjusting for the differences in the income of the study and application sites (Czajkowski and Ščasný, (2010); Ready and Navrud, 2006; Stellin and Candido, 2006). When transferring a unit value for the VSL from one country to another, the VSL must be scaled by the ratio of the purchasing power parity (PPP)-adjusted per capita incomes of the application and original study site, as demonstrated in table 1. Although not without controversy, this is done in order to take account of the differences between the purchasing power of individual nations.

The outcome of applying the benefits transfer as described in table 1, including its

adaptation for valuing incidence of disease, is shown in table 3. Over the 2010–2050 period, the discounted, present value excess statistical life burden resulting from climate change ranges from \$25,172,780–\$46,590,303 for Montserrat and \$3,288,691,276–\$8,461,197,476 for Saint Lucia.

Table 3: The mean discounted, present value statistical life burden 2010-2050 in PPP-adjusted US\$. Each range includes the B2 values discounted at 4% and the A2 values discounted at 1%.

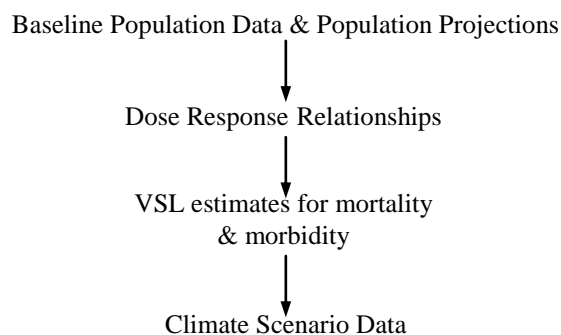
Mean Cumulative VSL Burden 2010-2050		Morbidity	Mortality	Total
Country	Range Type	B2 4% DR– A2 0.5% DR	B2 4% DR– A2 0.5% DR	B2 4% DR– A2 0.5% DR
Montserrat	Cumulative PV Range	300,182–464,724	24,872,598– 42,277,446	25,172,780– 42,742,170
	Mean Annual Range	7,322–11,335	606,649– 1,031,157	613,970– 1,042,492
	Mean Annual Range/Capita	1–2	91–153	92–154
Saint Lucia	Cumulative PV Range	29,259,230– 68,830,440	3,259,432,047– 7,411,196,574	3,288,691,276– 7,480,027,014
	Mean Annual Range	713,640– 1,678,791	78,498,343– 180,760,892	80,211,982– 182,439,683
	Mean Annual Range/Capita	4–8	396–874	400–882

## 6. DISCUSSION

### 6.1 The Hierarchy of Driving Variables

Completing the method described in section 3 revealed which of the variables had the largest impact on the quantitative outcomes described in sections 5.1 and 5.2. In order to reflect this, these variables have been organized into a hierarchy of decreasing impact (figure 2). Future efforts intending to refine the quantitative results presented can use this hierarchy to prioritize the use of research resources.

Figure 2: The hierarchy of variables uncovered using the method discussed in section 3



## 6.2 Variables Driving the Quantitative Results

Notwithstanding the cumulative uncertainties, the numerical results shown in tables 2 and 3 indicate that there is the potential for climate change to have a nontrivial impact on the health sectors of Montserrat and Saint Lucia. This is especially true considering that the statistical life burden represents only the value of the nonmarket costs of human life. When combined not only with the fact that the baseline health data is likely to have been under-reported, but also with the fact that only four dose-response relationships were utilized and that some diseases could not be projected at all, this supports the idea that the numerical results of this study may represent a lower bound figure on the economic costs that could be incurred in terms of human health as a result of climate change in the absence of adaptation efforts.

However, as the process of generating this valuation did involve significant amounts of uncertainty, the numerical results of this study should not be considered an end in and of themselves. They are preliminary and revisable results from one iteration of the method described in section 3. Instead, there are two outcomes worthy of discussion, the first of which is the hierarchy of variables shown in section 6.1 . This hierarchy is important in the context of rapid integrated assessments because refinement of the results requires addressing, first and foremost, the uncertainty in the variables that have the largest impact on the numerical output of the method.

Assuming that the health data utilized in this study constitutes essentially a complete set of the health data that has been recorded for Saint Lucia and Montserrat, the variable that had the most significant impact on both the pattern, and overall outcome of the results, is population (both in its baseline and projection forms). There are four reason for this:

- 1) As much of the baseline mortality data was nonexistent and had to be modeled using regionally defined mortality rates and local population, the baseline population data played a key role in the creation of the baseline health data set for several of the diseases considered in this study.
- 2) The baseline mortality and incidence rates, which are the cornerstones of the disease projections, are dependent on the baseline population data.
- 3) Because so few dose response relationships were found in the literature that could be transferred for use in this study, much of the disease projections under climate change are dependent entirely on the population projections, rather than on both population projections *and* the altered responses of the diseases to changes in climatic variables.<sup>3</sup>
- 4) Given a fixed disease incidence and mortality data set, the magnitude by which various population models/regressions can differ from each other over the 2010-2050 timeline typically exceeds that by which many projected climatic variables differ from each other across different scenarios or models. This means that the effects of changing the baseline population data used and/or the population projection models employed, can overpower the effects of changing the climate models used, particularly if the dose-response relationships available rely solely on annual temperature anomalies as a predictive variable.

As a consequence of this, future research efforts intending to increase confidence in the quantitative results of this study should focus firstly on refining the population data and

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<sup>3</sup> Population projections were not controlled for as there was insufficient evidence to demonstrate that future populations on Saint Lucia and Montserrat would truly be independent of climate change

projections utilized, rather than on other variables that can be overwhelmed by these decisions regarding population data and projections.

After sufficiently refining population, the next step suggested in the variable hierarchy is to focus on the weaknesses inherent in the set of dose response relationships utilized. Although the baseline health data set is too short for the derivation of dose response relationships specific to Saint Lucia and Montserrat, there is the potential that such relationships could be derived for neighboring islands that may have longer and more complete baseline data sets, or for the region as a whole. Neighboring islands would also be more socially, climatologically, and environmentally similar to Saint Lucia and Montserrat than the locations associated with the dose response relationships that were utilized in this study. This would likely be an improvement on the transfer of relationships from other parts of the world given the importance of local social variables in disease-environment relationships. This type of research may also allow for the generation of dose response relationships for a greater number of diseases and/or a greater number of environmental variables. In turn, this would allow for the overall excess disease burden figures to more fully include, and be dependent on, the projected temperature and precipitation changes associated with climate change, rather than solely on population projections associated with climate change.

Work focusing on the tertiary level in the variable hierarchy would, in this case, involve refining the VSL estimate utilized. For example, if made available, more recent PPP-adjusted GDP data could be utilized in the case of Montserrat. This would help make the VSL estimate used more relevant to Montserrat's current purchasing power parity. Similarly, at least some local, primary research should be conducted into the willingness that residents of these two islands have to trade income, in the context of climate change and adaptation, for reductions in the likelihood of contracting the specific fatal and nonfatal diseases included in this study. This would afford researchers the opportunity to more accurately represent both the residents' WTP for a statistical reduction in the likelihood of death, and their WTP for a statistical reduction in the likelihood of contracting a non-fatal condition in the context of climate change adaptation planning. Although this type of research could dramatically alter the results shown in tables 2 and 3, pursuing this prior to refining the population projections and the dose response relationships will do little to increase confidence in the overall valuation results, as these results will still be primarily driven by the population data and the availability of dose response relationships.

Further research could increase confidence in the overall results of this study by focusing on the downscaled climate models used to project temperature and precipitation anomalies from 2010 – 2050. The ECHAM4 model's downscaled and gridded anomaly data, which was provided for use in this study, does have some peculiarities, particularly with regards to the precipitation baseline and projection data generated. Changes in these projections, as well as the inclusion of additional climate variables or additional climatic events (such as short term heat waves in addition to annual mean temperature changes), would alter the disease projections, and might allow for additional health end points to be included in the study (such as ill health or death due to heat waves). However, this impact would remain small in terms of its ability to reduce overall uncertainty in the results in comparison to the previously mentioned variables that currently have a greater role in driving the results of the study.

### **6.3 The Value of Health and Environmental Information Systems**

The process of undertaking this study and implementing this method, and the sources of substantial uncertainty uncovered while doing so, have also highlighted key data gaps as well as the need for and value of health and environmental information systems in the

context of climate change adaptation efforts.

Health information systems are important for a variety of reasons, including that they allow for the storage and analysis *within* the health sector of a wide variety of data types, and that they greatly facilitate increased ease of access to health data. Equally importantly, however, they encourage and facilitate the consideration of health-related data by decision-makers focused on trade-offs *between* multiple sectors. This is critical to the success of adapting the health sector to climate change because, as Kovats et al. (2003) discuss, the ability to adapt in the health sector to climate change will depend on several things including: the availability of local resources; the maintenance of local infrastructure; the ability to spread and manage risk; public awareness; and political will. Essentially, the ability of Montserrat and Saint Lucia to successfully implement effective health sector adaptation plans will depend not just on the theoretical potential for health risks to be overcome, but also on the consideration afforded, and resources allocated to the health sector *relative* to the other sectors that are also threatened by climate change. The accessibility and usability of health data is therefore critical, and will to a large extent depend upon the creation and maintenance of health information systems as described in DCP (2007).

Environmental monitoring and information systems are also important in this context, however, because they can bridge the gaps between the limitations presented by the climate models and the decision-making that must occur in response to climate change. For example, in this study the downscaled climate data provided consisted only of temperature and precipitation anomalies. While temperature and precipitation each play a role in the life cycle and transmission scenarios of a great number of diseases, and while valuation efforts based on these models should contribute to adaptation planning, temperature and precipitation will not always be the best predicting variables for environmentally-sensitive diseases (Amarakoon et al., 2004; Fuller et al., 2009). Environmental monitoring and information systems can bypass this issue by focusing on monitoring whatever combination of variables does have the greatest predictive capacity for the locally relevant environmentally sensitive diseases, even if climate change models do not produce these variables as outputs, and even if doing so only allows for relatively short term disease predictions.

These systems are also useful in instances where the baseline health data is absent or shows zero incidence over the baseline period. In this study, as shown in table 2, several diseases (leptospirosis, ciguatera poisoning, meningococcal meningitis, and dengue fever) fell into these two categories, and were consequently projected to have a future impact of zero for each climate change scenario. However, due to the environmental suitability of both of these islands to these diseases, neither the absence of baseline data nor baseline data recording zero cases and/or deaths is sufficient justification for ignoring the potential for these diseases to contribute to the excess disease burden resulting from climate change. This point is especially important in a Caribbean context where frequent population movements throughout the region link multiple island nations together, each of which is susceptible to the re-establishment and escalation of the same set of environmentally sensitive diseases. A combination of regional and national environmental monitoring and information systems, operated in parallel to their regional and national health equivalents, could therefore help inform decision-making in the Caribbean when baseline national health data are unable to do so.

All of this taken together – that health and environmental monitoring and information systems are useful both within and out with the health sector, that they are relevant to climate change adaptation, and that they can facilitate decision-making and resource allocation across multiple time scales - makes investment in these monitoring systems a relatively no-



regrets strategy to pursue in the context of climate change adaptation planning. This is particularly true for countries like Montserrat and Saint Lucia that are especially vulnerable to the effects climate change and whose pre-1990 health data is limited in quantity and quality.

## 7. CONCLUSION

This paper presents an iterative methodology for projecting and valuing the excess disease burden due to climate change in research contexts where there is great uncertainty as a consequence of limited data availability, data quality, research time, and funding. The purpose of this method is to provide a series of specifically delineated steps such that the process of implementing these steps is both updateable and revisable, as well as revealing, despite the great uncertainty surrounding the quantitative results obtained.

The study utilized this method to produce the first valuation estimate for the non-market statistical life costs associated with the excess disease burden due to climate change Saint Lucia and Montserrat, as well as to highlight the key areas of data inadequacy. This study also identified the hierarchy variables driving the quantitative results, each of which can be the focus of future research efforts to improve the quality of the statistical life burden projections. The results of this study – namely quantitative statistical life valuations burdened by great uncertainty - also demonstrate the importance of investing in health and environmental information and monitoring systems as a risk-free, “no regrets” strategy within the larger process of designing and implementing climate change adaptation plans (see also: Hallegatte 2009).

The first round results of this method are intended to be utilized to inform specific future research efforts that in turn will iteratively update the initial quantitative results found in this paper, thereby allowing this information, despite significant starting uncertainty, to be ultimately useful in an international decision-making context.

## Appendix: Table 1 Equation Elaborations

Step (From Table 1)	Equation Number	Equation	Variable Explanations (Cumulative)
10	A.1  A.2	$\overline{BIR}_x = \left( \frac{\sum BI_x}{\sum BPop} \right)$ $\overline{BMR}_x = \left( \frac{\sum BM_x}{\sum BPop} \right)$	x: Disease (Step 5) BIR: Mean Baseline Incidence Rate BMR: Mean Baseline Mortality Rate BI: Annual Baseline Incidence BM: Annual Baseline Deaths BPop: Annual Baseline Population
12	A.3  A.4	$RIB_{xi} = (\overline{BIR}_x) * (RPop_i)$ $RMB_{xi} = (\overline{BMR}_x) * (RPop_i)$	i: Projection Year 0 (2010) → 40 (2050) RIB: Annual Reference Incidence Burden RMB: Annual Reference Mortality Burden RPop: Reference Population Projection
13	A.5  A.6	$PIR_{yxi} = (\overline{BIR}_x) * C$ $PMR_{yxi} = (\overline{BMR}_x) * C$	y: Relevant Climate Change Scenario PIR: Projected Incidence Rate PMR: Projected Mortality Rate C: Adjustment Factor For BIR & BMR, $C=1+(DR_{x+i}*CA_{y_i})$ DR: Dose-Response % Change CA: Climate Anomaly Data
14	A.7  A.8	$PIB_{yxi} = (PIR_{yxi}) * (SPop_{y_i})$ $PMB_{yxi} = (PMR_{yxi}) * (SPop_{y_i})$	PIB: Projected Annual Incidence Burden PMB: Projected Annual Mortality Burden SPop: Projected Annual Scenario Population
15	A.9  A.10	$EIB_{yxi} = (\overline{BIR}_x) * (SPop_{y_i})$ $EMB_{yxi} = (\overline{BMR}_x) * (SPop_{y_i})$	EIB: Estimated Annual Incidence Burden EMB: Estimated Annual Mortality Burden (i.e. no DR available)
16	A.11  A.12  A.13  A.14	$PIA_{yxi} = PIB_{yxi} - RIB_{xi}$ $PMA_{yxi} = PMB_{yxi} - RMB_{xi}$ $EIA_{yxi} = EIB_{yxi} - RIB_{xi}$ $EMA_{yxi} = EMB_{yxi} - RMB_{xi}$	PIA: Projected Annual Incidence Anomaly EIA: Estimated Annual Incidence Anomaly PMA: Projected Annual Mortality Anomaly EMA: Estimated Annual Mortality Anomaly
25	A.15  A.16	$PVSL_{(M)yxi} = VSL_i * PMA_{yxi}$ $EVSL_{(M)yxi} = VSL_i * EMA_{yxi}$	PVSL <sub>(M)</sub> : Projected Annual VSL Mortality Anomaly EVSL <sub>(M)</sub> : Estimated Annual VSL Mortality Anomaly
28	A.17  A.18	$PVSL_{(I)yxi} = VSL_i * LF_x * PIA_{yxi}$ $EVSL_{(I)yxi} = VSL_i * LF_x * EIA_{yxi}$	PVSL <sub>(I)</sub> : Projected Annual VSL Incidence Anomaly EVSL <sub>(I)</sub> : Estimated Annual VSL Incidence Anomaly LF: Approximated Life Fraction
29	A.19  A.20  A.21	$VSL_{(Total)yxi} = VSL_{(I)yxi} + VSL_{(M)yxi}$ <p style="text-align: center;">All x's</p> $VSL_{(Cumulative Total)y_i} = \sum VSL_{(Total)yxi}$ $PV_{yi} = \frac{\sum_0^i VSL_{(Cumulative Total)y_i}}{(1+r)^i}$	VSL <sub>(Total)</sub> : Total Incidence & Mortality VSL Burden For a Given Disease VSL <sub>(I)</sub> : Will either be PVSL <sub>(I)</sub> or EVSL <sub>(I)</sub> Depending on the Disease Data VSL <sub>(M)</sub> : Will either be PVSL <sub>(M)</sub> or EVSL <sub>(M)</sub> Depending on the Disease Data VSL <sub>(Cumulative Total)</sub> : The sum of each VSL <sub>(Total)</sub> in a given year PV <sub>yi</sub> : Discounted Present Value of the VSL <sub>(Cumulative Total)</sub> up to year <i>i</i> r: Discount Rate

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