STATE OF RHODE ISLAND AND PROVIDENCE PLANTATIONS
ENERGY FACILITY SITING BOARD

IN RE: Application of
Invenergy Thermal Development LLC's
Proposal for Clear River Energy Center

Docket No. SB 2015-06

PRE-FILED DIRECT TESTIMONY

OF

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Q. Please state your name and provide your office address.

A. My name is J. Timmons Roberts. My office address is 85 Waterman Street, Brown University, Providence, Rhode Island, 02912.

Q. Please state your position at Brown University.

A. I hold an endowed chair as the Ittleson Professor of Environmental Studies and Sociology.

Professional Background and Qualifications

Q. Do you have a curriculum vitæ?

A. Yes. I provide a current C.V. at Appendix A of this testimony.

Q. Please state any research and teaching areas in which you specialize that are relevant to this testimony.

A. Two of the research and teaching areas in which I specialize are climate change policy, and the relationship between climate change and development.

Q. Please tell us your educational background.

A. In 1983, I received a Bachelor of Arts degree in biology with Highest Honors from Kenyon College, and I was elected to Phi Beta Kappa. In 1989, I received a Masters degree in sociology from Johns Hopkins University. In 1992, a received a Ph.D. from Johns Hopkins.

Q. Have you held any other professional appointments that are relevant to your present testimony?

A. Yes. From 1999 to 2001, I was the Director of Environmental Studies at Tulane University in New Orleans, Louisiana. From 2001 to 2008, I was the Director of the Program in Environmental Science and Policy at the College of William and Mary, in Williamsburg,

Virginia. I was a James Martin 21st Century Professor at Oxford University in the United Kingdom during the 2006-2007 academic year. From 2009 to 2012, I was the Director of the Center for Environmental Studies at Brown University, in Providence, Rhode Island. During that same period, I was a full Professor of Environmental Studies and Sociology at Brown. I was named to the endowed chair of Ittleson Professor in 2009, and have held that chair continuously since then.

Since 2012, I have been a Non-Resident Senior Fellow at the Brookings Institution. The Brookings Institution is a nonprofit and non-partisan public policy organization based in Washington, D.C., the mission of which is to conduct high-quality, independent research and provide innovative, practical policy recommendations. Brookings is consistently ranked as the most influential, most quoted and most trusted think tank in the world. Part of my sabbatical in 2012 was funded by Brookings but since then I have not received any funding from or through the Brookings Institution.

I am also a Member of Climate Strategies. Climate Strategies is a not-for-profit, independent, scholarly organization based in London, England, that provides independent policy and economic research input on international climate policy. Climate Strategies works with an international network of experts to provide analysis for international decision-makers in the fields of climate change and energy policy. Climate Strategies is supported by entities including national governments, businesses and foundations. Membership in Climate Strategies is by invitation only, and is limited to scholars who have made significant contributions in fields of

climate change and energy policy. I have not received any funding myself from or through Climate Strategies.

Q. Are you the author or principal co-author of any scholarly books, published by peer-reviewed academic presses, on topics relevant to your present testimony?

A. Yes. I am one of three co-authors of *Power in a Warming World: The New Geopolitics of Climate Change*, published by MIT Press, Cambridge, Massachusetts, in 2015. I am one of two co-authors of *A Fragmented Continent: Latin America and the Politics of Climate Change*, which was also published by MIT Press, Cambridge, Massachusetts, in 2015. I am one of two co-authors of *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy*, published by MIT Press in 2007. Further information on my published books and monographs, including anthologies which I edited, dating back to 2000, appears in my C.V., on page 2.

Q. Are you the author or principal co-author of any book <u>chapters</u> of books published by peer-reviewed academic presses, on topics relevant to your present testimony?

A. Yes. In 2015, I was a co-author of two separate chapters in a book entitled *Climate Change and Society: Sociological Perspectives*, published by Oxford University Press. One of these two chapters was entitled "Adaptation to Climate Change." The other was "Climate Justice and Inequality." These two chapters were both invited and peer-reviewed.

Also in 2015, I was a co-author of a chapter in a book entitled *Research Handbook on Climate Governance*, published by Edward Elgar Publishing, a leading international academic

publishing house with offices in the United States and United Kingdon. The chapter that I was co-author of was entitled "Geopolitics." The chapter was invited, but not peer-reviewed.

In 2008, I was the author of a chapter entitled "Climate Change: Why the Old Approaches Aren't Working," which was an invited chapter in a book entitled *Twenty Lectures in Environmental Sociology*, published by Oxford University Press.

I am also the author of many other book chapters on topics pertaining to climate change and other topics, as reflected in my C.V., at pages 2 through 4.

Q. Are you the author or principal co-author of any peer-reviewed articles that have appeared in scholarly publications on topics relevant to your present testimony?

A. Yes, but these titles are too numerous to name here. My scholarly articles on topics directly related to my testimony here have been published in many peer-reviewed academic journals including the following: *Science; Nature: Climate Change; Climate Policy; Global Environmental Politics; Wiley Interdisciplinary Reviews –WIREs-Climate Change; Climate and Development; Philosophical Transactions of the Academy of the Royal Society; the Proceedings of the National Academies of Science (PNAS); Ecological Economics; Cambridge Review of International Affairs; and Society and Natural Resources.* The complete list of my 59 published articles in peer-reviewed academic and professional journals appears in my C.V., at pages 4 through 7.

An interested reader will also note that many (though by no means all) of the additional scores of articles, white papers, and policy briefings I have prepared and published in non-peer-

reviewed journals address topics related to my present testimony. These titles are on my C.V., on pages 7 through 9.

Q. Do you have other experience or qualifications relevant to this testimony?

A. Yes. I have led teams of students in a series of engaged climate policy research projects, at the local, state, national, and international levels. At the local and state levels, my students and I have reviewed and provided suggested updates and revisions to the Central Falls and the State of Rhode Island's Hazard Mitigation Plans, required by the Federal Emergency Management Agency for the receipt of disaster assistance. In both cases students under my guidance assisted by providing suggestions on how climate change impacts could be included in planning for future disasters, and avoiding costs. A student team has just presented results to the City of Providence on how to include "green infrastructure" to address flooding and heat island risks on the city's West End.

I have led students in my Climate and Development Lab in collaborative work with partners around the world to research and present policy reports on financing adaptation to climate change; some of these reports have been cited in the U.N. climate negotiations in Doha in 2013, and Paris, France, in December of 2015. I have co-authored many policy briefings, including ones that propose fair allocations of the remaining "global carbon budget" among the world's nations, and a fair sharing of the effort to reduce our impacts on the climate by reducing our emissions. That work was published by the Brookings Institution and the scientific journal *Nature Climate Change*. 2013 Grasso, Marco and J. Timmons Roberts. "A compromise to break

the climate impasse." *Nature: Climate Change*. Vol. 4:543-549. July. Published online 8 June. Doi:10.1038/nclimate2259

And I have worked with teams of students on researching climate impacts in Rhode Island, producing a report in 2010 entitled "Vulnerability to Climate Change in Rhode Island and its Options for Adaptation Action." That year, we worked with state Senators and Representatives to introduce the "Climate Risk Reduction Act of 2010," which created the Rhode Island Climate Change Commission. That 28-member commission, appointed by the Governor, Speaker of the House, and President of the Senate, functioned for several years, releasing a major report in November 2012. Later groups of students under my supervision worked with University of Rhode Island on an informational webpage on preparing for climate change in the state. Individual students have also conducted further work under my guidance.

Q. What was your role at the December 2015 United National Climate Change Conference (Conference of the Parties 21, or COP-21) in Paris, France?

A. As a central part of the work of my Climate and Development Lab, I have brought groups of Brown University students to the annual negotiations of the United Nations Framework Convention on Climate Change since 2010. The mission of the lab is to inform a more just and effective climate policy. Fifteen students traveled to Paris with me and conducted research on the process. They also provided research support to a number of organizations, including the Climate Vulnerable Forum (comprising three dozen of the world's most vulnerable nations), the Least Developed Countries group (the 48 poorest countries), the Small Island Developing States, the Union of Concerned Scientists, the World Wildlife Fund, and other national and civil society

organizations. We released the report described above on climate finance with a global network called AdaptationWatch, and my students and I published numerous blogs and op-ed articles about the negotiations.

Q. Are you familiar with the Resilient Rhode Island Act, which is a Rhode Island statute that is codified at Chapter 6.2 of Title 42 of the Rhode Island General Laws?

A. Yes, I am.

Q. Please tell us what your role was in the drafting of the bill that became the Resilient Rhode Island Act.

A. During 2014, I provided faculty guidance to four teams of student interns at Brown who did work on the bill that eventually became the Resilient Rhode Island Act. The first group researched and drafted the initial legislation, together with legislators and outside consultants. The second and third groups worked on edits and revisions to the bill, and developed proposed language. These groups were working at the time the bill was under consideration by the General Assembly. The version that passed the General Assembly, however, was developed by the Senate Policy Office with direction from the Senate leadership; this was an entirely new and different piece of legislation upon which we offered several suggested revisions, most of which were adopted. I am pleased to say that the bill passed unanimously in the state Senate, and the vote in in the House was nearly unanimous. The Governor signed it into law on August 1st, 2014. A fourth group of students, which I also supervised, assisted in putting the new statute into operation; this included providing information and assistance to state agencies to help them to understand how the law might be acted upon in the short and medium terms.

Q. Were you also involved in supporting the Act, including providing General Assembly testimony, on behalf of the Resilient Rhode Island Act?

A. Yes. I spoke as a citizen in favor of the bill that became the Resilient Rhode Island Act in testimony in the relevant committees in both the Senate and the House. In my testimony, I spoke about the value to the state in beginning planning for the impacts that are increasing with rising global temperatures, rising sea levels along Rhode Island's coast and in Narragansett Bay, and in preparing for increasingly strong storms, heat waves, and droughts. I also spoke about the benefits of reducing our greenhouse gas emissions, and the need to be part of the rapid reduction in the waste of energy and the switch to new renewable energy sources.

Q. On whose behalf are you testifying in this proceeding?

A. I am testifying on behalf of the Conservation Law Foundation (CLF).

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to consider the implications of Invenergy's proposal to build a new 900-megawatt (MW) fossil-fueled-fired combined-cycle electricity generating facility in Burrillville, Rhode Island in two specific contexts. The first of these two contexts is the just-mentioned Resilient Rhode Island Act, a statute enacted by the Rhode Island General Assembly in 2014 that sets out carbon-emission-reduction targets for the state. The second of the two contexts in which I consider the proposed Invenergy plant is the potentially devastating consequences that construction of this carbon-emitting plant could have on world climate, and national and world action on climate change. As I demonstrate in my testimony, I believe that these two contexts are related to each other.

In the application materials that Invenergy filed with this Energy Facility Siting Board (EFSB) on October 29, 2015, Invenergy refers to its proposed facility as the Clear River Energy Center, or "CREC." However, in my testimony, I refer to it as the "Invenergy Proposal" or the "Invenergy plant."

Q. Have you ever testified before the Rhode Island Public Utilities Commission or the Rhode Island EFSB before?

A. No, I have not.

Q. How is your testimony organized?

A. My testimony proceeds in two parts.

In the first part, I discuss the Invenergy Proposal in the context of the Resilient Rhode Island Act. Specifically, I show that if this plant is built and operates, it will be impossible for Rhode Island to meet the carbon-emission-reduction goals stated in the statute. In this section of my testimony, I also examine some of the specific claims or statements that Invenergy made in its application materials filed with the EFSB.

In the second part of my testimony, I discuss the implications of the Invenergy proposal in the broader context of climate change. In this discussion, I situate what happens here in Rhode Island in a national and global context.

A. Resilient Rhode Island Act

Q. Does the Resilient Rhode Island Act contain any carbon-emission-reduction goals?

A. Yes, it does. In fact, I believe that the carbon-emission-reduction goals contained in Section 2 of the statute are a key, central provision of the law. The reason I say that the carbon-

emission-reduction goals are such an important part of the law is that the Resilient Rhode Island Act is designed to address the problem of climate change, and carbon emissions from human activity are the most important factor contributing to climate change.

Q. What are the carbon-emission-reduction goals contained in the Resilient Rhode Island Act?

A. The carbon-emission-reduction goals in the Resilient Rhode Island Act appear in Section 2(a) of the law. The goals are to reduce Rhode Island's greenhouse gas emissions to 10% below 1990 levels by the year 2020; to reduce greenhouse gas emissions to 45% below 1990 levels by the year 2035; and to reduce greenhouse gas emissions to 80% below 1990 levels by 2050.

The explicit, repeated reference to "1990 levels" is significant, because carbon-emission levels today are significantly above 1990 levels. The State Energy Plan recently adopted suggests that these emissions may be over ten percent higher than in 1990, since Rhode Island is now producing more electricity for the New England electrical grid. Therefore, achieving the goals set forth in the law is a more ambitious challenge than it would be to achieve the same percentage reductions from today's levels.

Q. How were the carbon-emission-reduction goals in the Resilient Rhode Island Act arrived at?

A. Reduction of worldwide carbon emissions by 80% below 1990 levels by 2050 is widely seen by scientists as being absolutely necessary in order to avoid the worst effects of climate change. The most commonly cited report in this regard was the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), which stated that emissions from developed

nations need to drop by 80-95% below 1990 levels by 2050 for the rise in global mean temperatures to remain below two degrees Celsius. Staying below two degrees Celsius of warming was the level believed by scientists to be required in order to avoid the worst impacts of climate change, and to avoid tipping the global climate system into unpredictable destabilization. Recent research and the recent Paris negotiations suggest that much more dramatic carbon emissions reductions need to be made, so we can stay below 1.5 degrees of warming, which will still have devastating impacts on a number of regions, including coastal areas like Rhode Island and especially the poor low-lying and drought-prone areas of the world.

The interim goals for 2020 and 2035 were included in the Resilient Rhode Island Act as a recognition and acknowledgement of the fact that the profound societal and systemic economic changes that will be necessary to reduce carbon-emission levels by 80% by 2050 cannot and will not happen overnight. In order to reach our 2050 goal of an 80% reduction, it is absolutely essential to start making significant reductions now. That is why the Resilient Rhode Island Act calls for a 10% reduction below 1990 levels by 2020, and a 45% reduction below 1990 levels by 2035.

Q. So is it correct to say that these interim goals are a crucially important part of the Resilient Rhode Island Act?

A. Yes. These interim goals are a crucially important part of the statute for the reason I say above: profound change cannot and will not occur overnight. This approach – of setting short-, medium-, and long-term goals – is one that is widely used by climate scientists, political leaders, and others who are addressing the problem of climate change.

For example, this is the approach to climate change adopted by the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP). This is the non-partisan association that includes the governors of all six New England states as well as the Premiers of five eastern Canadian Provinces (New Brunswick, Newfoundland & Labrador, Nova Scotia, Prince Edward Island, and Quebec). In August 2001, the NEG/ECP adopted what it called a "Climate Change Action Plan." I provide a copy of that plan at Appendix B. That Action Plan (at page 7) called for greenhouse gas emission reductions of 75-85% as a long-term goal; it also called for a series of mid-term or interim reductions, including 10% by 2020, to be followed by additional, iterative goals in five-year increments. I should note that the 2001 Action Plan acknowledges (as I do in this testimony) that these goals may need to be modified from time to time "as the understanding of climate science advances." (Page 6.) The understanding of climate science has indeed advanced since 2001, and it suggests that temperatures are rising and impacts occurring more quickly than previously predicted. Therefore, more action is needed than was previously believed.

Since 2001, the NEG/ECP have renewed their commitment to reducing carbon emissions several times, and have clarified their interim targets. They did this most recently on August 31, 2015 at their meeting in St. John's, Newfoundland & Labrador. At that time, the NEG/ECP adopted an interim goal for 2030 of "at least 35% - 45% below 1990 levels."

Q. How ambitious are the carbon-emission-reduction goals contained in the Resilient Rhode Island Act?

A. The goals are ambitious, yet they are achievable, as shown in the new State Energy Plan. That Plan includes a scenario where emissions reductions on these levels are possible while maintaining affordable and reliable energy supply for Rhode Island.

However based on reviewing the scientific evidence I believe now that the targets in the Resilient Rhode Island Act were almost certainly not ambitious enough to meet the emerging consensus that we need to stay as close to 1.5 degrees Celsius of warming as possible, the level which was agreed to by the world's nations in Paris. The targets just agreed to in Paris aimed "to strengthen the global response to the threat of climate change…by…[h]olding the increase in the global average temperature to well below 2° C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5° C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." That is why it is absolutely crucial that we start working toward the goals immediately. The longer we wait the harder – and more expensive – it will be to achieve the ambitious goals in the law, goals which are more than required by the emerging science estimating climate impacts here and abroad.

In fact, even if we start immediately, meeting the carbon-emission-reduction goals in the law will be very challenging. The longer we wait, the harder it will be. The sooner we act, the more we can improve our economic efficiency and reduce the risk of volatile fossil fuel prices and the burden of outdated fossil fuel infrastructure. Acting sooner also creates many more jobs in Rhode Island, since fossil fuels are all imported to the state, while installing renewable energy infrastructure and doing the important work of reducing energy waste in the state will create thousands of jobs. In fact, they are already.

Q. Do you have an opinion about the effect that building a new 900-megawatt combined-cycle gas-fired electricity-generating plant in Rhode Island would have on the state's ability to achieve the carbon-emission-reduction goals set forth in the Resilient Rhode Island Act?

A. Yes.

Q. What is your opinion?

A. My opinion is very simple, and it can be stated in a single sentence: I believe that building a new 900-megawatt combined-cycle gas-fired electricity-generating plant in Rhode Island would make it impossible for the state to achieve the carbon-emission-reduction goals as set forth in the Resilient Rhode Island Act.

The Invenergy proposal calls for the plant to be up and running in mid-2019. [Invenergy Cover Letter to EFSB, 10/28/15, page 4.] As I explain below, this would make it impossible for Rhode Island to meet its 2020 goal of reducing carbon emissions by 10% below 1990 levels. The Invenergy Proposal does not say exactly how long Invenergy believes its proposed plant would be operational, but on page 123 Invenergy suggests a life expectancy of at least 20, and perhaps as much as 40, years. If we use the 20-year figure, then it would also be impossible for Rhode Island to meet its carbon-emission-reduction goals for 2035. And if we use the 40-year figure that Invenergy lists, then it would also be impossible for the state to meet its carbon-emission-reduction goal for 2050.

Q. What do you base your opinion on?

A. I base my opinion on several things.

First, the 900-megawatt combined-cycle gas-fired electricity-generating plant will be a "baseload" facility, as described in Invenergy Application page 122, ¶ 5. The plant will be emitting about 900 lbs. of carbon per MWh, which is higher than the current average on our New England electricity grid, which is about 730 lbs carbon per MWh. The rate of emissions from natural gas is lower than from coal or fuel oil combustion, and the wholesale shift of New England away from coal- and oil-fired power plants has improved our emissions levels substantially. Natural gas *has been* an important bridge fuel in this regard. The reason I say that natural gas *has been* a bridge fuel is that we have now crossed that bridge (away from coal- and oil-fired thermal electricity generation). We are now building a *second bridge* that includes renewable energy for an increasing proportion of our electricity on the New England grid. Thus, building a new, long-lived, fossil-fuel fired power plant now would be going the wrong way back across that bridge, back toward higher emissions.

Second, achieving the Resilient Rhode Island Act's carbon-emission-reduction targets will require a major drive to energy efficiency and a very fast shift away from fossil fuels and toward renewable energy sources and electricity storage. Given the long life of generating plants and the $700 million cost [Invenergy Application, page 20], Rhode Island will be locked into a fossil-fuel future if this plant were built, just as the world is shifting rapidly away from fossil fuels. The plant will have to be used, or there will be huge stranded costs for the firm and the state. No policy-maker would be responsible if they assumed that a company would be willing to invest $700 million dollars for a power plant they intend to turn off in just a few years.

Third, the Invenergy facility will include two 1,000,000 gallon above-ground fuel oil storage tanks. [Invenergy Application, page 13, Section 3.5.3] The plant is to be duel-fuel, capable of burning gas or low-sulphur diesel oil. Diesel is significantly worse than natural gas in terms of its impact on climate change per unit of electricity generated. The recent gains in emissions reductions in that Rhode Island has made were made largely by switching away from diesel fuel oil to natural gas. Thus, building this plant now, with its large oil-burning capacity, would be a further bridge in the wrong direction and at the wrong time.

There are conflicting numbers in Invenergy's own documents on how often the plant might switch over to this much dirtier fuel. The Invenergy Proposal mentions 5 days a year – [Invenergy Application, page 51, ¶ 3]. And it mentions 60 days a year. [Invenergy Application, page 34, ¶ 7.] Meanwhile, Invenergy's DEM Air permit [Appendix C, page 1] mentions that it could be run 30 days a year. If the Invenergy plant were to burn oil for either 30 or 60 days a year, its emissions of carbon, ozone precursors, and other air pollutants would be significantly higher than if it burned only gas. Further, these days are likely to be during heat waves in the summer, when air quality is worst and burning dirty fossil fuels compounds ground level smog and ozone problems, causing significant public health problems, including increased emergency room admissions for individuals suffering from cardiovascular disease and asthma.

Q. Are there additional reasons that you would cite in support of your opinion that granting the permit for this fossil-fuel plant would make it impossible for Rhode Island to meet its carbon-emission-reduction goals under the Resilient Rhode Island Act?

A. Yes. I have two more reasons supporting my opinion.

First, building and installing substantial new fossil-fuel-generation capacity now is to take the narrowest and most short-term approach to resolving the long-term policy issue of how to meet our state's and region's energy service needs. Solar and wind power are rapidly reaching "grid parity" in many places around the world. By "grid parity," I mean that renewable energy generation capacity is rapidly becoming as affordable to install as fossil-fuel generating capacity. The trend in price of these renewable energy sources is steadily and substantially downward. Considering the predictability of the price of wind and solar energy (the energy is free, once the equipment is put in place and maintained), installing them is now a prudent investment. Conversely, having a surplus of natural gas-fired electricity here in the state will decrease the incentive to make the competing long-term investments that will be needed for new renewables like wind, solar, geothermal, tidal, and wave energy.

For this reason, I would encourage the Invenergy group to make a $700 million investment in Rhode Island for renewable energy. I note that in its January 12, 2016 presentation to the EFSB, Invenergy stated that, while 37% of the generation capacity it has built over the past decade is fossil fuel generation (natural gas), 63% is renewable. Invenergy told the EFSB that it had built eight wind projects in 2015, totaling 1,100 MW; and that it had built 726 MW of wind projects in 2014, including two each in Colorado, Quebec, and New York, and one each in Nebraska, Texas, and Poland. Investing in clean renewable energy would help lower the state's carbon emissions and *would create five to 10 times as many jobs*, including permanent jobs, as the proposed fossil-fuel plant would. For this reason, supporting the proposed natural gas plant is actually the position that would badly hinder the ability of Rhode Island to create numerous,

stable, good-paying, skilled and non-skilled jobs in the state. This plant will drive a very narrow type of development and lock in our dependence upon imported fossil fuels, hindering much broader-based development that will create much greater and longer-lasting economic development.

Second, the natural gas that will be burned in the Invenergy facility will largely come from Marcellus Shale fields in Pennsylvania, extracted through the process of hydraulic fracturing, or "fracking." This process involves the injection of toxic liquids deep into the Earth at extremely high pressures, to break layers of shale and force out natural gas. This process has a series of risks, including endangering local groundwater, creating earthquakes in places they have not been felt in recent history, and most importantly for this case, fracking has been associated with high levels of leakage of methane. Methane is a greenhouse gas of extremely high potency, from 20 to 100 times more effective at warming the Earth than is carbon dioxide. Especially in the short term, methane could send temperatures up quickly. Natural gas infrastructure, including drilling and pipeline tubes, joints and compressors, tend to leak. Rhode Island lacks a firm estimate of the methane leakage impact of our natural gas infrastructure and of the electricity we consume. Including methane leakage in estimates of emissions, especially with greater consumption of natural gas in the state, will make it impossible for Rhode Island to meet its targets under the Resilient Rhode Island Act.

Q. I would like to direct your attention to a portion of the Invenergy Application. Section 6.0 of the Invenergy Application is entitled "Assessment of Environmental Impacts." Sub-Section 6.1 is entitled "Air." The last sentence in the first paragraph of this Sub-Section 6.1

says: "The expected decreases in greenhouse gas emissions [from the Invenergy plant] will help Rhode Island . . . to achieve compliance with . . . greenhouse gas emission reduction goals and initiatives." [Invenergy Application, page 29.] Do you agree with that statement?

A. No, I do not.

Q. Why not?

A. There are different ways – that is, entirely different methodologies – that one can use for calculating carbon emissions.

One way of measuring carbon emissions – and emission reductions – is on a state-by-state basis. This is what the Rhode Island General Assembly chose to do when it enacted the Resilient Rhode Island Act. The respective state legislatures of our neighboring states of Massachusetts and Connecticut made exactly the same choice – to measure statewide emissions – when those legislatures enacted Global Warming Solutions Acts in those two states.

A completely different way of measuring carbon emissions – and carbon reductions – is by taking a different geographical area (that is, not just a single state). In theory, one could choose any geographical area – for example, the six New England states, or the nine states that are now in the Regional Greenhouse Gas Initiative, or the 48 contiguous United States, or all 50 United States, or just those states east of the Mississippi River.

You will note that the Invenergy Proposal consistently calculates the carbon emissions of its plant in the context of aggregating emissions from seven states that Invenergy chose: the six New England states and New York combined. For example, on that same page 29 of the

Invenergy Proposal, there is a chart, called Table 5.2-1, that purports to show the Invenergy plant's impact on total carbon emissions in the ISO-NE – NYISO footprint. ISO-NE is the Independent System Operator-New England that runs the electricity grid for the six New England states; NYISO is the New York Independent System Operator that runs the electricity grid for New York. There is text at the bottom of page 28 of the Invenergy Proposal that corresponds to the chart on page 29; this text makes the claim that Invenergy's proposed plant will reduce overall carbon emissions distributed over the combined seven state area of New York and New England.

I want to be clear about what I am and am not saying here. I am *not* saying that the methodology that Invenergy chose to use is wrong in every case. What I *am* saying is that the methodology that Invenergy chose to use for calculating carbon emissions is different from the methodology that the Rhode Island General Assembly enshrined in law and in public policy when it enacted the Resilient Rhode Island Act.

The Resilient Rhode Island Act sets clear carbon-emission-reduction goals *for the state of Rhode Island*. As a matter of democratic principles, this is what the members of the *Rhode Island* General Assembly were elected to do: set public policy for the state of Rhode Island. Those carbon-emission-reduction goals in the statute (10% by 2020, 45% by 2035, 80% by 2050) pertain to Rhode Island, not to any other hypothetical geographical configuration (like seven states combined, or states east of the Mississippi). The seven-state geographical area that Invenergy cites has no single governmental structure (such as a legislature or governor). This seven-state area does not make up the member states in the Regional Greenhouse Gas Initiative

(RGGI), which is now comprised of nine states. This seven-state area is not the control area of any ISO, but is controlled by two different ISOs. Invenergy says that there is a "high degree of interconnectivity" [Invenergy October 28, 2015 Letter to EFSB, page 3] between New England and New York; but New England also has a high degree of interconnectivity with other areas, including the Hydro-Quebec Interconnection; and Invenergy provides no evidence that more electricity flows from New York to New England in the course of a year than flows from New England to New York.

It seems to me that Invenergy may have cherry-picked this specific seven-state area in order to make its point about carbon emissions. However, the geographical area that I am discussing in my testimony is the state of Rhode Island. And, as I said in the preceding paragraph, the Rhode Island General Assembly has set carbon-emission-reduction goals for Rhode Island.

Q. Are you saying that the Table 5.2-1, on page 29 of the Invenergy Proposal, is factually incorrect in its claim of reduced carbon emissions in the ISO-NE/NYISO footprint if this plant is built?

A. No, I am not. I performed no analysis on the overall effect on carbon emissions for that seven-state area if the Invenergy plant is or is not built. Thus, I express no opinion about the accuracy, or lack of accuracy, in that chart.

The specific question I was responding to above was whether Invenergy's claim is correct that building this fossil-fuel plant in Burrillville "will help Rhode Island . . . to achieve compliance with . . . greenhouse gas emission reduction goals and initiatives." My answer to

that question is a resounding and unequivocal no. To date, Rhode Island's clearest statement about its "greenhouse gas emission reduction goals and initiatives" is the Resilient Rhode Island Act.

It is my testimony, and my opinion, that building a new 900 MW fossil-fuel-fired generator in Rhode Island will make it impossible for Rhode Island to meet its short-, medium-, and long-term emission-reduction goals set by the Resilient Rhode Island Act.

Q. Are the carbon-emission-reduction goals in the Resilient Rhode Island Act mandatory?

A. No, they are not.

Q. Do you know whether any permit or license has ever been denied in Rhode Island because the application was inconsistent with the Resilient Rhode Island Act?

A. Not to the best of my knowledge.

Q. Nevertheless, you are asking the EFSB to deny Invenergy a license for its plant. Why?

A. You can look at this in both a narrow way and in a broader context.

First, in a narrow – Rhode Island centric – sense, the Resilient Rhode Island Act is a law enacted by the General Assembly. The law does not only *reflect* the public policy of the state; it *is* the public policy of the state. The law was passed by the House (nearly unanimously) and the Senate (unanimously), and signed by the Governor. And, as I explained above, building this plant would make it impossible for Rhode Island to meet the carbon-emission-reduction goals set forth in the statute.

In addition, I believe that the Resilient Rhode Island Act is not merely *a* law; it is a very important law, because it addresses the climate change emergency that directly affects every

human being on Earth and will also affect the ability of future generations to live on this planet, the only inhabitable one we know of.

That is, the emission-reduction goals in the Resilient Rhode Island Act may be aspirational, but they are also very, very important. They are sound public policy, representing a managed glide path to a transition in our energy systems away from fossil fuels, avoiding the disruption of a drastic shift.

And, in Section 8 of the law, the General Assembly carefully, deliberately empowered boards, agencies and commissions like the EFSB to apply the law as the public policy of the state.

In short, the carbon-emission-reduction goals in the Resilient Rhode Island Act are the public policy of the state; they address a crucially important subject, climate change; and the General Assembly specifically empowered the EFSB to consider carbon and climate. In this Docket, the way that the EFSB can apply the Resilient Rhode Island Act is to deny Invenergy its requested permit to build a new 900-MW fossil-fuel-fired power plant in Burrillville that might continue emitting dangerous carbon pollution into the atmosphere for 40 years. The gases it emits will be in the atmosphere for hundreds of years to come.

I urge the EFSB to do that. The Resilient Rhode Island Act is a clear mandate for the EFSB to act to meet these goals, and given that mandate the EFSB should play its role as a key agent in the state's public policy system.

Second, the broader context is also important. What I saw at the United Nations Climate Change Conference in Paris was 195 nations coming together to adopt what the White House

called "the most ambitious climate change agreement in history." That agreement is based on individual countries setting individual targets – that is, goals – for carbon-emission reductions. You could say that, in this way, the Paris Agreement is "like" the Resilient Rhode Island Act in the sense that both the Act and the Paris Agreement are based on goals. Neither the Act nor the Agreement is legally enforceable in the sense that you could sue someone to enforce the emission-reduction goals that are in the Act or in the Agreement.

But this fact does not make them less important. Adherence to the emission-reduction goals set in the Paris Agreement is crucially important to addressing climate change at the global level. Adherence to the emission-reduction goals set in the Resilient Rhode Island Act is crucially important to addressing climate change at the state level, and in the United States. And Rhode Island is in many ways the logical state to lead the U.S. in being a global leader in moving away from fossil fuels. This is true because Rhode Island has 400 miles of vulnerable ocean and bay coastline at risk as sea levels rise. It is true because Rhode Island produces zero fossil fuels, and therefore every dollar we spend on fossil fuels is a dollar that bleeds out of the state's economy. And it is true because Rhode Island is already one of the five most energy efficient states in the U.S. Having spoken with corporate leaders and experts from around the world, I am convinced that being a leader on climate change and energy efficiency also will bring national and international attention *and investment* to our state. Global renewable energy firms, for example, are looking for beachheads in America to pilot their products and services. Major corporations are looking for places that will make it easy for them to be among the greenest workplaces in the world, and where their Millennial workers will be eager to live.

The Paris Agreement reflected the shared recognition of 195 countries that, if climate change is to be successfully addressed, it will take the combined efforts of all countries, states, cities, and individuals. I am proud that Rhode Island public policy is in agreement with that principle. Now it is up to the EFSB to put the public policy of Rhode Island into effect by denying Invenergy a permit to build a new fossil-fuel plant in Burrillville.

B. The Invenergy Proposal In the Global Context

Q. This brings us to what you described earlier as situating the implications of the local, Rhode Island Invenergy Proposal within the broader context of the global of climate change. As a preliminary matter, what do you see as some of the major effects of climate change?

A. The global consequences of climate change may well be truly catastrophic. There are a number of key ways that climate change is increasingly likely to disrupt the systems our society depends upon for our survival and improvement of our lot by social development. In the name of brevity I'll focus on four: sea level rise, extreme weather events, drought, and disease.

I will start by discussing sea level rise.

I am recently back from a visit with students to Bangladesh, where I spoke at a conference and we were taken on a tour of coastal cities and villages. There have always been floods in Bangladesh, but things are now changing there: the land is barely above sea level, and as the oceans rise, drinking-water wells and rice fields are being ruined by the intrusion of salt water. We met villagers whose homes and latrines had to be raised in the face of worsening floods, and slum-dwellers in cities whose home villages were no longer habitable and fields no

longer farmable after hurricanes ruined them. A recent major study in the journal *Nature Climate Change* predicts that with different warming scenarios the number of people who will experience flooding in this century will increase four to 25 fold because of climate change. The number rises from 15-40 million people with 2 degrees Celsius of warming above pre-industrial temperatures, to 50-100 million if temperatures rise 4 degrees Celsius. This study demonstrates a large increase in flood frequency in Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes. Hirabayashi, et al., "Global Flood Risk Under Climate Change," 3 *Nature Climate Change* 816-821 (2013). I attach that article at Appendix C.

Another study of low-elevation coastal zone residences stated that "The number of people at risk from coastal flooding could reach between 268 million and 286 million in 2030, globally...and...[b]y 2060, up to 411 million people could be affected by extreme flooding events." Neumann, et al., "Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding – A Global Assessment," PLOS-One (March 11, 2015). I attach that article at Appendix D.

Rhode Island is at high risk due to our 400 miles of coastline in a small state. The Graduate School of Oceanography Seagrant program at the University of Rhode Island reports that the Newport tide gauge has registered an 8.7 inch rise in sea level from 1930 to 2012, and rate of rise is increasing. They describe the potential impact of increasingly strong coastal storms on top of rising sea levels: "An estimated 2,700 housing units are within an elevation of one meter (3.3 feet) above sea level in Rhode Island. Residential and business properties in low-lying areas will likely be inundated permanently or during more frequent extreme high tides.

Ten at-risk coastal wastewater treatment facilities will need to be evaluated to determine risk, and options to reduce damage and disruption to service; other sectors with critical coastal infrastructure such as port facilities and energy and gas networks will also need to evaluate potential impacts . . ." See *Sea Level Rise in Rhode Island*, at 4. I attach that article at Appendix E. Because warming water expands and the Antarctic and Greenland ice sheets are melting faster than predicted, state agencies and national experts are warning that sea level rise may occur far more rapidly than expected.

Q. The next category you mentioned was extreme weather events. Do you want to discuss that?

A. Yes. With climate change, extreme weather events, including hurricanes and lethal heatwaves, will become more frequent and intense.

The most recent IPCC Assessment Report states that "many of the impacts of climate change are likely to manifest themselves through extreme weather." IPCC Assessment Report V, Ch. 10, p. 914 (link). The report discusses research by the U.S. Climate Change Science Program, which concluded that: (1) it is very likely that anthropogenic greenhouse-gas emissions have increased sea surface temperatures in parts of the world where hurricanes form, and (2) these increased temperatures have a strong statistical relationship with increased hurricane activity. *Id.* at 913 (citing Knutson, T. R., et al., "Tropical cyclones and climate change," 3 *Nature Geosci.* 157–163 (2010)). Indeed, the paper discussed in the report (Knutson 2010) concludes that, as a result of climate change, hurricanes will become more intense over the course of the next century – that is to say, hurricanes' maximum wind speeds and rainfall rates

will increase. Knutson, T. R., et al., "Tropical cyclones and climate change," 3 *Nature Geosci.* 157–163 (2010) (link). And more recent research by Knutson and colleagues projects that these more-intense hurricanes (specifically, Category 4 and 5 hurricanes) will appear 87% more often. Knutson, T.R., et al., "Dynamical downscaling projections of twenty-first-century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenarios," 26 *J. Climate* 6591-6617 (2013) (link). It is quite simple and commonsensical: warmer waters and air hold more moisture and energy. Hurricanes, thunderstorms and even blizzards essentially become supercharged.

The IPCC report also reviews a wide body of research and concludes that "increasing numbers of studies are finding that the probability of occurrence of events associated with extremely high temperatures has increased substantially due to the large-scale warming since the mid-20th century." IPCC Assessment Report V, Ch. 10, p. 916. In other words, according to the IPCC, "it is likely that human influence has substantially increased the probability of occurrence of heat waves in some locations." *Id.* A recent article in the journal *Nature Climate Change* puts it more bluntly: "In 2003, Europe suffered its hottest summer by far for at least 500 years," and research shows that "the risk of a heatwave of the magnitude of the 2003 European event has at least doubled but probably quadrupled (best estimate) as a result of human influence on climate." Coumou, D., et al., "A decade of weather extremes," 2 *Nat. Climate Change* 491-96 (2012) (citing Stott, P. A., et al., "Human contribution to the European heatwave of 2003," 432 *Nature* 610–614 (2004)) (link). Public-health research has concluded that the 2003 European heat wave killed 70,000 people. Robine, J. M., et al., "Death toll exceeded 70,000 in Europe during the summer of 2003," 331 *Comptes Rendus Biologies* 171–178 (2008). One needn't look across the

ocean: the 1995 heat wave in Chicago killed thousands of residents, especially elderly people afraid to or unable to open their windows. See Eric Kleinenberg, *Heat Wave: A Social Autopsy of a Disaster* (University of Chicago Press, 2003).

Q. Next, you mentioned droughts. What do you want to say about that?

A. Droughts will become more frequent and severe, creating wildfires and water shortages in the U.S. and abroad. Agriculture could be disrupted, which is especially worrisome since billions of the world's population live on rain-fed crops without any systems for irrigation.

A 2008 paper by Justin Sheffield and Eric Wood in the journal *Climate Dynamics* reviewed previous work suggesting "that the interior of the northern hemisphere continents will become drier over the next century, especially in the summer" based on data relating to temperature, precipitation rates, and soil moisture. Sheffield, J., and E. F. Wood, "Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations," 31 *Climate Dynamics* 79–105 (2008) (link). They noted that eastern North America is considered a "climate change 'hot-spot.'" *Id.* And their summary of this previous work is unequivocal: "The consensus from these and other studies into the hydrologic impacts of future warming and the synthesis conclusions of the past two IPCC reports point towards a greater risk of drought during the twenty-first century." *Id.* And that review of past findings was just the lead-up to their own work, which found that there will likely be "decreases in soil moisture at global scales for the future scenarios with a corresponding doubling of the spatial extent of severe soil moisture deficits and frequency of short-term (D4–6) droughts from the mid-twentieth century to the end of the twenty-first." Other research demonstrates a strong

link between drought conditions and increased wildfires, especially in forested areas. *See, e.g.*, Westerling, A.L., and B. P. Bryant, "Climate change and wildfire in California," 87 *Climatic Change* 231-249 (2006) (link).

The research relating droughts to agricultural disruptions is unequivocal. A 2010 paper by Jemma Gornall and colleagues reviewed research discussing the effects of climate change on agriculture. Gornall, J., et al., "Implications of climate change for agricultural productivity in the early twenty-first century," 365 *Proceedings of the Royal Society B* 2973-89 (2010) (link). They stated that "historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events," and added that "even small changes in mean annual rainfall can impact on productivity." *Id.* (internal citations removed). They also noted some specific examples: for example, the 2003 European heat wave resulted in drought conditions that reduced crop yields 36% in Italy's Po valley. *Id.* (citing Ciais, P., et al., "Europe-wide reduction in primary productivity caused by the heat and drought in 2003," 437 *Nature* 529–533 (2005)). And they discussed research estimating that, accounting for expected climate-related increases in drought, "drought related yield reductions would increase by more than 50 per cent by 2050 for the major crops." *Id.* (citing Li, Y. P., et al., "Climate change and drought: a risk assessment of crop-yield impacts," 39 *Clim. Res.* 31–46 (2009)).

Q. Finally, you mentioned disease. What do you want to say about that?

A. Several major diseases are spread by specific species of mosquitoes, including malaria, dengue fever, West Nile and now the very worrisome Zika virus. In the past, these diseases have been largely confined to tropical areas. But as the earth's climate warms, the geographical range

of these animal vectors expands, and so do the geographical range of areas where these infections can likely occur. The Centers for Disease Control have recently reported for the first time likely cases of dengue fever caused by mosquito bites that occurred in southern parts of the United States. Chikungunya used to be limited to tropical Africa; now indigenous cases are being reported in Western Europe.

Other diseases, such as cholera and diarrheal disease (this latter one of the world's largest killers of infants and children) will become more widespread as climate conditions change for the warmer.

In sum, the World Health Organization estimates that "Between 2030 and 2050, climate change is expected to cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhea and heat stress."

Q. That is quite a list of catastrophic consequences. How would you sum all this up?

A. The moral point here is clear: leaving people to suffer and die when we could have prevented their suffering is reprehensible; it is wrong. From purely selfish perspectives, the disruption of the global economy by disasters and wars will hurt our national and our state economy, and worsen our lives here. We have seen the disruption a million refugees have created in Europe. With climate change, there are estimates that over 30 million people could be displaced by sea level rise alone. This is a humanitarian crisis that will overtax all systems we can imagine to address their needs.

Q. Is it your testimony that the outcome of this EFSB Docket could be significant in the global picture in terms of preventing or averting some of these consequences?

A. Yes, I am saying that.

Q. What is the basis for your opinion?

A. In order for the world to reduce carbon emissions as drastically and as quickly as we must, it is necessary to quickly reduce, and eventually eliminate, our reliance on fossil fuels, and instead switch to renewable energy. The Invenergy Proposal comes to the EFSB at an important time, because scientists are now very clear on what changes must be made if we are to prevent the worst effects of climate change. We – all of us – can and must do the right thing, even if it is not politically easy to do so.

I am a sociologist, so the finding that people look around to see what others are doing before deciding how to act themselves makes perfect sense to me. The only way to change behaviors and make a transition like this one is with each individual action, which will in turn cause another. And another. And so on. The "butterfly effect" -- that very small causes can have very large effects -- may sound cheesy, but in the case of social change, it is absolutely a fact: people need examples to point to of courageous action, and it inspires them to take actions they never would have. That is, in order to effect the necessary large transition from an entrenched fossil fuel economy to a whole new technology and way of organizing our energy supply system, the only hope may be to start out making smaller, individual changes locally.

On the one hand, accepting the status quo and building a huge new fossil fuel plant will create cynicism and delay innumerable actions by others. On the other hand, switching now to renewable energy will be important in and of itself, but will also have cascading positive

consequences of job creation and more stable energy costs, allowing Rhode Island to be an example to other states and countries making decisions on energy deployment.

In order to help us make the right choice here, we should ask ourselves the following question: What would the world be like if everyone followed our decision and followed our example? Like the Paris Agreement, our own Resilient Rhode Island Act only inspires change if nations, states, and cities take bold and constructive action; in this case, that would mean denying a permit for a huge, new fossil-fuel plant that will have the inevitable consequence of locking Rhode Island into a fossil-fuel future for at least two to four decades to come. The world simply won't be changed without examples, people who showed that another way forward is possible, that rejecting a fossil fuel power plant and boldly stepping to efficiency and renewable energy is possible and beneficial, economically and socially.

My now-13-year-old daughter, a 7th grader at Lincoln School in Providence, said to me when she was 12, "Daddy, I wish I were old so I didn't have to worry about climate change." I am here today because we have to do every single thing in our power to stop this terrible destabilization of the very systems that sustain our society and make life worth living. I told my daughter that we *are* going to solve this problem, because we *must*.

At the recent climate conference in Paris a slogan for "Solutions Day" was "We Can. We Must. We Will." I love living and working in Rhode Island because one person can make a difference here, and because we are a community, an innovative, brave and tolerant group from our founding days. This facility decision is where we can, we must, and we will begin to be the change we need to happen to solve this incredibly tough problem. We lost 15 years of action on

climate change in bickering and avoidance of the reality of this issue: there really cannot be any further delay.

Q. Are there other aspects of the context outside of Rhode Island that you want to discuss?

A. Yes. Despite recent actions of the Obama Administration (such as enacting the E.P.A.'s Clean Power Plan) the United States Congress has – at least so far – failed completely to enact comprehensive, effective, mandatory legislation addressing climate change. Similarly, Congress has not passed any major legislation aimed at curbing carbon emissions. In this context of a lack of meaningful action from the *federal* legislature, actions taken by *state* legislatures become all the more important. For example, I discussed earlier the fact that our neighboring states of Massachusetts and Connecticut have enacted so-called "Global Warming Solutions Acts," (GWSAs) which contain mandatory, economy-wide carbon-emission-reduction provisions. California has done that also. Rhode Island's Resilient Rhode Island Act is less strong than those Acts, but the Rhode Island law is still an important step in the right direction, but only *if it is enforced by Rhode Island agencies and commissions.*

That is why I urge the Rhode Island EFSB to deny Invenergy a permit to build a new 900-MW fossil fuel plant in Rhode Island.

Conclusion

Q. Does this conclude your testimony?

A. Yes.

Tab A

Curriculum Vitae (Brown University Format)
Updated 19 January 2016

1. Name, position, academic departments

J. Timmons Roberts
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2. Address and Phone: Available upon request

3. Education:

1983 B.A. *Kenyon College* (Highest Honors in Biology, Phi Beta Kappa).
1989 M.A. *The Johns Hopkins University* (Sociology).
1992 Ph.D. *The Johns Hopkins University* (Department of Sociology/Program in Comparative International Development). Dissertation topic: Urban development, workforce fragmentation, and household survival in a Brazilian Amazon resource boomtown

4. Professional appointments:

1990-1991	**Lecturer** (Adjunct Professor), *Greensboro College*, Greensboro, North Carolina, [while completing dissertation]
1991-2001	**Assistant to Associate Professor**, *Tulane University*. Joint appointment in Sociology and Latin American Studies
1998-2000	**Director of Graduate Studies**, Department of Sociology, *Tulane University*
1999-2001	**Director of Environmental Studies**, *Tulane University*
2001-2009	**Chancellor Professor of Sociology** (2008-9), *College of William and Mary*
2001-2008	**Director of the Program in Environmental Science and Policy**, *The College of William and Mary*
2006-2007	**James Martin 21st Century Professor**, Environmental Change Institute, *Oxford University* (Research and graduate teaching fellowship—sabbatical)
2007-2010	**Research Fellow**, Institute for the Theory and Practice of International Relations, *The College of William and Mary*
2009-2012	**Director, Center for Environmental Studies and Professor** of Environmental Studies and Sociology, *Brown University.*
2009-present	**Ittleson Professor of Environmental Studies and Sociology**, *Brown University*
2013	**Invited Faculty,** Semester at Sea, University of Virginia, Summer 2013
2013-2015	**Faculty Fellow**, Watson Institute for International Affairs, *Brown*
2012-present	**Non-Resident Senior Fellow**, *Brookings Institution*
2013-present	**Core Faculty Fellow,** Institute at Brown for Environment and Society
2015-present	**Member**, *Climate Strategies,* London

5. Completed Publications: (*Student and former student coauthors are noted with an asterisk)

5.a. books/monographs (authored and/or edited volumes);

2000 ***From Modernization to Globalization: Perspectives on Development and Social Change***. J. Timmons Roberts and Amy Hite*. London: Blackwell Publishers.

2001 ***Chronicles from the Environmental Justice Frontline***. J. Timmons Roberts and Melissa Toffolon-Weiss*. Cambridge: Cambridge University Press.

2003 ***Trouble in Paradise: Globalization and Environmental Crises in Latin America***. J. Timmons Roberts and Nikki Thanos*. London: Routledge publishers.

2007 ***A Climate Of Injustice: Global Inequality, North-South Politics, and Climate Policy***. J. Timmons Roberts and Bradley Parks*. Cambridge, Mass.: MIT Press.

2007 ***The Globalization and Development Reader: Perspectives on Development and Social Change.*** J. Timmons Roberts and Amy Hite*. London: Blackwell Publishers.

2008 ***Greening Aid? Explaining Environmental Foreign Assistance.*** Robert Hicks, Bradley Parks*, J. Timmons Roberts, and Michael Tierney. Oxford: Oxford University Press.

2008 ***Climate change and the fate of the Amazon*** edited by Yadvinder Malhi, Richard Betts and Timmons Roberts. Special Issue of the *Philosophical Transactions of the Royal Society*. Vol. 363, No. 1498 / May 27 2008: p. 1727-1932 (27 articles).

2011 ***Expanding Our Understanding of Aid with a New Generation in Development Finance Information.*** Edited by J. Timmons Roberts, Darren Hawkins and Michael Findley. Special Issue of *World Development*. November, 2011 (Vol. 39, No. 11)]. (12 articles)

2015 ***The Globalization and Development Reader (Second Edition).*** J. Timmons Roberts, Amy Hite*, and Nitsan Chorev. London: Wiley-Blackwell.

2015 ***Power in a Warming World: The New Global Politics of Climate Change and the Remaking of Environmental Inequality***. David Ciplet*, J. Timmons Roberts, and Mizan Khan. Cambridge, Mass.: MIT Press. Released September 11.

2015 ***A Fragmented Continent: Latin America and the Global Politics of Climate Change.*** Guy Edwards and J. Timmons Roberts. Cambridge, Mass.: MIT Press. Released November 15.

2016 ***The Globalization and Environment Reader.*** Peter Newell and J. Timmons Roberts. London: Wiley-Blackwell. Forthcoming Spring 2016.

5.b. chapters in books: (*Student and former student coauthors are noted with an asterisk)

1996 "Global Restructuring and the Environment in Latin America." Pp. 187-210 in *Latin America in the World Economy*, Edited by Roberto P. Korzeniewicz and William C. Smith, Greenwood Press. [Chapter in edited volume, peer-reviewed]

1997 "The Military-Industrial-Media Complex: Old Biases, New Linkages." P. 45-54 in *The Gulf War as Popular Entertainment: An Analysis of the Military-Industrial Media Complex*. Edited by Paul Leslie. Symposium Series Vol. 42, Lewiston: Edwin Mellen Press. [Chapter in edited volume, non-peer reviewed]

1997 "The Social Context of Democracy in Brazil." Timothy J. Power and J.Timmons Roberts. In Peter Kingstone and Timothy J. Power (eds.), *Democratic Brazil*, University of Pittsburgh Press. [Chapter in edited volume, peer-reviewed]

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1999 "Extending the World-system to the Whole System: Towards a Political Economy of the Biosphere." J. Timmons Roberts and Peter E. Grimes. P. 59-83 in *The Global Environment and the World-System*. Greenwood Press. Walter Goldfrank, David Goodman, and Andrew Szasz, editors. [Chapter in edited volume, peer-reveiewed]

2001 "North American Conceptions of Environmental Justice." Wilson Madeira Filho (ed.) "Direito e Justiça Ambiental". Rio de Janeiro, Brazil: UFF - Universidade Federal Fluminense. [Chapter in non-peer reviewed edited volume]

2002 "World-System Theory and the Environment: Toward a New Synthesis." J. Timmons Roberts and Peter E. Grimes. in *Sociological Theory and the Environment: Classical Foundations, Contemporary Insights*. Edited by Riley E. Dunlap, Fredrick H. Buttel, Peter Dickens, and August Gijswijt. Lanham: Roman and Littlefield Publishers. [Chapter in edited volume, peer-reviewed]

2002 "Explaining Outcomes of Environmental Injustice Struggles: A Framework and Evidence from Louisiana." J. Timmons Roberts and Melissa M. Toffolon-Weiss*. In Henri Acselrad and Selene Herculano (eds.) *Justiça Ambiental, Trabalho e Cidadania.* Volume funded by the Ford Foundation. [Chapter in edited volume, peer-reviewed]

2005 "Environmental and Ecological Justice." J. Timmons Roberts and Bradley C. Parks*. In Michele M. Betsill, Kathryn Hochstetler and Dimitris Stevis *Palgrave Advances in International Environmental Politics*. Palgrave. [Chapter in edited volume, peer-reviewed]

2005 "Who Wins, Who Loses? Understanding Outcomes of Environmental Injustice Struggles." J. Timmons Roberts and M. Toffolon-Weiss*. In David N. Pellow and Robert J. Brulle, eds. *Power, Justice and the Environment: A Critical Reappraisal of the Environmental Justice Movement.* MIT Press. [Chapter in edited volume, peer-reviewed]

2006 "Globalizing Environmental Justice: Trend and Imperative." J. Timmons Roberts. In Ronald Sandler and Phaedra C. Pezzullo (Eds.) *Environmental Justice and Environmentalism: The Social Justice Challenge to the Environmental Movement*. MIT Press, November, 2006. [Chapter in edited volume, peer-reviewed]

2007 "Globalization: The Environment and Development Debate." Pp. 3-18 in *The Politics of the Environment*. London: Routledge Europa. Chuks Okereke editor. [Chapter in edited volume, invited, not peer-reviewed]

2008 "Climate Change: Why the Old Approaches Aren't Working." In *Twenty Lectures in Environmental Sociology*. In Kenneth Gould and Tammy Lewis, editors. Oxford University Press, Forthcoming 2008 [Chapter in edited volume, invited, not peer-reviewed]

2008 "Grandfathering, Carbon Intensity, Historical Responsibility, or Contract/Converge?" J. Timmons Roberts and Bradley C. Parks*. P. 158-178 in Steven Berntein, Jutta Brunnee, David G. Duff, and Andrew J. Green. *A Globally Integrated Climate Policy for Canada.* Toronto: University of Toronto Press. [Chapter in edited volume, invited, not peer-reviewed]

2010 "Addressing Inequality and Building Trust to Secure a Post-2012 Global Climate Deal" Bradley C. Parks* and J. Timmons Roberts. In Maxwell Boykoff (Editor) *The Politics of Climate Change: A Survey*. London: Routledge/Europa. [Chapter in edited volume, invited, not peer-reviewed]

2010 "Structural Obstacles to an Effective Post-2012 Global Climate Agreement: Why Social Structure Matters and How Addressing it Can Help Break the Impasse." Bradley C. Parks* and J. Timmons Roberts. *The International Handbook of Environmental Sociology*, Second Edition. Edited by Michael R. Redclift and Graham Woodgate. London: Edward Elgar. [Chapter in edited volume, invited, not peer-reviewed].

2010 "A 'Shared Vision' of Global Climate Policy: Why Inequality Must Be Addressed to Build a Durable North-South Consensus." J. Timmons Roberts and Bradley C. Parks*. In *Climate Change, Ethics and Human Security*, edited by Karen O'Brien, Asuncion Lera St. Clair and Berit Kristoffersen. Cambridge: Cambridge University Press. [Chapter in edited volume, invited, not peer-reviewed].

2013 "The Impact of Climate Change on Human Security in Latin America and the Caribbean." Úrsula Oswald Spring, Hans Günter Brauch, Guy Edwards and J. Timmons Roberts. In Michael Redclift and Marco Grasso (Editors). *Climate change and Human Security Handbook.* (Cheltenham: Edward Elgar, 2013). [Chapter in edited volume, invited, not peer-reviewed]

2013 "Towards a Binding Adaptation Regime: Three Levers and Two Instruments." Mizan Khan and J. Timmons Roberts. In Suzanne Moser and Maxwell Boykoff (Editors), *Successful Adaptation.* (London: Routledge Publishers). [Chapter in edited volume, invited, peer-reviewed]

2014 "Sociology." Jennifer Swanson, Stephen Brechin, and J. Timmons Roberts. In *Conservation and Social Sciences*, edited by Michael Mascia. Wiley-Blackwell. [Chapter in edited volume, invited, not peer-reviewed].

2015 "Geopolitics." Ciplet, David*, Timmons Roberts and Mizan Khan. In *Research Handbook on Climate Governance*, edited by Karin Bäckstrand and Eva Lövbrand. Edward Elgar. Chapter 10. [Chapter in edited volume, invited, not peer-reviewed]

2015 "Climate Justice and Inequality." Sharon L. Harlan, David N. Pellow and J. Timmons Roberts. P. 127-163 in *Climate Change and Society: Sociological Perspectives*, Riley E. Dunlap and Robert J. Brulle, Editors. Report of the American Sociological Association's Task Force on Sociology and Global Climate Change. Oxford University Press. [Chapter in edited volume, invited, peer-reviewed]

2015 "Adaptation to Climate Change." JoAnn Carmin, Kathleen Tierney, Eric Chu, Lori M. Hunter, J. Timmons Roberts and Linda Shi. P. 164-198 in *Climate Change and Society: Sociological Perspectives*, Riley E. Dunlap and Robert J. Brulle, Editors. Report of the American Sociological Association's Task Force on Sociology and Global Climate Change. Oxford University Press. [Chapter in edited volume, invited, peer-reviewed]

5.c. Refereed Journal Articles (*Student and former student coauthors are noted with an asterisk)

1992 "Squatters and Amazon Urban Growth." ***The Geographical Review***. Vol. 82 No. 4, pp. 441-457. February, 1992.

1993 "Psychosocial Effects of Workplace Hazardous Exposures: Theoretical Synthesis and Preliminary Findings." ***Social Problems*** Vol. 40, pp. 74-89, March, 1993.

1993 "Power and Placenames: A Case Study from the Contemporary Amazon Frontier." ***Names*** Vol. 41 No. 3, pp. 159-181, September, 1993.

1995 "Perceived Work Hazards and Job Strain in Eleven Nations" J. Timmons Roberts and John E. Baugher*. ***International Journal of Contemporary Sociology*** Vol. 32, No. 2, pp. 235-249.

1995 "Expansion of Television in Eastern Amazonia." ***Geographical Review*** Vol. 85, No. 1, pp. 41--49.

1995 "Trickling-Down and Scrambling-Up: Informal Sectors and Local Benefits of a Mining 'Growth Pole' in the Brazilian Amazon." ***World Development***, Vol. 23 No. 3, pp. 385-400.

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1995 "Subcontracting and the Omitted Social Impacts of Development Projects: Household Survival at the Carajás Mines in the Brazilian Amazon." ***Economic Development and Cultural Change***, Vol. 43 No. 4, pp. 735-58.

1995 "Compulsory Voting, Invalid Ballots, and Abstention in Brazil." Timothy J. Power and J. Timmons Roberts. ***Political Research Quarterly*** Vol. 48, No. 3, pp. 795-826.

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1995 "Population Growth, Sex Ratio and Women's Work on the Contemporary Amazon Frontier." J. Timmons Roberts and F. Nai-Amoo Dodoo. *1995* ***Yearbook of the Conference of Latin American Geographers***, pp. 91-105.

1996 "Predicting Participation in Environmental Treaties: A World-System Analysis." ***Sociological Inquiry***, Vol. 66, No.1, pp. 38-57.

1997 "Negotiating Both Sides of the Plant Gate: Hazardous Facility Workers and Community Responses to Hazards." ***Current Sociology*** (1997) Vol. 45 No. 3: 157-177.

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1998 "Fear of Crime and Collective Action: An Analysis of Coping Strategies." Lesley Williams Reid*, J. Timmons Roberts and Heather Munro Hilliard*. ***Sociological Inquiry*** 68(3): 312-328.

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2003. "Social Roots Of Global Environmental Change: A World-Systems Analysis Of Carbon Dioxide Emissions." J. Timmons Roberts, Peter E. Grimes, and Jodie Manale*. ***Journal of World-System Research*** Vol. IX, No. 2, July, 2003. 277-315.

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2011 "New and additional to what? Assessing options for baselines to assess climate finance pledges." Martin Stadelmann, J. Timmons Roberts, and Axel Michaelowa. ***Climate and Development*** Vol. 3 No. 3: 175-192 (lead article).

2011 "Social Development Aspects of Kyoto Protocol Clean Development Mechanism Projects: A Review of Six Hydroelectricity Projects in Brazil and Peru." John C. Cole and J. Timmons Roberts. ***Climate and Development*** 3 (4), 361-379.

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2013 "The Climate and Development Lab: An Experiment in Engaged Education for Global Just Sustainability." David Ciplet*, J. Timmons Roberts, and Guy Edwards. ***Journal for Sustainability Education***. June 2013.

2013 "No Talk, but Some Walk: The Obama Administration's First Term Rhetoric on Climate Change and its International Climate Budget Commitments." Graciela Kincaid* and J. Timmons Roberts. ***Global Environmental Politics*** 13(4), November.

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2015 Pickering, Jonathan, Jakob Skovgaard, Soyeun Kim, J. Timmons Roberts, David Rossati; Martin Stadelmann, and Hendrikje Reich. "Acting on Climate Finance Pledges: Inter-Agency Dynamics and Relationships with Aid in Contributor States." ***World Development***. Vol 68: 140-162.

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5.d. Non-Refereed Journal Articles and Policy Briefings (*Student and former student coauthors are noted with an asterisk)

1992 "Crisis and Environment [Features: Brazil]." *Hemisphere: A Magazine of Latin American and Caribbean Affairs*. 6(1): 26-30. 1992. [not peer reviewed]

1996 "Classroom Simulations of Environmental Conflicts--A Pedagogical Note." *Environment, Technology and Society* No. 82, Summer 1996, p. 1-4. Also in *Environmental Justice Teaching Resource Guidebook*, Robert Bullard, ed. [pedagogical note, not peer-reviewed]

1997 "Environmental Sociology." Syllabus and introductory statement. In "Teaching Political Ecology" section of *Capitalism, Nature, Socialism* (Vol. 8), 1997. Also available through the Center for Political Ecology's "Clearinghouse on Political Ecology" on its World Wide Web page. [pedagogical information, not peer reviewed]

1997, 1999 Syllabi published in American Sociological Association Curriculum Resource Center's 1999 Environmental Sociology volume, 1997 Internationalizing Sociology volume. [pedagogical note, not peer-reviewed]

1999 "Mobilizing Environmental Sociology Classes in Collective Projects." *Environment, Technology and Society* No. 89, Spring, 1999, p. 1-4. This note is also available through the section webpage at Communications for a Sustainable Future. http://csf.colorado.edu/envtecsoc/etwjtr.htm [pedagogical note]

2000 "Brazil: Sociology" section of the Library of Congress' *Handbook of Latin American Studies*, 2000. With Joyce Baugher. Austin: University of Texas Press. [major section of reference volume, not peer-reviewed]

2000 "Environmental Issues." Major Entry for the *Encyclopedia of Contemporary Latin American and Caribbean Cultures*. Routledge. [encyclopedia entry, not peer-reviewed]

2000 "Environmental Concern and Activism." Major Entry for the *Encyclopedia of Contemporary Latin American and Caribbean Cultures*. Routledge. [encyclopedia entry, not peer-reviewed]

2000 "Entrevista: Timmons Roberts." *Jornal Segurança & Saúde no Trabalho*. Ano 5, No. 52, December, 2000. P. 6-7. [interview, non-peer reviewed]

2000 "Towards a Sociology of Brownfields: An Interview with David Pellow." *Environment, Technology and Society*, No. 97, Spring 2000. p. 1, 4-5. [not peer reviewed]

2003 "Globalization and the Environment" syllabus and supporting materials published in Rik Scarce and Michael Mascarenhas, editors. *Syllabi and Instructional Material in Environmental Sociology*. 5th Edition. Washington, DC: American Sociological Association. 2003. [pedagogical notes/syllabus]

2004. "Environment and Vulnerability in Latin America and the Caribbean: Our Shared Responsibility in a Globalized World." *Catholic Institute for International Relations (CIIR)* Comment Series, Summer 2004. J. Timmons Roberts and Bradley C. Parks*. [not peer-reviewed]

2007 "Urgent But Uncertain: The Dilemmas for Climate Change, Development, Adaptation and Justice for Development and Humanitarian Work." *Monday Developments: The Latest Issues and Trends in International Development and Humanitarian Assistance*. August, 2007: p.10-11. [Specialty magazine article, not peer-reviewed]

2007 "Saving the Earth One Place at a Time: Working for Change in Local Government." [Commissioned piece for Annenberg Foundation citizenship education curriculum guide, Keith Whitescarver, editor, not peer-reviewed]

2007 "The Media and Climate Change Aid." (Maxwell Boykoff and J. Timmons Roberts), background paper commissioned by the United Nations Development Programme for *Human Development Report 2007*. [white paper, not peer-reviewed]

2007 "The Clean Development Mechanism: As Assessment of Current Practice and Future Approaches for Policy." Emily Boyd, Nathan E. Hultman, J. Timmons Roberts, Esteve Corbera, (Contributing authors: Johannes Eberling, Diana M. Liverman, Kate Brown, Robert Tippmann, John Cole, Phil Mann, Marius Kaiser, Mike Robbins, Adam Bumpus, Allen Shaw, Educardo Ferreira, Alex Bozmoski, Chris Villiers and Jonathan Avis.) Tyndall Centre for Climate Change Research/Oxford University Environmental Change Institute Working Paper 114. [working paper, not peer-reviewed]

2008 "The Reality of Official Climate Aid." J. Timmons Roberts, Kara Starr*, Thomas Jones*, Dina Abdel-Fattah*. Oxford Energy and Environment Comment, November 2008. Oxford Institute for Energy Studies. [Working paper, not peer-reviewed.]

2009 "Billions at Stake in Climate Finance: Four Key Lessons." International Institute for Environment and Development (IIED) Briefing, November 2009. Peter Newell, J. Timmons Roberts, Emily Boyd, and Saleemul Huq. Online at: www.iied.org/pubs/display.php?o=17075IIED [policy briefing, not peer reviewed]

2010 "Copenhagen's Climate Finance Promises: Six Key Questions." International Institute for Environment and Development (IIED) Briefing, February 2010. J. Timmons Roberts, Martin Stadelman, and Saleemul Huq. Online at www.iied.org/pubs/pdfs/17071IIED.pdf [policy briefing, not peer reviewed]

2010 "Baseline for Trust: Defining 'New and Additional' Climate Funding." International Institute for Environment and Development (IIED) Briefing, June 2010. Martin Stadelman, J. Timmons Roberts and Saleemul Huq. Online at http://www.iied.org/pubs/pdfs/17080IIED.pdf [policy briefing, not peer reviewed]

2010 "Copenhagen's Climate Finance Pledges." *Tiempo: A Bulletin on Climate and Development.* Issue 77, p. 28.

2010 "How many people does it take … to administer long-term climate finance?" David Ciplet*, Benito Mueller, and J Timmons Roberts. European Capacity Building Initiative (ECBI) Policy Report October 2010.

2010 "Fast-start Adaptation Funding: Keeping Promises from Copenhagen." International Institute for Environment and Development (IIED) Briefing, November 2010. David Ciplet*, Achala Chandani, J. Timmons Roberts and Saleemul Huq. Online at http://www.iied.org/pubs/pdfs/17080IIED.pdf [policy briefing, not peer reviewed]

2010 "Keeping a big promise: options for baselines to assess "new and additional" climate finance." Martin Stadelmann, J. Timmons Roberts, and Axel Michaelowa. Working Paper Series, University of Zurich. November 2010. [Working Paper, not peer reviewed]

2011 "A Collective Commitment"? Nailing down Climate Finance at Cancun and Durban." J. Timmons Roberts and Martin Stadelmann. *Outreach* special issue on Cancun climate negotiations, January 2011.

2011 "Scoring fast-start climate finance: leaders and laggards in transparency." David Ciplet*, J. Timmons Roberts, Martin Stadelmann, Saleemul Huq, Achala Chandani. International Institute for Environment and Development (IIED) Briefing, September 2011. Online at http://pubs.iied.org/17100IIED.html. [policy briefing, not peer reviewed]

2011 "Adaptation finance: How can Durban deliver of past promises?" David Ciplet*, J. Timmons Roberts, Mizan Khan, Linlang He* and Spencer Fields*." International Institute for Environment and Development (IIED) Briefing, November 2011. Online at http://pubs.iied.org/17115IIED.html [policy briefing, not peer reviewed]

2012 "The Eight Unmet Promises of Fast-Start Climate Finance." David Ciplet*, Spencer Field*, Keith Madden*, Mizan Khan, and J. Timmons Roberts. International Institute for Environment and Development (IIED) Briefing, November 2012. [policy briefing, not peer reviewed] Online at:

2013 "Least Developed, Most Vulnerable: Risks and Opportunities of Fast Start Climate Finance and Beyond for the LDCs." David Ciplet*, Timmons Roberts, Spencer Fields*, Keith Madden*, and Mizan Khan. Policy Briefing, European Capacity Building Initiative/Oxford Climate Policy, March 2013. [white paper, not peer reviewed]

2013 Marcoux, Christopher, Bradley C. Parks, Christian M. Peratsakis, J. Timmons Roberts, and Michael J. Tierney. *Environmental and climate finance in a new world: How past environmental aid allocation impacts future climate aid.* No. 2013/128. WIDER Working Paper, 2013. [Working paper, not peer-reviewed]

2013 "A Fair Compromise to Break the Climate Impasse: A Major Economies Forum Approach to Emissions Reductions Budgeting." Marco Grasso and J. Timmons Roberts. Global Views Policy Briefing, The Brookings Institution. Washington, April. [white paper, not peer reviewed]

2013 "First Steps Toward a Quality of Climate Finance Scorecard (QuODA-CF): Creating a Comparative Index to Assess International Climate Finance Contributions." Katherine Sierra, Michele de Nevers,

Timmons Roberts, Claire Langley, Cory Smith. Brookings Institution/Center for Global Development. [White Paper, not peer reviewed]

2013 "European and Latin American and the Caribbean cooperation on climate change: paving the road towards a new climate change treaty in 2015." Guy Edwards and J. Timmons Roberts. EU-LAC Foundation. November 2013. [White Paper, not peer reviewed]

2014 "High-Carbon Partnership? Chinese-Latin American Relations in a Carbon-Constrained World." Guy Edwards and J. Timmons Roberts. Brookings Institution Global Working Papers 68. Washington, DC.

2015 "COP15 and the Latin American Bloc: Not in harmony." Guy Edwards and J. Timmons Roberts. *Americas Quarterly*. Winter 2015: 31-36.

2015 "Walking the Talk? World Bank Energy-Related Policies and Financing 2000-2004 to 2010-2014." A joint policy briefing from Brown University's Climate and Development Lab and the Institute for Policy Studies. Janet Redman, Institute for Policy Studies, Alexis Durand, Maria Camila Bustos, Jeff Baum, and Timmons Roberts. October. Washington DC: IPS.

2015 "Toward Mutual Accountability: The 2015 Adaptation Finance Transparency Gap Report." *AdaptationWatch.org*. 98 page policy report. Co-lead author with Romain Weikmans.

5.e. Book Reviews:

1992 Review of: *Virtual Reality*, by Howard Reingold. *American Journal of Sociology*, Vol. 98 No. 3, Nov. 1992.

1995 Review of *Commodity Chains and Global Capitalism*. Edited by Gary Gereffi and Miguel Korzeniewicz (Praeger, 1994). *Social Forces* Vol. 73, pp. 1170-1.

1995 Review of *Asia's Environmental Crisis*. Edited by Michael C. Howard (Boulder: Westview Press, 1993). *Contemporary Sociology*, Vol. 24, No. 2, pp. 211-212.

1995 Review of: *The State of Nature: Ecology, Community and American Social Thought* by Gregg Mitman (Chicago: University of Chicago Press, 1992). *Society and Natural Resources* Vol. 7, p. 267-269, 1995.

1998 Review of *Understanding Globalization: The Social Consequences of Political, Economic, and Environmental Change*, by Robert K. Shaeffer (Roman and Littlefield, 1997). *Contemporary Sociology* 27(6): 596-597.

1999 Review of *The Promise and Peril of Environmental Justice*, by Christopher H. Foreman, Jr. (Brookings Institution Press, 1998). *Organization and Environment*, 12(2): 225-228. Melissa M. Toffolon-Weiss and J. Timmons Roberts.

2001 Review of *Exporting Environmentalism: U.S. Multinational Chemical Corporations in Brazil and Mexico*, by Ronie Garcia-Johnson (MIT Press, 2000). *Society and Natural Resources*. Forthcoming.

2007 Review of *Environmental Sociology: From Analysis to Action*. Edited by Leslie King and Deborah McCarthy. (2005. Roman and Littlefield). *Contemporary Sociology*, September, 2007

2007 Review of A. Hall (ed.) "Global Impact, Local Action. New Environmental Policy in Latin America", (Inst. For the Study of the Americas 2005), Forthcoming in *E.I.A.L (Estudios Interdisciplinarios de America Latina y el Caribe)* Instituto de Historia y Cultura de America Latina.

2009 Review of *Labor-Environmental Coalitions: Lessons from a Louisiana Petrochemical Region*. By Thomas Estabrook. (2007, Baywood Publishing). *Review of Radical Political Economics*.

5.x. Op-Eds, Blogs and Other Public Scholarship

To be completed. Many have appeared, especially on brookings.edu, newsweek.com, intercambioclimatico.com, and climatedevlab.org and in the *Providence Journal*.

5.g. Invited Lectures (since 2005, more available in online CV);

2015 Invited Lecture. Leeds University Sustainability Research Institute, Centre for Climate Change Economics & Policy (CCCEP) and Polis (Political Science), Centre for Global Development Leeds, England. 24 November.
2015 Invited Lecture. Tyndall Centre, University of Manchester, England. 23 November.
2015 Invited Keynote. Lisbon Conference: I Congresso CPLP Sobre Alterações Climáticas (First Conference of the Portuguese Speaking Nations on Climate Change.). 19-20 November. Directorate of the Universidade de Lisboa, Portugal.
2015 Invited Panelist. "Prospects for the Paris Climate Negotiations: A View from the Global South." Boston University Pardee School. November 5.
2015 Invited Keynote. "The Political Economy of Ecologically Unequal Exchange" conference, University of Tennessee, Knoxville. October 15.
2015 Invited Panelist. "The Social Life of Climate Change." Stanford University Woods Institute/ Center for Advanced Study in the Behavioral Sciences. September 30.
2015 Invited Panelist, "US-Japan Forum: Uncertain Prospects and Policy Challenges for the Global Economy." Brookings Institution and Japan Economic Foundation. Sept. 25, Washington, DC.
2015 Invited Keynote. "Constructing a Non-System: Failing Trust and the Enduring Tensions Over (What Counts as) Climate Finance." 2015 Lund Climate Finance Workshop: "Climate Finance: Taking Stock, Future Directions for Policy and Research" Lund University, Sweden, 17-18 April. By teleconference.
2015 Invited Panelist, ClimateWorks/Climate Advisors Workshop on "Energy Efficiency in Foreign Aid." April 2015. Washington, DC.
2015 Discussant. "Brown-Hertie School Workshop 'China Environmental Governance.'" Hertie School of Governance/Watson Institute. 14-15 May, 2015.
2014 "Revisiting "Common But Differentiated Responsibilities": Opportunities for the 2015 Climate Agreement." Commentator. German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE) Tuesday, 11 March 2014.
2014 "Inequality and Climate Change: Vulnerability, Responsibility, Action." School of Environment and Natural Resources, Ohio State University, SENR Seminar Series. 6 February.
2014 "Climate Justice, Latin America, and the UN Negotiations." Mershon Center for International Security Studies, Ohio State University. Climate Justice Lecture Series. 7 February.
2013 "Heat waves and vulnerable populations in Rhode Island: Identifying and addressing barriers to protection." Exploring Climate Change Impacts on Health- Heat and People 65+. Rhode Island Department of Public Health. 8 October.
2013 "Foreign Aid, Emerging Powers and Climate Change Politics." Instituto de Estudos Sociais e Políticos da Universidade do Estado do Rio de Janeiro (IESP-UERJ). 10 May.
2013 "Contexto das políticas de mudanças climáticas nos EUA." Federal University of Fluminense, Brazil, Post-graduate Program in Sociology and Law, miniconference on Climate Change and Public Policy. 7 May.
2013 "Sustainable Development Policies." Harvard University South Asia Institute International Seminar on Environment-Development Relationship in Bangladesh, 13 April.
2013 "Managing $30 Billion for Sustainability: Tracking, Evaluating and Improving 'Fast Start' Climate Change Finance." The George Perkins Marsh Institute Seminar Series, Clark University. Jan 31.
2013 "Climate Justice: Looking Forward." Boston University Department of Environmental Health at Boston University School of Public Health seminar series Climate Change: Science, Health, and Policy. Feb 1.
2013 "Some Walk but No Talk: Obama Administration Rhetoric and Action on International Climate Finance." Vanderbilt University Symposium on Climate Politics and Denial. February 8.
2013 Invited panelist, Brookings Institution/World Bank Independent Evaluation Group event "Adapting to Climate Change: Learning from the World Bank's Experience." February 13.
2012 Invited panelist, High level panel on climate finance, *Development and Climate Days,* United Nations Framework Convention on Climate Change negotiations, Doha, Qatar. December 2.

2012 "A divided greenhouse: ideological and strategic differences between two transnational climate change advocacy networks." Program for Society and the Environment, University of Maryland. Nov. 14.
2012 "Climate Change and Global Inequality: Vulnerability, Responsibility, Action." Rutgers University, keynote address for the Rutgers Climate Symposium. November 9.
2012 "Just International Climate Policy." Brown International Advanced Research Institute on "Climate Change and its Impacts." June 14.
2012 "Climate Change and the Global 99 Percent." Occupy Providence invited talk, June 8.
2012 "Governing Billions for the Earth." University of Colorado Environmental Studies Program. April 25.
2012 "The Politics of Adaptation Finance Governance." Invited Semi-Plenary at the *Lund Conference on Earth System Governance: Towards a Just and Legitimate Earth System Governance*, Lund, Sweden, April 16-18.
2012 "Climate Change: Global and Local Perspectives." Sustainable Communities Initiative, Critical Issues in Sustainability Lectures, Rhode Island College. April 12.
2011 "Tracking and evaluating climate finance: Possible, Needed." Presentation at Climate and Development Days, International Institute for Climate and Development conference at the Durban United National climate change negotiations, Dec. 3-4.
2011 "A justice approach to climate change." Interfaith Power and Light. La Salle Academy, Providence, 24 March.
2010 Invited Presentation, "Monitoring and Evaluation of Funding for Adaptation to Climate Change." Climate and Development Days, side conference at the Cancun UNFCCC negotiations, organized by the International Institute for Environment and Development, December 5, 2010.
2010 Invited Presentation, "Tracking Climate Finance; Latin American Climate Networks." International Climate Change Symposium: Relevant Research for Mexico. Side event at UNFCC negotiatiations co-organized by Oxford University Environmental Change Institute, University of Arizona and the National Institute of Ecology of Mexico. 2 Dec.
2010 Invited Keynote ""International Climate Justice and the Road to Cancun: Identifying and Addressing the Structural Roots of Non-Cooperation." Berlin Conference on the Human Dimensions of Global Environmental Change. October 8-9, Berlin.
2010 Invited Plenary/Integrative Session Lecture, "Climate Change, Social Theory, and Justice." International Sociological Association's World Congress, Gothenburg, Sweden, July 2010.
2010 Invited Presentation, "From Kyoto to Copenhagen: Climate Justice in a Multipolar World." International Sociological Association's World Congress, Gothenburg, Sweden, July 2010.
2010 Invited Lecture, "Global Inequality, Social Theory, and the North-South Impasse at Copenhagen." Yale University School of Forestry and Environmental Studies. March 3.
2010 Invited Lecture, "Climate Change, Inequality, and Social Theory." Sociology Colloquium, Brown University, March 9.
2009 Invited lectures during the fall for the Brown Cogut Center, the Brown Democrats, and the Marine Biological Laboratory, Woods Hole
2009 Invited Lecture, "Why Global Inequality Matters for Breaking the Impasse over Climate Change." Drexel University. 17 February.
2009 Invited Lecture, "Foreign Aid and Climate Change: Adaptation, Mitigation, Compensation?" University of Michigan School of the Environment and Natural Resources, Feb. 9.
2008 Commentator, "Non-Governmental Diplomacy: New Challenges/Climate Change." Conference on Non-Governmental Diplomacy. InterAction, Ronald Reagan Building, Washington, DC. December 11, 2008.
2008 Invited Speaker, "Greening Aid? Understanding the Environmental Impacts of Development Assistance." Science, Technology and Environmental Policy Program, Woodrow Wilson School of Public Policy, Princeton University. November 17, 2008.
2008 Invited Speaker, "The Climate Justice Movement: Clear Need, Unclear Path." Massachusetts Institute of Technology, Environmental Policy and Planning Program, October 21, 2008.

2008 Invited Speaker, "Environmental Policy and the Next President." *Blue Planet Forum*, Norfolk, Virginia, Oct. 7, 2008.
2008 Invited Speaker, *Tipping Points: Climate and Art* University of Oxford Conference, September 2008.
2008 Invited Speaker. "Environment, Climate Change and the Packaging Industry." PrintPack Corporation Rampart Division, Williamsburg, Virginia.
2007 Invited Keynote, UNESCO Side Event, Kyoto Protocol Meeting of the Parties, Bali, Indonesia, Dec. 14, 2007.
2007 Invited Public Lecture, "A Climate of Injustice: Global Inequality and Climate Change Vulnerability, Responsibility, and Action." Faculty of Law, University of Toronto. Nov. 1, 2007.
2007 Panelist, "Climate Change and the Future of Tourism." Council for Hospitality Management Education. Oxford, UK. May 10.
2007 Public Lecture "Inequality, Trust, and the Kyoto Impasse: World-Systems Insights on Climate Vulnerability, Responsibility, and Action." Wageningen University, Netherlands. May 23.
2007 Public Lecture "Global Inequality and Climate Change: Vulnerability, Responsibility, and Action." Institute for Social Ecology, IFF, Klagenfurt University, Vienna Austria. March 27.
2007 Lecture "The Greening of Aid?" London School of Economics, Geography Series, January 17
2006 Guest lecturer, MSc/MPhil course, *Environment and Society*, Cambridge University, October 18.
2006 Presenter, "Understanding the Carbon Economy" workshop, Environmental Change Institute, Oxford University. August.

5.h. Papers Read (since 2005, many more available on web CV):

2015 "Neoliberal Climate Governance." American Sociological Association annual meetings, Chicago.
2015 "Beyond the North-South Divide? Global Climate Politics in the New World Order" Regular Session: "Can Comparative Historical Sociology Save the World? (2) Climate Change". David Ciplet, J. Timmons Roberts, and Mizan Khan. American Sociological Association, Annual meetings, Chicago.
2014 "Climate change and the global South: Vulnerability, Responsibility, Identity, Solidarity and Resistance." J. Timmons Roberts and David Ciplet*. Thematic Session: Environmental Climate Change and Social Inequality. American Sociological Association, Annual meetings, San Francisco.
2014 "Climate Justice and Sociology: A Research Agenda." Presentation at the International Sociological Association World Congress of Sociology. Yokohama, Japan.
2012 "A Divided Greenhouse: Understanding Inter-network power dynamics in transnational civil society." Watson Institute for International Studies workshop on "Transnational Strategies for Supporting Collective Capabilities." October 26-27. Organizers: Peter Evans and Nitsan Chorev.
2012 "No Talk but Some Walk: Obama Administration Rhetoric on Climate Change and International Climate Spending." American Sociological Association annual meeting, Denver, CO. Aug 18.
2012 "Power in a Warming World: Consent and Inequality in Global Climate Change Politics." American Sociological Association annual meeting, Denver, CO. Aug 20
2012 "Politics and Justice in International Climate Adaptation Finance: Supply, Governance, Allocation David Ciplet*, J. Timmons Roberts and Mizan Khan. International Studies Association annual meeting, San Diego CA.
2012 ""Three Hungry Giants: China, the US and the EU in the Search for Resources in the Developing World" Guy Edwards and J. Timmons Roberts. Presented at "Beyond Competition? China, Climate Change, Security and the Developing World," a Year of China Miniconference, April 6, Brown University.
2011 Rethinking Development—First Sociology of Development Conference, Cornell University. David Ciplet* and J. Timmons Roberts. November.
2011 "Climate adaptation and finance: mapping a research domain and agenda focused on a global/transnational sociology of climate change." J. Timmons Roberts. Thematic Panel, American Sociological Association, 18-22 August, Las Vegas.
2011 "Political Economy of the Environment: A Commodity Chain Approach." JoAnn Carmin, J. Timmons

Roberts and Thomas Rudel. American Sociological Association, 18-22 August, Las Vegas.

2011 "Tracking funding of climate efforts in developing countries and potential for tracking with georeferencing and crowdsourcing." United Nations International Strategy on Disaster Reduction/Government of Finland Preparatory Workshop for Third Session of the Global Platform for Disaster Risk Reduction 2011: Tracking of Disaster Risk Reduction and Recovery Investments in International Aid. 13-14 April 2011, Helsinki, Finland.

2011 "The Politics of International Climate Adaptation Funding: Divisions in the Greenhouse." J. Timmons Roberts, David Ciplet and Mizan Khan. Princeton University workshop on the Politics of Climate Change, February 17, 2011.

2011 "National indicators of vulnerability and the politics of adaptation finance." Mapping and Modeling Climate Security Vulnerability. University of Texas at Austin; May 16-17, 2011.

2010 "Funding for International Adaptation and North-South Climate Justice: Claims, Bargaining, and Proposals in the Copenhagen Round." International Studies Association, New Orleans, February, 2010.

2010 "Understanding Global (Non-) Cooperation on Climate Change: Social Theory, Hybrid Justice, and The Need to Re-Link Development and Environment." International Sociological Association, Gothemberg, Sweden, July, 2010.

2009 "Coping With Climate Change: Dimensions of Injustice." Thematic Session: Climate Change and Threatened Communities. American Sociological Association 2009 Annual Meetings, San Francisco.

2009 "Addressing Real Needs or Greasing Political Skids? Insights on the Allocation of Environmental Aid." With Robert Hicks, Michael Tierney, and Bradley Parks*. International Studies Association, New York, March, 2009.

2009 "Unequal Vulnerability to Climate Change and Breaking the Negotiations Impasse: Environmental Justice and Potential Solutions." With Bradley C. Parks*. International Studies Association, New York, March, 2009.

2009 "The Importance of International Adaptation Funding for Climate Justice." WE-ACT (West Harlem Environmental Action) conference on Climate Justice, Fordham University, NYC, 29-30 January.

2008 "Warming Climate? Labor-Environmentalist Relations and the Global Climate Crisis." With Tammy Lewis and Kenneth Gould. American Sociological Association, August 2008, Boston

2008 "Coping With Climate Change: Dimensions of Injustice." Co-sponsored panel, Section on Race, Gender and Class, American Sociological Association, August 2008, Boston.

2008 "Ecologically-Unequal Exchange, Ecological Debt, and Climate Justice: History and Implications of Three Linked Ideas for a New Social Movement." With Bradley C. Parks*. American Sociological Association, August 2008, Boston.

2008 Participant, "What's New About the New Carbon Economy" Workshop, Environmental Change Institute, Christ Church College, University of Oxford. September 2008.

2007 Presenter at conference "Climate Change: A Globally Integrated Climate Policy for Canada." Nov. 2, Faculty of Law/ Centre for International Studies/Hart House, University of Toronto. With Bradley Parks*.

2007 Presenter at conference "Climate Change and Development in Africa." Centre for the Environment, University of Oxford, Tyndall Centre for Climate Change Research. March 12, 2007.

2007 Presenter at conference "Climate Change and the Fate of the Amazon." Environmental Change Institute, Oxford University Centre for the Environment, James Martin 21st Century School. March 20-22, 2007. Maria Carmen Lemos and J. Timmons Roberts.

2007 Presenter at conference "Shifting the Discourse: Climate Change as an Issue of Human Security." European Science Foundation Exploratory Workshop, Oslo, Norway, June 20-22, 2007.

2007 "Emerging contradictions for civil society in climate governance: carbon offsets, food miles, forests and development." Diana Liverman and Timmons Roberts. "Blind Spots of Global Climate Governance" 16th February 2007. Berlin, Germany

2006 "Addressing the Structural Roots of Carbon Emissions Intensity: Export Profiles, Foreign Assistance, and 'Pathway Switching' to Low Carbon Development Strategies in LDCs." Berlin Conference on the Human Dimensions of Global Environmental Change, Nov. 17-18, 2006.

2006 "The Political Market for Environmental Aid: Explaining Cross-National Donation Patterns." Robert Hicks, Bradley Parks* and Timmons Roberts. International Studies Association annual conference, March 22-25, San Diego

2006 "Is Kyoto Suffering From a Wider Disease? Explaining Participation and Non-Participation in the Kyoto Protocol and Other Major Environmental Treaties." Bradley Parks* and Timmons Roberts. International Studies Association annual conference, March 22-25, San Diego.

2005 "Understanding Vulnerability to Disasters: A Cross-National Analysis of 4,040 Climate-Related Disasters." Bradley C. Parks* and J. Timmons Roberts. American Sociological Association Annual Meeting, August 13-16, 2005, Philadelphia, Pennsylvania.

5.i. Work Under Review:

Several books, chapters and articles are in progress and under review. Details are available on request.

5.j. Work in Progress:

Several books, chapters and articles are in progress and under revision. Details are available on request.

6. Research Grants:

6.a. Current Grants:

2015-2016 John Merck Fund. Support for the EnergizeRI coalition to pass carbon pricing legislation in Rhode Island. $50,000, through the Environment Council of RI.

2015-2016 Merck Family Fund. Support for the EnergizeRI coalition to pass carbon pricing legislation in Rhode Island. $25,000, through the Environment Council of RI.

2015 Institute at Brown for Environment and Society Small Grants. Mapping and Tracking Climate Adaptation Projects: A Pilot Study." $30,000. [Internal]

6.b. Completed Grants

1989-1990 *Fulbright Commission* Doctoral Research Fellow, Grant Total: $14,000.

'92, '93, '97,'00 Research Fellow, *Mellon/Tinker Foundations*/Tulane Latin American Studies. Summer research grants for research in Brazil, $4000 each.

1993-1995 Principal Investigator, *National Science Foundation* Sociology Program Grant: "Social Roots of Environmental Damage: A World-Systems Analysis of Global Warming and Deforestation." Total costs: $140,438.

1993-1994 Principal Investigator, *Department of Energy* Grant: "Risk, Stress and Restructuring in the U.S. Petrochemical Industry: A Case Study from Louisiana." (Administered through Tulane/Xavier Consortium). Total costs: $38,892.

2002-2003 Co-Principal Investigator, *Virginia Environmental Endowment*. "Environmental Impacts of Development in Southeastern Virginia Watersheds: Interdisciplinary Measurement and Analysis." Total Costs: $25,944 plus $25,977 matching grant.

2003-2006 Co-Principal Investigator, *National Science Foundation* Research Experience for Undergraduates (REU) program. "Interdisciplinary Watershed Studies," P.I. Randy

Chambers, Director of the Keck Environmental Field Laboratory. Total costs: $200,621.

2005-2008 Director and Lead Writer, Renewal Grant from *Mellon Foundation* "Enhancing Undergraduate Environmental Science and Policy at the College of William and Mary." $300,000 ($530,000 in institutional match).

2005-2008 Co-Principal Investigator, *National Science Foundation Political Science Program Research Grant*: "Collaborative Research: Analyzing Development Finance Using PLAID Data" [Project-Level Aid]. Michael Tierney, PI. Total Costs: $253,000.

2006-2007 James Martin 21st Century Professor, *Environmental Change Institute, Oxford University*. Office, travel, research, conference organizing, and living support totaling over $40,000.

2008-2011 Co-Principal Investigator, *Bill and Melinda Gates Foundation* Grant to the Project-Level Aid Research Project, awarded August, 2008. $1.44 million and $1.5 million supplement.

2008-2011 Program Director, *Mellon Foundation* Grant for the Creation of Postdoctoral Teaching and Research Fellowships in Environmental Science and Policy, and the Creation of a Center for Geospatial Analysis at the College of William and Mary. $1.5 million.

2009-2011 Principal Investigator, UK government Department of International Development (DFID) commissioned research: "Measuring DFID Spend on Climate Adaptation." $82,000.

2010-2012 Principal Investigator, *Rhode Island Foundation*. Support for Rhode Island Climate Change Commission. Collaborative project with the Statewide Planning office, the Senate Policy Office, and the Environment Council of Rhode Island to provide staff assistance for a new commission created by legislation penned by my students. $25,000.

2008-2013 Co-Principal Investigator, *William and Flora Hewlett Foundation* Grant to the Project-Level Aid Research Project, awarded May, 2008. $500,000 initial grant plus $250,000 supplement; $1.0 million further funding awarded in 2010.

2009-2014 Lead of contract research team for US Department of Defense MINERVA research project to University of Texas on Fragile States and Climate Change in Africa. Total Subaward $66,131.

2014-2015 Sidney E. Frank Foundation, "Mapping Climate Change Civil Society Organizations in Latin America." Timmons Roberts and Guy Edwards. $7,000.

2014 "Engaged Climate Policy at the UN Climate Negotiations." Global Engaged Learning and Teaching grant for bringing 12 Brown undergraduates to the UN climate negotiations in Lima, Peru. $25,000. Funded. [Internal]

6.c. Proposals Submitted but not Funded

Over 2011-14 I led the submission of major proposals and letters of inquiry to the MacArthur and Rockefeller Foundations, and to the Climate and Development Knowledge Network. I submitted three other proposals to NSF; I have participated in requests to USAID and other agencies for the PLAID/AidData initiative for tracking development finance. I led preparation of a proposal to the Rockefeller Foundation for AdaptationWatch on tracking climate finance, the grant was for $1.2 million. While Director of the Center for Environmental Studies, I worked with Advancement, the VP for Research, and Corporate and Foundation relations at Brown to develop a series of proposals for the CES and ECI to initiate a think tank and environmental clinic.

7. Service:

7.i. Service to the University

The College of William and Mary:

2001-2003	Environmental Science and Policy Cluster Board
2002-2005	Landscape, Environment and Energy Committee
2002-2003	International Studies Committee
2001-2006	Dean's Advisory Committee (also 2007-2008)
2008-2009	Transportation Task Force, Committee on Sustainability

Tulane University:

1992-1994	Co-Organizer, Latin American Political Economy working group
1993-1998	Official Representative for *Tulane University* to the Inter-University Consortium for Political and Social Research, Ann Arbor, Michigan.
1993-1997	*Sociology Department* Undergraduate Committee (Chair 1995-1997).
1993,94,95	Created and ran graduate student grant writing workshop, January-April, *Center for Latin American Studies*
1995-1997	ESL (English as a Second Language) Committee
1995-1997	Latin America Library Committee
1996-1997	Co-coordinator, Tulane Environmental Project.
1996-2001	Environmental Studies Committee
1996-2001	Executive Committee, Neotropical Ecology Institute
1997-2000	Executive Committee and Director Search Committee, *Center for Latin American Studies*
1998	Steering Committee, Tulane Environmental Management System Initiative
1998-2001	Steering Committee, Murphy Institute of Political Economy
2000-2001	Senate Committee on Faculty Tenure, Freedom and Responsibility

Brown University:

2009-	Steering Committee, Environmental Change Initiative
2009-2012	Chairs and Directors Committee
2009-2011	Energy and Environment group (VP for Research)
2009-2010	Environment Council (and surrogate efforts to build interdisciplinary links)
2009, 2010	Advisor to student delegation to Copenhagen, Cancun climate negotiations
2010-2011	Co-Chair of Search Committee, joint double search in environment
2011-2012	Search Committee, Director of Watson Institute for International Studies
2011-2012	Chair of Search Committee, senior social scientist, Environmental Studies
2012	Chair of Search Committee, Visiting Professor, Environmental Studies
2013-2016	Campus Life Advisory Board
2015-2017	Tenure, Promotion and Appointments Committee

Also, I have led the production of key guidance documents for university sustainability planning:

The *Campus Sustainability Road Map*. June, 2008. (College of William and Mary)
http://greeningwm.com/campus_sustainability_roadmap.pdf
Environmental Science and Policy students supervised by J. Timmons Roberts and 11 other faculty.

Green=Gold? Energy Audit of The College of William and Mary. J. Timmons Roberts and Environmental Sociology Class. 2006.

"Greening the Green and Gold: 2002 Environmental Assessment of the College of William and Mary." Available at http://faculty.wm.edu/jtrobe. J. Timmons Roberts and Environmental Sociology Class. 2002.

7.ii. Service to the Profession

1992-1993	Nominations Committee, Political Economy of the World Systems Section, *American Sociological Association.*
1993-1994	Roundtables Organizer, Annual Meetings of the section on Political Economy of the World System, *American Sociological Association.*
1994-2003	Founder and Co-editor, Environment in Latin America (electronic) Network, (ELAN@csf.colorado.edu) formed by the Environment and Natural Resources Working Group of the *Latin American Studies Association.*
1994-2005	Chair, Electronic Networking Committee of the Environment and Technology section of the *American Sociological Association.* Set up and administered section's electronic network (ENVTECSOC@csf.colorado.edu, now envirosoc@neu.edu)
1995-2000	Elected co-chair Environment and Natural Resources Working Group of the *Latin American Studies Association.* Secretary-treasurer 1997-1998.
1995-1998	Elected to the Council of the Political Economy of the World System section, *American Sociological Association.*
1995-1996	Nominations Committee co-chair, Environment and Technology section, *American Sociological Association.*
1998-2001	Elected to the Council of the Environment and Technology section of the *American Sociological Association.*
2000-2001	Track Chair, Environment, *Latin American Studies Association*, 2001 Conference, Washington, DC. Organized 17 sessions for the international meeting
2003-2004	Track Chair, Environment, *Latin American Studies Association*, 2004 Conference, Las Vegas, NV. Organized 10 sessions for the international meeting
2005-2009	Chair-Elect and Chair of the Environment and Technology section of the *American Sociological Association.*
2005-2009	Editorial Board, *Contemporary Sociology.*
2012	External Reviewer, all 23 interdisciplinary programs, Tufts University, March 28-29.
2013-2015	Editorial Advisory Panel, social sciences, *Nature: Climate Change*
2013-2015	Member, American Sociological Association Task Force on Global Climate Change.

Other editorial boards: *Environmental Sociology* [new Routledge journal from the International Sociological Association, launching 2015]; *Human Ecology Review*; *Journal of World-Systems Research*

I have prepared 2-6 external review letters for tenure, promotion to Associate Professor and promotion to Full Professor every year for the past decade, and I review for a half dozen or more journals and book publishers each year, including *World Development; Nature: Climate Change; Social Problems; American Sociological Review; Climatic Change; Climate and Development; Environmental Science and Policy; Global Environmental Change; Global Environmental Politics; Social Science Research; Society and Natural Resources; Latin American Research Review; Law and Policy;* National Science Foundation Sociology Program; and others.

CONFERENCES AND SESSIONS ORGANIZED:

2016 Co-convener, Finance and Investment theme for Adaptation Futures conference (AF2016), 10 to 13 May 2016 in Rotterdam, the Netherlands.

2015 Co-organizer. "Sociology of Development 2015 Conference." Brown University. 240 presenters and attendees. (The organizing team was six sociologists from Brown).

2014 Organizer. "Greenhouse Gas Emissions Reductions in RI: from Goals to Implementation. An intensive workshop." Organized with the collaboration of the Office of the Governor, Rhode Island. September 26.

2014 Co-Organizer. "Governing Climate Change: New Ideas and Latin American Leadership as Peru Prepares to Host the 2014 UN Climate Negotiations." Watson Institute, Brown University. April.

2012 Lead Organizer, "China, Climate Change, Security, and the Developing World." April 6, Brown University, co-sponsored with the Watson Institute of International Studies. One day workshop.

2011 Co-lead organizer, Official side event at the UNFCCC negotiations in Bonn, Germany, organized with the International Institute for Environment and Development, CPI-Venice.

2011 Co-Lead Organizer, "Latin America and Climate Change." April 7-8, Brown University Watson Institute of International Studies.

2010 Lead Organizer, Official Side Event at the UNFCCC negotiations in Cancun, Mexico, "The Reformed Financial Mechanism & Accounting of Climate Finance." Co-sponsored by Brown University, Oxford Institute of Energy Studies/Oxford Climate Policy, the International Institute for Environment and Development (IIED) and CIS, University of Zurich. 3 December 2010, Cancunmesse.

2010 Co-Lead Organizer, "What is Going On With Aid? Insights from a New Generation of Aid Information." University College, Oxford University, March 22-25. Co-sponsored with the Global Economic Governance Program, Oxford University.

2009 Co-Organizer, Washington, DC PLAID (Project-Level Aid) Data Vetting Workshop, 16-18 September.

2009 Series of Sessions Co-Chair, "Climate Change: Global Risks, Challenges and Decisions." Copenhagen Science Conference of the International Association of Research Universities, 10-12 March 2009. International Alliance of Research Universities. Co-organized two sessions in Theme 2-11 "Equity Between Nations and Regions" with Coleen Vogel, University of Witwatersrand, South Africa.

2007, 2008, 2009 Co-organizer of all section sessions for the Environment and Technology Section, American Sociological Association annual meetings, August (Duty as Chair Elect and Chair of the section; total 9 sessions).

2007 Co-organizer, "Climate Change and Development in Africa." Centre for the Environment, University of Oxford, Tyndall Centre for Climate Change Research. March 12, 2007, with Henny Osbaugh.

2007 Co-organizer, "Climate Change and the Fate of the Amazon." Environmental Change Institute, Oxford University Centre for the Environment, James Martin 21st Century School, Oriel College, Met Office. March 20-22, 2007.

2006-2007 Co-organizer, "Climate Change and the Future: A Forum for Research in Progress." Seminar series, Environmental Change Institute, Tyndall Centre for Climate Change Research, and James Martin 21st Century School, Oxford University.15 speakers.

2006 "Divide to Conquer?: Union Schisms and New Opportunities for Environmentalist-Labor Coalition Formation." Kenneth A. Gould, Tammy Lewis, and J. Timmons Roberts. Eastern Sociological Society Annual Meeting, February 23 - 26, 2006, Boston,

2004 Environment Track (9 sessions), "Latin American Studies Association" XXV International Conference, Las Vegas, October 7-9, 2004 (Track Chair).

2000 "Globalization and the Environment." Miniconference co-sponsored by the Political Economy of the World System and Environment and Technology sections of the American Sociological Association. Anaheim, California, August 17, 2001. (co-organized with Paul Gellert, Cornell University).

2001 Environment Track (17 sessions), "Latin American Studies Association" XXIII International Conference, Washington DC, September 6-8, 2001. (Track Chair)

2000 "Sociological Reflections on Sustainability." *International Sociological Association*, Research Committee 24, conference on environmental policy, Rio de Janeiro, August 1-3, 2000 (co-organized with Eduardo Viola, University of Brasilia, Fredrick Buttel, University of Wisconsin, and an international organizing committee).

1999 "Poverty, Disasters and the Environment in Latin America." *Neotropical Ecology Institute*, Tulane University, April 9 and 10, 1999.

SESSIONS ORGANIZED AT PROFESSIONAL MEETINGS:

2009 Session Co-Chair, "Climate Change: Global Risks, Challenges and Decisions." Copenhagen, 10-12 March 2009. International Alliance of Research Universities. Co-organized two sessions in Theme 2-11 "Equity Between Nations and Regions" with Coleen Vogel, University of Witwatersrand, South Africa.

2004 "Environmental Activism and Movement Structure;" "The Environment in the Global System." Two regular sessions for the American Sociological Association annual meetings, San Francisco, CA.

2003 "Environmental Justice Movements in Latin America." ENV011 session for the XXIV International Congress of the Latin American Studies Association, March 27-29, Dallas, Texas.

2002 "Environmental Movements and Environmental Justice." Session co-organized with Leo Rinckevicius for the International Sociological Association's world conference in Brisbane, Australia, 2002.

2000 "Corporate and Urban Environmental Stewardship." *Latin American Studies Association* XXII International Conference, Miami, March 16-18, 2000.

1998 "Author Meets Critic: *A Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Carribean.*" With author Douglas Graham of the World Bank. *Latin American Studies Association* XXI International Conference, Chicago, Illinois, September, 1998.

1998 "Latin American Environmental Policy and Performance: Assessing Directions and Causes of Change." *Latin American Studies Association* XXI International Conference, Chicago, Illinois, September, 1998.

1997 "Assessing International Environmental Pressures on Latin American Firms and Governments." *Latin American Studies Association* XX International Conference, Guadalajara, Mexico, April, 1997.

1995 "Latin American Environmentalists: Who Are They?" *Latin American Studies Association* XIX International Conference, Sept. 28-30, 1995, Washington, D.C. Co-organized with Kathryn Hochstetler.

1995 "Environmental Regulations and Corporate Flight to Latin America: Comparative Perspectives." *Latin American Studies Association* XIX International Conference, Sept. 28-30, 1995, Washington, D.C.

1994 Informal Discussion Roundtables (twelve), Political Economy of the World-System Section of the *American Sociological Association* Annual Meetings, August, 1994, Los Angeles, California.

1992 "Economic Restructuring and Local Response: Cross-National Perspectives." *Latin American Studies Association* XVII International Congress, September 24-26, 1992, Los Angeles, California. Organized with Carol Zabin

1995 "Global Issues in Sociology." *Mid-South Sociological Association*, Mobile Alabama, October, 1995.

7.iii. Service to the Community

Legislation: In 2010 a group of students and I drafted the RI Climate Risk Reduction Act of 2010 which created the Rhode Island Climate Change Commission. From December 2013 to December 2014 I led a team of twenty Brown undergraduate interns and consultants to research, draft, and pass the first comprehensive climate change legislation in the state's history, called the ***Resilient Rhode Island Act***. The work involved legal, education, writing, communication and outreach, informing legislators and coordination with the Office of the Governor, the Senate Policy Office, the Department of Environmental Management, and the Environment Council of Rhode Island. The bill passed nearly unanimously and was signed into law August 1, 2014 by Governor Lincoln Chafee. I was appointed by Governor Gina Raimondo to the Scientific and Technical Advisory Board of the Executive Climate Change Coordinating Council (the EC4), where state agency heads coordinate planning for climate change in Rhode Island, as mandated by the Resilient RI Act.. From January 2015 to June 2016 I am co-leading a team of student interns and consultants in developing legislation on pricing carbon and dispersing revenue (including dividends and funding to weatherizing low-income housing and small businesses). Both projects are funded by the Office of the President, Brown.

I have not kept careful records of community service work I have done, but most of it has been in the form of unpaid policy research and service on advisory boards. From 2010-2014 I served on the Rhode Island Climate Change Commission (created by 2010 legislation my students and I authored); I co-chaired the Health and Well-Being subcommittee. I serve on the board of EcoEquity.org, an international climate justice organization, served on the Environmental Sustainability Task Force of the City of Providence, RI in 2012 and 2013, I served on the board of the J4C (James City County Concerned Citizens), on the executive committee of the Louisiana Chapter of the Sierra Club, and co-founded and led RRLU (Residents for Rational Land Use). In 2015, I was appointed by Governor Gina Raimondo to the Scientific and Technical Advisory Board of the Executive Climate Change Coordinating Council.

I routinely give public speeches on climate change and justice; in 2015 I keynoted at the Interfaith Power and Light annual conference and spoke Unitarian Universalists church in Providence. I have given speeches to groups as diverse as OccupyProvidence and the Lions Club of Williamsburg, Virginia.

I also have led students in the production of a series of policy research reports to address important local environmental issues such as: *Williamsburg Accessibility Project*. Pdf file available online at http://faculty.wm.edu. J. Timmons Roberts and Environmental Sociology Class. 2005. Presented to city and county officials; *Development and Watersheds in Greater Williamsburg: A Guide for Citizens and Students*. Pdf. File available online at http://faculty.wm.edu/jtrobe. Feldbaum, Maureen, Melanie Marzolf, and Timmons Roberts. 2002. *Preliminary Assessment of Rhode Island's Vulnerability to Climate Change and its Options for Adaptation Action*. 2009. *Trees and the Urban Heat Island Effect: A Case Study for Providence, Rhode Island*, 2010. *The Floods of March 2010: What Have We Learned?* 2011. In 2012 we worked with URI's Coastal Resources Center in developing a website on climate change in Rhode Island. In 2012 and 2013 we worked with the City of Central Falls in updating their Hazard Mitigation Plan to include more current climate information and some consideration of likely future climate impacts. Students reviewed the State of Rhode Island's Vulnerability Assessment and Hazard Mitigation Plan and proposed revisions to include past and likely future climate change impacts. In both cases we paid significant attention to identifying especially vulnerable populations and developing outreach, as these are the groups who suffer most from disasters.

Consultancies:

2013	EU-Latin America and Caribbean Foundation. Policy briefing on EU-LAC collaborations. With Guy Edwards.
2012	Freidrich Ebert Foundation (Germany). Policy briefing on China, Latin America, and Climate Change. With Guy Edwards.
2010	European Capacity-Building Initiative, Oxford Climate Policy. Research brief on staffing needed for administering climate finance. With Benito Mueller and David Ciplet*.
2009	Department for International Development (DFID), government of the United Kingdom. Assessment of the proportion of the DFID portfolio of projects which could help developing countries adapt to climate change.
1998-2000	Consultant to the Louisiana Office of Public Health, Department of Environmental Epidemiology. Providing recommendations on OPH contacts with communities and stakeholder groups and ways to address stress and fear of toxic exposures. Facilitated development of brochure on pesticide poisoning.
1998	Research Consultant, The World Wildlife Fund/Conservation Foundation's MPO: Macro-Economic Policy Organization. Prepared position paper on the relationship between government policies, poverty, and environmental damage in the rural areas of developing nations.
1997, 1999	Research Consultant, Louisiana Environmental Action Network. Researched legislative voting records, prepared scorecards. Presented environmental attitudes survey results to state legislators.
1990	Research Consultant, Municipal Planning Secretariat, Parauapebas County, Pará, Brazil. Conducted research and analysis on economic and social conditions in an Amazon boom town.
1989	Research Consultant, The World Wildlife Fund/Conservation Foundation. Prepared background document for conservation policy on the Brazilian Amazon.
1989	Research Consultant, Institute for Policy Studies, The Johns Hopkins University. Conducted analysis of socio-economic data for a study of Maryland's economy.

8. Academic honors, fellowships, honorary societies:

1982	M.P. Elliot Prize, *Kenyon College*
1983	Nominated to Sigma Xi, scientific research honorary

1983	Highest Honors for Research, *Kenyon College*
1986	*Earthwatch Foundation* Teacher Expedition Fellow
1986-1991	The *Johns Hopkins University* Faculty of Arts and Sciences University Graduate Fellowship
1989-1990	Fulbright Scholarship for a year of dissertation research in the Brazilian Amazon
1993, 1996	Nominated for the *Tulane Graduate School Student Association* Award for Excellence in Graduate Teaching
1999	Presidential Certificate in Undergraduate Teaching in recognition of the Service Learning Teaching Award
1999	The Tulane College Senior Class Outstanding Advisor Award for Exemplary Service to Students
2001	Graduate Student Association "Teacher of the Year" Award, Department of Sociology, Tulane
2000, 2001	Mortar Board (Alpha Sigma Sigma Chapter) Award for Outstanding Teaching, Newcomb College
2001	Latin American Studies Graduate Student Association Teaching Award
2006-2007	James Martin 21st Century Professor (fellowship), Oxford University
2008	Fred Buttel Distinguished Contribution Award, the Environment and Technology Section of the American Sociological Association
2011	Named Ittleson Professor of Environmental Studies, Brown University
2011	Nominated and Selected to National Academy of Sciences' Board on Environmental Change and Society
2014	Frederick Buttel Award for Distinguished Scholarship, Environment and Society Research Committee RC24 of the International Sociological Association.

9. Teaching: chronologically, for the last three years. Include in addition to regular courses (and enrollment figures for each): GISPs and Independent Studies by number, and the number of Honors, Master's and Ph.D. theses directed, including academic advising, as well as the number of students advised.

COURSES TAUGHT AND ADVISING: (last five years)

Fall, 2015-Spring 2016: Teaching Engaged Climate Policy at the U.N. Climate Negotiations (Fall); TRI-Lab: Environmental Justice and Climate Change in Rhode Island (Fall); Globalization and the Environment (Spring).

Fall, 2014-Spring, 2015 Teaching: Engaged Climate Policy at the U.N. Climate Negotiations (Fall); Power, Justice and Climate Change (Fall); TRI-Lab: Environmental Justice and Climate Change in Rhode Island (Spring).

Advising: I advised David Ciplet (PhD, completed May, 2015), Michael Murphy (PhD, Sociology, third year), served on doctoral committee of Peter Klein (Sociology, completed Mary 2015), Eric K. Chu (completed February 2015 MIT Dept. of Urban Studies and Planning) and Linda Shi, MIT Dept. of Urban Studies and Planning. I have since been asked to serve on the committees of Matt Hodgetts (Political Science), Appolonya Porcelli (Sociology). I supervised Romain Weikmans, Post-Doctoral Research Fellow 2015-2016.

Undergraduates: I advised Trevor Culhane, Honors in Environmental Studies, Alexis Durand, Honors in Environmental Studies, Ali Kirsch, Senior Capstone in Environmental Studies, and eight departmental independent studies students (Spring). I am advising Alexis Durand on Honors thesis in Environmental Studies, advising Olivia Santiago on her Senior Capstone Practicum, and serving on thesis committee of Camila Bustos. I did concentration advising for 6 ENVS students, First Year Advising for 4 undergraduates,

and Sophomore Advising for 3 students.

Fall, 2013-Spring, 2014 Teaching: Power, Justice and Climate Change (Fall); Climate and Development Lab (Fall and Spring); Social Science of the Environment (Spring, Core ENVS); Globalization and the Environment (Spring, Capstone Seminar). I advised David Ciplet (PhD, expected to complete May, 2015), Michael Murphy (PhD, Sociology), served on doctoral committee of Eric K. Chu, MIT Dept. of Planning. I advised Development Studies student Madeline Weiner on her senior thesis, and departmental independent studies students (Spring). I did concentration advising for 11 ENVS students, and First Year Advising for 3 undergraduates.

University of Virginia Semester at Sea, Summer 2013**:** SEMS 3500-107/SOC 3595: The Social and Political Dimensions of Climate Change; and SOC 2595: Environmental Sociology

Brown University: Fall 2009, 2010, 2011: Taught ENVS 2010: Special Topics in Environmental Studies. Led all first-year Master's students required inquiry-based project, research methods, and thesis design course.

Spring 2010, 2011, 2012: Taught ENVS 1920: a core course required of all Environmental Studies and Science AB, ScB concentrators covering research methods, thesis planning, and joint research project for policy.

Earlier Advising:

In 2012-13 I was on sabbatical, but advised Brown Sociology PhD students David Ciplet and co-advised Alyssa Cordner on their dissertations (Cordner completed 4/13), and three MA students in the Center for Environmental Studies, Sara Mersha, Brianna Craft, and Kathryn Birky on their theses, all three of whom completed their degrees. I served on Martin Stadelmann's PhD thesis committee for the University of Zurich, Switzerland (completed February 25, 2013).

In 2011-12 I advised Brown Sociology PhD student David Ciplet's dissertation research, and served on Alissa Cordner's committee (also in Sociology). I supervised two completing MAs in Environmental Studies (Adam Kotin, Sara Mersha), and one first-year MA student on her thesis (Brianna Craft). I supervised three students doing Honors theses or senior theses in environmental studies: Spencer Field, Cecilia Pineda, and Marisa Hobbs.

In 2010-11 I advised Brown Sociology PhD student David Ciplet's dissertation research, and serving on Alissa Cordner's committee (also in Sociology). I supervised three students doing Honors theses or senior theses in environmental studies: Lucy Higgins, Ambika Roos (Honors, International Relations, co-advisor), and Arielle Balbus (Development Studies, Honors). I supervised one completed MA in Environmental Studies (Kimberly Damm), and two ongoing MA theses (Adam Kotin, Sara Mersha)

In 2009-10 I supervised two students doing their Senior theses in Environmental Studies: Aisha Pasha and Kyle Poyar (Honors). I helped Juniors prepare for the thesis: Lucy Higgins Senior Thesis, co-advised Abika Roos' Honors Thesis in International Relations, and Arielle Balbus' Honor's thesis in Development Studies. I mentored two first-year Master's students in ES: Sara Mersha and Kimberly Damm. I am advising Brown Sociology PhD student David Ciplet's dissertation research.

2008-2009 academic year I was on research leave for my Gates and Hewlett Foundation research grant to develop the PLAID/AidData database

2007-2008 I taught Globalization and the Environment, a senior seminar, with 19 students, and Environmental Sociology (with 65 students).

2006-2007 I was on sabbatical at Oxford on a fellowship in the Environmental Change Institute. I taught in the MSc in Environmental Management program, an options course with eight students and many guest lectures.

OTHER GRADUATE TRAINING:

I recently chaired two Ph.D. committees at Brown University, David Ciplet (completed 7/2015); Alissa Cordner completed 4/13 (co-chair).
I currently serve on Ph.D. committee of Linda Shi at MIT Department of Urban Policy and Planning. I served on the Ph.D. committee of Eric Chu there, who completed in 2015.
I served on the doctoral committee of Martin Stadelmann from the University of Zurich, Switzerland, 2013.
I have served on three Ph.D. committees at Oxford University, including evaluating two D. Phil. students on their "upgrades" to full candidacy for the doctorate, and advised 4 M.Sc. students on their dissertations (2007). Fall 2009 I served as Internal Examiner for John Cole's Oxford PhD., the defense was held at Brown.
I was on a Ph.D. committee for one Virginia Institute for Marine Studies (VIMS) doctoral candidate Erica Holloway who completed in November, 2011 (2006-2011).
At Tulane University, I served on 14 completed Ph.D. committees, of which I chaired 5: Amy Bellone Hite, Ted Henken, John Baugher, Melissa Toffolon-Weiss, Mistu Ghosh.
At Brown, I have advised 8 Master's theses. At Tulane I also served on 17 completed Master's committees, of which I chaired 10.
I have served as outside reviewer on doctoral dissertations at the University of East Anglia (UK), and The Flinders University of South Australia.

OTHER UNDERGRADUATE TRAINING (College of William and Mary and Brown University):

I routinely lead groups of students in research, including 5-12 students in my Climate and Development Lab (including travel to the U.N. negotiations and supporting local and international NGOs, think tanks, governmental offices, and UN negotiating groups—see climatedevlab.org). I lead four teams of student interns to create, pass and assist implementation of the Resilient Rhode Island Act of 2014 (see ResilientRI.org), and five teams of five interns working to pass the EnergizeRI carbon pricing legislation in 2015-6. While at William and Mary, I helped supervise up to 20 students at a time in our PLAID/AidData research project; over a hundred worked for the project over the time I was there. In addition, five undergraduates conducted paid research under my supervision during the summers of 2002, 2003, 2004, 2005, 2006, 2008 and 2014.

Tab B

New England Governors
and the Eastern Canadian Premiers
"Building on Tradition"

Nouvelle-Angleterre et des Premiers ministres
de l'Est du Canada
"Une tradition à enrichir"

New England Governors/Eastern Canadian Premiers

Climate Change Action Plan 2001

August 2001

Prepared by

The Committee on the Environment and
the Northeast International Committee on Energy
of the Conference of New England Governors and Eastern Canadian Premiers

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The Conference of New England Governors and Eastern Canadian Premiers

Climate Change Action Plan
August 28, 2001

Preamble

In July of 2000, the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted Resolution 25-9 on global warming and its impacts on the environment. The NEG/ECP recognized that global warming, given its harmful consequences to the environment and the economy, is a joint concern for which a regional approach to strategic action is required. The Conference directed its Committee on the Environment, the Northeast International Committee on Energy (NICE), in collaboration with the New Brunswick Premier's Round Table on Environment and the Economy, to:

1) hold a workshop to examine the regional impacts of global warming, discuss options for reducing greenhouse gas (GHG) emissions, and clarify the need for this region to adapt to climate change and explore methods for doing so; and

2) evaluate the conclusions and recommendations of the workshop from a strategic and scientific viewpoint, and to present a summary of findings of the meeting and a recommended action plan to the 2001 annual meeting of the Conference of New England Governors and Eastern Canadian Premiers.

This action plan is the culmination of efforts between the New England governors and the Eastern Canadian premiers and their respective environment and energy agencies. The plan supports and complements other regional, state and provincial initiatives currently being implemented, including the NEG/ECP's Mercury Action Plan and Acid Rain Action Plan. The plan also strives to be consistent with the Canadian National Implementation Strategy for Climate Change prepared jointly by the federal, provincial and territorial governments of Canada.

Improving climate science indicates that aggressive action is needed to reduce greenhouse gas emissions toward the ultimate goals of stabilizing the earth's climate and eliminating the negative impacts of climate change. Although an essential first step, the successful implementation of this action plan will only address a portion of the problem of globally increasing concentrations of greenhouse gases in the atmosphere. Due to the uncertainty of corresponding actions on a worldwide basis, and the lengthy response time necessary for climate actions to have an impact, it

is also prudent for our jurisdictions to undertake adaptive measures to mitigate the impacts of climate change.

The NEG/ECP Climate Change Action Plan identifies steps to address those aspects of global warming which are within the region's control to influence. Specifically, the action plan includes:

- a comprehensive and coordinated regional plan for reducing greenhouse gases;
- a commitment to reach specified reduction targets for the region as a whole;
- a commitment from each state and provincial jurisdiction to carry on its own planning for climate change gas reductions, with a coordinated process that includes disclosure of our progress, and a sharing of information including case studies of how various programs are working;
- a plan for the adaptation of the region's economic resource base and physical infrastructure to address the consequences of climate change;
- a public education and outreach effort to ensure that the region's citizens continue to be educated about global warming and climate change in order to better protect the earth's natural climatic systems and natural environment.

This action plan is intended to reduce the region's emissions of heat-trapping gases and to build the foundation for a longer-term shift to cleaner and more efficient ways of using energy, as well as identifying and adopting adaptive measures.

Under a "business as usual" scenario, the forecast of the emissions of warming pollutants shows one of rapid increase. For example, *Canada's Emissions Outlook: An Update* forecasts that Eastern Canada's emissions will grow from 133.0 megatonnes of carbon dioxide equivalent in 1990 to 160.8 megatonnes in 2020—a 20% increase. Forecasts indicate an approximate 30% increase in CO_2 emissions from New England between 2000 and 2020, in the absence of mitigating action. National CO_2 emissions levels in the U.S. have been growing about 1.1% per year based on the U.S. Department of Energy's Energy Information Agency, with the largest emissions increases coming from the transportation sector.

Given these increases in the face of doing nothing, this plan seeks to reverse the trend. Specifically, the plan presents a set of near-term options for our region that would help protect the climate, reduce GHG emissions and other pollutants, cut energy demands, and promote future job growth by harnessing sustainable energy resources and advanced technologies. Furthermore, the plan will address climate changes that have occurred and that are anticipated through a variety of adaptive measures, such as shifts in agriculture and forestry, building codes, and infrastructure rehabilitation, particularly in coastal areas. By focusing on a set of concrete, achievable, near-term opportunities, we hope to demonstrate leadership and build a foundation from which more dramatic progress can be realized.

Basis for Action

Scientific evidence of the destabilizing human influence on global climatic systems is continuing to build, creating a growing momentum for a response. For example, the Intergovernmental Panel for Climate Change (IPCC), an international body of atmospheric scientists, in its *Third Assessment Report*, states that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." The report concludes that the "human influences will continue to change atmospheric composition throughout the 21st century" and that change "will persist for many centuries."

The IPCC predicts that if no action is taken, average rates of warming by 2100 will "be greater than any seen in the last 10,000 years." Such instability will increase the incidence and severity of extreme weather events such as storms, droughts, floods, and heat waves; cause sea levels to rise; shift and/or expand certain disease and pest vectors; and further stress already vulnerable species and ecosystems.

In the *Canada Country Study, Atlantic Region Report*, for example, scientists predicted that sea level rise is the impact with the highest degree of certainty associated with it and will lead to predictable and dramatic impacts. Many of these impacts would be common to the Eastern Canadian provinces and to New England states. The warming would stress our common natural resources—especially in the areas of agriculture, fisheries and forestry.

Another recent analysis of regional impacts of future climate change in the United States, concluded that key issues for New England (and we can assume for the Eastern Canadian provinces as well) were likely to include an increase in weather extremes; stresses on estuaries, bays, and wetlands; changes in precipitation rates impacting water supply and food production; multiple stresses on urban areas; and recreation shifts. In addition, the composition of northeastern forests is anticipated to change dramatically, affecting our biodiversity and our forest industries.

These multiple impacts will have substantial consequences for the cost and quality of life of the region's citizens. For instance, weather extremes are already a feature of the regional environment and an increase in the severity and incidence of such extremes, including ice storms, flooding, nor'easters, hurricanes and drought, would therefore be of considerable concern to states and provinces. Recent examples of such events and their potential impacts include the ice storm of January 1998 and the severe flooding associated with tropical depression Floyd in 1999. Rising sea level and elevated storm surge levels—with associated problems of coastal erosion and saltwater inundation—would likely have severe impacts on our harbors, islands, and for the many communities located near the region's shoreline. Other climate-induced stresses on major urban areas could include increased heat-related illness and death and increased ground-level ozone pollution. In addition to exacerbating some types of air pollution, warming would likely favor increased mosquito and tick populations, with associated public health as well as recreational impacts. Other recreational impacts might include (on the positive side) an extended season for warm-weather activities and (on the negative side) muting of fall foliage and a less viable winter recreation industry. The agriculture sector may benefit from a longer season but will, in all likelihood, need to contend with loss of moisture and increased pests.

Due to the strength of its high technology industries, our region is in an excellent position to develop and implement programs and projects to meet this critical environmental challenge, thus enabling economic opportunities created by a worldwide transition to new technologies and less intensive use of fossil fuel resources. The purpose of this plan is to recommend many actions to reduce regional greenhouse gas emissions in a manner that is cost effective and advances other important regional objectives. These objectives include:

- reducing other pollutant emissions that threaten human health and the natural environment;
- maintaining a reliable supply of reasonably priced energy within our region;
- reducing dependence on energy imports to the region, thereby keeping energy dollars in our regional economy;
- reducing our collective vulnerability to energy price shocks; and
- providing 'early adoption' opportunities to enhance the competitive advantage of our region's technology industries.

Considering the above-noted information, it is believed that the risks posed by global warming are real and will have serious consequences for the region. Atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and other heat-trapping gases are substantially higher than any recorded in recent millennia and these increases are linked to human activity. In recent years, consensus that these increased concentrations could have unpredictable consequences on global weather patterns has grown steadily stronger to the point that action is warranted.

These objectives converge on the wise use of resources—particularly energy. The Climate Change Action Plan builds on presentations and discussions held at the NEG/ECP Climate Change Workshop on March 29th and 30th in Fredericton, New Brunswick. It is the goal of the plan to raise the issue of climate change and to seek opportunities for reducing the region's impact on the climate while benefiting the region's economy. At the workshop, many opportunities were identified to promote greenhouse gas reductions and appropriate adaptation measures while meeting other governmental goals. These included:

- shifting to less polluting energy resources;
- maximizing the efficiency and effectiveness of energy conversion, transport, and consumption within the region;
- encouraging and aggressively promoting new technologies which reduce the use of fossil fuels, thus reducing carbon emissions;
- taking actions to maintain a greater share of the region's energy dollars in the regional economy leading to more productive reinvestment;
- taking actions to support agriculture, fisheries, aquaculture, timber, and other natural resource-based economic sectors to adapt to the climate impacts already being felt;
- encouraging similar sensible action by fellow states/provinces and federal governments;
- designing and building any new infrastructure to minimize the impacts of climate changes that:
  - are likely to occur, based on the extended residence time of gases already released into our atmosphere, and

- may occur due to inadequate greenhouse gas emission reductions elsewhere;
- preserving green spaces, including forests and farm lands;
- creating new jobs in the area of energy efficiency and renewables; and
- contributing to the long-term economic and environmental sustainability and human health and safety of the states and provinces.

As a result of the Climate Change Workshop, each state and province will initiate a coordinated set of policies and actions aimed at advancing our common goals. This plan provides short descriptions of some key initiatives that jurisdictions may enact to move towards near and mid-term goals (in the context of this action plan, the term *jurisdiction* refers to state and provincial governments in New England and Eastern Canada). Beyond these measures, each jurisdiction will choose additional measures to contribute towards the regional target.

The NEG/ECP Committee on the Environment and Northeast International Committee on Energy (NICE) will appoint a Climate Change Steering Committee, consisting of state and provincial government representatives in our region, to oversee the implementation of the NEG/ECP Climate Change Action Plan. This Steering Committee will report to the Committee on the Environment and the Northeast International Committee on Energy on a regular basis. Both committees will report annually to the Conference of New England Governors and Eastern Canadian Premiers.

Guiding Principles

The New England governors and Eastern Canadian premiers recognize the following principles as guidelines for action on climate change in the region.

1. The need to identify constructive measures to reduce energy and non-energy related GHG emissions wherever possible, such as to:
   a) shift to lower and zero carbon energy sources, wherever economically feasible; and
   b) implement actions that result in higher efficiency in the transportation of passengers and goods.

2. Actions which will support and develop the states' and provinces' economy (so-called "no regrets" measures), when compared to other possible actions, and compared to the cost of inaction, including to:
   a) be cognizant of the energy supply needs of our region and find constructive measures with regional energy reliability in mind; and
   b) involve all segments of society—government, business, and citizens—in contributing to reductions in greenhouse gas emissions.

3. The need to foster long-term environmental and economic sustainability, in order to favour economic growth while decreasing total emissions of carbon and other climate change gases, such that states and provinces may:

a) explore ways to adapt to the already changing climate, to take advantage of any benefits that might come from these changes, and to adapt our infrastructure and natural resource base accordingly; and
b) to explore ways to adapt to climate change in ways that do not increase the production of greenhouse gases in the process, and to be mindful of the health and safety of citizens.

4. The need to work with our federal governments to seek additional solutions that can be addressed at a national level including emission standards, grant programs, and cooperative agreements. There is also a need to work with federal counterparts to improve the energy efficiency of vehicles for sale to the public.

Regional Goals

While there is a recognition that emissions of greenhouse gases are a global problem that ultimately require a global solution, New England states and Eastern Canadian provinces are well positioned to play a leadership role in addressing the issue of climate change. Therefore, our region is establishing a short-term goal to demonstrate its commitment for action over the next decade.

There are a number of precedents that illustrate that a clearly articulated, ambitious policy goal is necessary to spur advancement in relevant technologies. The intent is for the mid-term goal to signal a promising future for energy-efficient and greenhouse gas reducing technologies, and to encourage the growth of related industries in the region. Furthermore, the region will undertake a planning process every five years, beginning in 2005, to ensure that the mid-term reduction target is as aggressive as possible for the year 2015, ten years ahead. This review will be based on findings of new efficiency technologies, changes in the resources available and estimated economic and energy impacts.

The ultimate goal mirrors that of the United Nations Framework Convention on Climate Change, to which both the United States and Canada are signatories. Over the long term, anthropogenic GHG emissions must be reduced to levels that no longer pose a dangerous threat to the climate. The best science available at present indicates that attaining this goal will require reductions in GHG emissions of approximately 75–85% below current levels. The long-term goal will be modified as the understanding of climate science advances.

It is important to note that the goals and results outlined in this plan are for the New England and Eastern Canada region in aggregate and may not be achieved in equal measure by each jurisdiction. It is recognized that differences in emissions characteristics and inventories, social and political systems, economic profiles (including transportation/utility/industrial infrastructures), and resources will lead to varying approaches among the jurisdictions in contributing to the regional goals. However, each jurisdiction in the region commits to participate in the achievement of the regional goals and work with the other states and provinces in the region on this important effort.

Short-term Goal: Reduce regional GHG emissions to 1990 emissions by 2010.

Mid-term Goal: Reduce regional GHG emissions by at least 10% below 1990 emissions by 2020, and establish an iterative five-year process, commencing in 2005, to adjust the goals if necessary and set future emissions reduction goals.

Long-term Goal: Reduce regional GHG emissions sufficiently to eliminate any dangerous threat to the climate; current science suggests this will require reductions of 75–85% below current levels.

Action Steps for the New England States and the Eastern Canadian Provinces

Action Item 1: The Establishment of a Regional Standardized GHG Emissions Inventory

Basis for Action

The process of creating jurisdictional level inventories of existing emissions will assist jurisdictions in the identification of specific measures that will reduce greenhouse gas emissions. A full understanding of the present circumstances and a complete assessment of opportunities for action, in all sectors of the economy, are essential for states and provinces to address climate change issues effectively.

Goal

Jurisdictions will establish a standardized inventory beginning with their 1990 GHG emissions levels, reported every three years.

Recommendations

1. Assign a task force to draft a work plan for the establishment of a regional inventory protocol leading to a consistent basis for the inventories.

2. Distribute state/provincial data sets as they are developed.

3. Coordinate, as appropriate, the regional actions of the Climate Change Action Plan with other programs and efforts outside the region, and with federal initiatives.

Action Item 2: The Establishment of a Plan for Reducing GHG Emissions and Conserving Energy

Basis for Action

To make reductions in greenhouse gases, each jurisdiction will develop its own plan, programs and policies. In this plan, each jurisdiction will choose the measures and programs that will benefit its own economy and work most smoothly for its citizens and businesses. During the separate plan development process, the Steering Committee will work to benefit all jurisdictions by transferring ideas, hosting discussions, and making technology options available, so that all parties may benefit from the experiences of others.

Goal

The creation of a plan by each jurisdiction articulating measures to achieve GHG reductions in view of the regional short and mid-term targets.

Recommendations

4. Report to the NEG/ECP annually on progress made regionally.

5. Recommend items for joint action and develop specific task forces to coordinate projects, as needed.

6. Include a forecast of future energy usage and greenhouse gas emissions in its action plan.

7. Review progress towards meeting GHG objectives, and produce an updated plan every three years. Overall results will be reported regionally.

8. Identify the benefits of action steps and programs and check for consistency among states and provinces including developing common conversion factors.

9. Monitor the results of the actions and policies and share information on their effectiveness.

Action Item 3: The Promotion of Public Awareness

Basis for Action
Public awareness should be a high priority and the region will require the support and participation of its citizens to make the action plan fully effective.

Goal
By 2005, the public in the region will be aware of the problems and the impacts of climate change and what actions they can take at home and at work to reduce the release of greenhouse gases. The public should also be cognizant of adaptive measures they can undertake.

Recommendations

10. Promote a dialogue between traditional conservation organizations, land managers, natural resource-based industries, recreational industries, major energy users, non-government organizations (NGOs) and interested citizens as to the implications of climate change.

11. Develop coordinated education and outreach programs for schools, parks, government and all other appropriate media to communicate why this issue is important to the citizens.

12. Use disclosure and labeling of electrical generation fuel mixes to promote consumer awareness of greenhouse gas production from the utility sector. Under this approach, utilities would provide information on a periodic basis to all retail customers describing the fuel mix it has used to generate electricity. This disclosure statement would also include a disclosure of the electricity product delivered relative to the regional power mix in terms of carbon intensity of electrical production.

13. Measure the effectiveness of efforts to educate the public on the significance of the climate change issue.

Action Item 4: State and Provincial Governments to Lead by Example

Basis for Action
Given the high cost of energy, citizens of New England and Eastern Canada will benefit when they use less energy or use lower carbon fuel to operate our government buildings, vehicles and end-use facilities. In addition, demonstrating energy efficiency, clean energy technologies and sustainable practices should be a fundamental task of government.

Goal
The region will reduce end-use emissions of GHGs through improved energy efficiency and lower carbon fuels within the public sector by 25% by 2012, as measured from an established baseline.

Recommendations

14. Implement, or continue to implement, a public sector energy reduction program and designate an appropriate lead agency or individual with the responsibility to implement it. The goal of this program is to reduce greenhouse gases without compromising government services or worker conditions. Authorities and quasi-public entities would be encouraged to join this program voluntarily.

15. Institute policies to encourage the purchase of the most fuel-efficient vehicle available for each type of use, given the availability and utility of the vehicles in the marketplace. Each jurisdiction will also support efforts by municipalities and political subdivisions in establishing similar vehicle purchase programs.

16. Educate government employees about the specific operational changes they can undertake to reduce greenhouse gases and reduce fuel use. Examples include promoting carpooling incentive programs and/or telecommuting policies for government employees; educating building managers on measures to improve efficiency in heating, cooling, and lighting; and providing office managers with information regarding energy-efficient office products and equipment.

17. Establish policies that all state and provincial expenditures related to energy conservation and efficiency, having simple payback periods of ten years or less, will be adopted whenever feasible.

18. Establish jurisdictional policies on sustainable building design to be applied to all state/provincial construction and renovation projects where such practices are feasible and cost-effective. Sustainable design practices include using recycled, energy-efficient, and less toxic materials; day lighting and other energy saving measures; piloting on-site renewable energy projects; and separating and recycling construction and demolition debris.

19. Create a regional market for "Environmentally Preferable Products" (EPPs) by requiring their use at all state/provincial facilities. EPPs include materials with recycled content, those that

minimize generation of toxic materials, and products otherwise designed to minimize the environmental impact from manufacture to disposal.

20. Create a regional clearinghouse of "best practices" for the operation and management of public facilities so jurisdictions can share and benefit from each other's experiences.

Action Item 5: The Reduction of Greenhouse Gases from the Electricity Sector

Basis for Action

The strength of the region's economy depends upon a reliable and a reasonably priced supply of electricity. Increasing the use of renewable sources of energy in electricity production is an important means of improving fuel diversity, and thus the overall reliability of electrical supply. By enhancing regional commitments to energy conservation, states and provinces can slow the increase in electrical demand while maintaining economic growth. The regional commitment to renewable energy and energy efficiency technologies will encourage the development of new industries and the creation of new jobs in the region. In view of these benefits, the following goal has been established:

Goal

By 2025, reduce the amount of CO_2 emitted per megawatt hour of electricity use within the region by 20% of current emissions. It is important to note that Action Items 5 and 6 are interrelated and complementary and the goal is to lower the overall carbon intensity of electricity production.

Recommendation

21. Achieve the above-noted goal through a combination of new renewable energy sources including solar, wind and bioenergy among others, by using lower carbon fuels, increasing the efficiency of the electricity generation and transmission system and the use of new, efficient distributed generation.

Action Item 6: The Reduction of the Total Energy Demand Through Conservation

Basis for Action

The rationale for integrating energy efficiency activities into this plan is to capture the benefits, both economic and environmental that include:

- a reduction of emissions of greenhouse gases as well as of other environmental pollutants;
- a direct electricity cost savings for consumers;
- an increased system reliability for all consumers by reducing energy use during peak demand periods;
- a reduction in the need for additional transmission lines, distribution wires and transformers, avoiding costs for all consumers;
- a reduction in operating and maintenance costs and increased productivity for businesses;
- an increase in incentives to grow our regional energy efficiency industries;
- a reduction of emissions from the need to mine and transport fossil fuels.

Goal

By 2025, increase the amount of energy saved through conservation programs (as measured in tons of greenhouse gas emissions) within the region by 20% using programs designed to encourage residential, commercial, industrial and institutional energy conservation.

Recommendation

22. Reduce the overall regional demand for electricity by increasing the participation of firms and households in programs to encourage energy conservation through reductions in energy use from the industrial sector, where feasible. Actions recommended include: greater participation in the U.S. EnergyStar program and the Canadian Energy Guide Program; participation in programs to promote green building design and energy efficient building codes; and demand side management (DSM) programs to promote energy savings in homes and businesses. This measure will also benefit from actions elsewhere in the plan to enhance public understanding of the need for, and benefits of, energy conservation and renewable energy use.

Action Item 7: The Reduction and/or Adaptation of Negative Social, Economic and Environmental Impacts of Climate Change

Basis for Action

Adaptation in the northeast means understanding regional climate changes and their impacts on our man-made infrastructure and our natural resources, including surface and ground water, forests and natural wildlife. An increase in temperature will lead to: a degradation in air quality and increase urban smog (with its associated human health impacts); public health risks; insect reproduction and the population of disease-bearing pests such as mosquitoes; the magnitude and frequency of extreme climatic phenomena, as well as changes the water cycle and availability of water. Adaptation also concerns economic activities, such as building and infrastructure planning, coastal land use planning, farming, forestry management, fisheries, transportation, energy services and tourism. Current infrastructure will be subject to periodic reassessment, in response to the impacts of climate changes that will inevitably occur, based on the extended residence time of gases already released into the atmosphere. The New England and Eastern Canadian region is rich in natural resources and many of the economic sectors rely on the health of these resources.

Climate change affects human lifestyles as well. Part of the adaptation work will include measuring impacts on societal and individual activities. There is a need to find ways to minimize the negative social and economic consequences of climate change. This implies examining a spectrum of activities in the context of climate change—for example, which economic activities will expand and which will contract—and developing policies to effectively address these changes.

Goal

To broaden the understanding of forecast climate impacts and to plan the adaptation to these changes, where possible. In addition, the intent is to seek climate adaptation options that do not increase greenhouse gas emissions further.

Recommendations

23. Seek to enhance the understanding of the impacts of climate change by establishing a regional climate change monitoring network and cooperating with scientific and academic research centers. These efforts could include documenting impacts, exchanging information and research, developing modeling capacities, identifying areas most susceptible to catastrophic events and proposing adaptation and mitigation strategies. Perhaps most importantly, there is a need to begin the process of adapting to the inevitable changes in climate that have already been set in motion. In addition, states and provinces will seek to work with all sectors that rely directly on natural resources to adapt production and exploitation processes, where possible.

Work on a cooperative scientific basis with groups like the Canadian Impacts and Adaptation Information Network (CAIRNS) in Nova Scotia and Quebec, and U.S. Global Change Research Program's New England Regional Assessment Team, to provide jurisdictions with useful policy-relevant information on a regular basis. Activities could include:

a) monitoring the living organisms and sensitive habitats for signs of stress or change related to temperature and humidity changes;
b) assessing the vulnerability of marketed plant and animal species and the market potential of less vulnerable or new species;
c) increasing the density of climatological stations to gain a better information on regional and local temperature and climatic activity, and to better understand impacts on natural resources such as forests, public health, water bodies and wildlife;
d) expanding the use of land conservation techniques such as conservation restrictions to protect green spaces, forest resources and soil carbon;
e) creating an on-going information exchange on the potential impacts of climate change and feasible, sustainable adaptation measures for the natural resource industry base;
f) mapping and information exchange on the coastal zone for the purposes of adaptation;
g) encouraging cooperative working relationships among the emergency management agencies to ensure a coordinated approach for likely climate change impacts as a part of their emergency planning;
h) enhancing the monitoring of forest fires and forest pestilence;
i) developing new agricultural methods and evaluating the potential of new products;
j) evaluating new tourism products and strategies;
k) increasing native tree planting programs in each state/province, improving maintenance of existing trees, and monitoring the carbon uptake and release of planting programs over time to establish a better understanding of the long-term carbon benefits of such programs;
l) improving development practices to limit the destruction of existing trees and encourage/require the planting of native replacement trees when changing the nature of land use. Adding trees, where feasible, to urban areas to reduce heat island effect, thereby reducing the need for nearby building air conditioning;
m) expanding and/or establishing farm preservation protection program in each state and province. To further create economic benefits for farms, states and provinces will look to: i) integrating wind power into farms to supplement farm incomes where feasible; ii) promoting better farm practices for climate protection, including the use of methane recapture and pesticide reductions where feasible, and the integration of soil carbon retention; and iii) making efforts to enhance the amount of locally-grown food (to preserve farm lands and to reduce transportation related CO_2 emissions);
n) establishing a working group of academic, governmental and non-government staff,- natural resource managers, and climate change professionals to ensure cross fertilization across natural resource and climate change issues. This effort is intended to lead to a comprehensive evaluation of the impacts to natural resources and the mitigation opportunities among state and provincial natural resource employees.

Action Item 8: A Decrease in the Transportation Sector's Growth in GHG Emissions

Basis for Action

Slowing the growth of emissions in the transportation sector presents one of the most significant challenges to overall climate change mitigation efforts. In New England and Eastern Canada, transportation is the single largest source of primary energy consumption and of greenhouse gases. Fortunately, the development of new technologies in this area has been fruitful. These new, efficient technologies offer citizens options for reducing their fuel costs while reducing greenhouse emissions. Many additional options for reducing greenhouse gas emissions from the transportation sector simultaneously address the problems of traffic congestion and urban air quality.

Goal

To slow the growth rate of transportation emissions in the near future, to better understand the impacts of transportation programs and projects on overall emissions, and to seek ways to reduce these emissions. Work with federal officials to improve the energy efficiency of vehicles for sale to the public.

Recommendations

25. Promote the shift to higher efficiency vehicles, lower carbon fuels and advanced technologies through the use of incentives and education.

26. Disclose GHG emission impacts from new publicly-funded passenger and freight transportation projects and alternatives.

27. Promote compact development and transit/pedestrian development and other "smart growth" measures to encourage local communities to consider the energy impacts of development and infrastructure construction.

28. Undertake programs designed to manage and reduce transportation demand in communities.

29. Enhance mass transit infrastructure, intermodal connections, optimizing existing services and, where feasible, boosting ridership.

30. Encourage shifts to lower-carbon fuels and advanced vehicle technologies for all transit services.

31. Examine opportunities in freight transportation that would improve the energy efficiency of the movement of goods across the regions.

32. Support the development of inter-connected regional, state, provincial, and local greenway and bicycle/pedestrian pathway systems to promote non-fossil transportation alternatives.

Action Item 9: The Creation of a Regional Emissions Registry and the Exploration of a Trading Mechanism

Basis for Action

States and provinces are seeking to gain experience in emissions trading as a means of providing the most economically efficient greenhouse gas reductions. To that end, it is believed that the creation of a common set of rules and approaches for the establishment of baseline assessment, and for the evaluation of the benefits of reduction strategies within the region, would be beneficial.

Goal

To create a uniform, coordinated basis for emissions banking and trading. The intent is to create a regional emissions registry and to gain experience in certifying credits and trading within the geographic region. In this way, states and provinces will offer industries, organizations and other entities an ability to disclose their current baseline in advance of actions, so as not to be penalized while making early reductions.

Recommendations

33. Develop an Emissions Trading Registry, and methods for baseline creation and credit generation. Recommendations will be presented to the governors and rremiers at their next Conference after the adoption of this action plan, and the Climate Change Steering Committee will coordinate its efforts on these issues with other states, provinces, federal governments, business entities, non-governmental organizations and any other relevant stakeholders.

34. Encourage the development of markets and implementation of energy efficient and environmentally friendly technologies by working with programs such as the U.S. EPA's Environmental Technology Verification (ETV) program and Environment Canada's TEAM program. Where pertinent, it will be important to utilize technology verification information to aid in jurisdictional purchasing and regulatory/programmatic development.

Tab C

nature climate change

LETTERS

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Global flood risk under climate change

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A warmer climate would increase the risk of floods[1]. So far, only a few studies[2,3] have projected changes in floods on a global scale. None of these studies relied on multiple climate models. A few global studies[4,5] have started to estimate the exposure to flooding (population in potential inundation areas) as a proxy of risk, but none of them has estimated it in a warmer future climate. Here we present global flood risk for the end of this century based on the outputs of 11 climate models. A state-of-the-art global river routing model with an inundation scheme[6] was employed to compute river discharge and inundation area. An ensemble of projections under a new high-concentration scenario[7] demonstrates a large increase in flood frequency in Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes, with small uncertainty in the direction of change. In certain areas of the world, however, flood frequency is projected to decrease. Another larger ensemble of projections under four new concentration scenarios[7] reveals that the global exposure to floods would increase depending on the degree of warming, but interannual variability of the exposure may imply the necessity of adaptation before significant warming.

Floods are among the most major climate-related disasters. In the past decade, reported annual losses from floods have reached tens of billions of US dollars and thousands of people were killed each year. Losses and the number of casualties could be larger in the future. Thus, an assessment of changes with regard to floods is a public concern. The latest assessment of the Intergovernmental Panel on Climate Change (IPCC) on observed changes and future projections of floods was provided in chapter 3 (ref. 8) of the IPCC special report on extremes, often called the IPCC SREX report[1]. A summary on projected flooding in this report stated that, 'Overall there is low confidence in projections of changes in fluvial floods. Confidence is low due to limited evidence and because the causes of regional changes are complex.'

The available literature on global-scale assessments is limited in number. Ref. 2 projected future changes, mostly increases, in great floods of 29 major river basins based on monthly river discharge simulated by a single atmosphere–ocean general circulation model (AOGCM) and a river routing scheme. On the basis of daily river discharge calculated from another single AOGCM and a simple global river routing model, ref. 3 provided a global distribution of flood frequency changes in a warmer future climate. The use of a single AOGCM, however, was the source of a limited evidence statement in the summary of SREX. At the time of such previous studies, which is coincident with that of the third phase of the Coupled Model Intercomparison Project[9] (CMIP3) for the IPCC Fourth Assessment Report (AR4), global-scale flood projections could not be implemented easily owing to the limitation of data availability. Specifically, daily runoff data for multiple AOGCMs were not available in the public domain, such as in the data portal of CMIP3.

Here, we used outputs of the latest 11 AOGCMs participating in CMIP5 (ref. 10) to compute a global projection of changes in flooding and evaluate its consistency and spread. Daily runoff data of two sets of AOGCM simulations were employed in this study: historical simulations (1850–2005) forced by natural (for example, volcanic and solar) and anthropogenic (for example, greenhouse gases and ozone) forcings, and future simulations (2006–2100) forced by the Representative Concentration Pathway (RCP) scenarios[7]. The RCP spans a range of radiative forcing from 2.6 to 8.5 W m^{-2} and represents various possible climate outcomes[11].

A change in flooding between a present (20C) and a future (21C) time period was obtained as a change in the return period (probability) of a river discharge having a particular magnitude. Following previous studies[3,12], a river discharge corresponding to a 100-year flood in 20C was selected as the particular magnitude. The time series of simulated annual maximum daily river discharge in 20C (1971–2000) and 21C (2071–2100) were fitted respectively to an extreme distribution function; subsequently, the magnitude of river discharge having a 100-year return period in 20C was calculated at each location. Finally, the return period (generally, not equal to 100 years) of the same magnitude river discharge (equal to the 20C 100-year flood discharge) was computed for the time series of 21C river discharge at each location. The details of the above processes are described in the Methods. Note that the river routing model of this study does not consider the effects of the anthropogenic regulation of flood water, such as by reservoir operations, and potentially simulates a higher peak discharge. Hence, our projection provides the potential risk of flooding, irrespective of non-climatic factors such as land-use changes, river improvements or flood mitigation efforts such as the construction of dams.

The global distribution of the multi-model median return period of the 20C 100-year flood discharge in 21C is presented in Fig. 1a. In Figs 1 and 2, we show only the results of RCP8.5 in which changes are most remarkable. Thus, Figs 1 and 2 present aspects of the most dangerous climate change outcomes for the near-end of this century (the most dangerous among the four representative scenarios for CMIP5). The results of three other RCP scenarios (Supplementary Fig. S9) show similar spatial distributions, although the magnitude varies depending on the scenario. Dry regions (mean annual discharge of a retrospective simulation[13] forced by an observation-based atmospheric data for 1979–2010 of <0.01 mm d^{-1}, corresponding to 26% of the land grid cells) and regions with no consistency among the AOGCMs (defined as 6 of the 11 AOGCMs showing the same, increase or

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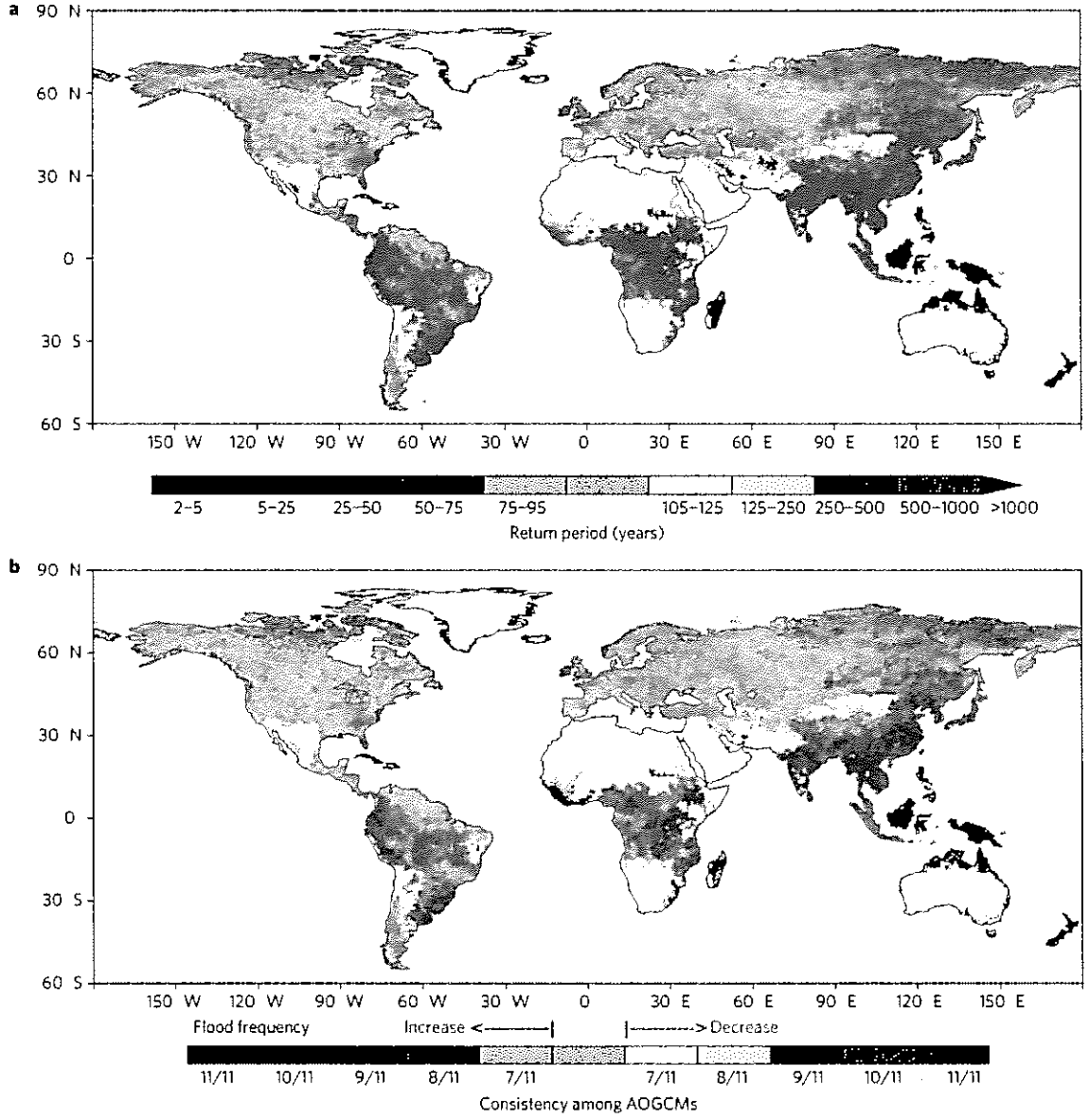

Figure 1 Projected change in flood frequency. a, Multi-model median return period (years) in 21C for discharge corresponding to the 20C 100-year flood. **b**, Model consistency. Grid cells with mean annual discharge of a retrospective simulation[13] for 1979–2010 of $<0.01\,mm\,d^{-1}$ are screened out. The case for the RCP8.5 scenario is shown.

decrease, direction of change: 14% of the land grid cells) in Fig. 1b were screened out or judged uncertain. The increase or decrease in flooding was therefore determined from the multi-model median return period for regions for which 7 or more AOGCMs showed the same direction (increase or decrease) of change.

The frequency of occurrence increases (the return period decreases) across large areas of South Asia, Southeast Asia, Northeast Eurasia, eastern and low-latitude Africa, and South America. In contrast, flood frequency decreases in many regions of northern and eastern Europe, Anatolia, Central Asia, central North America and southern South America. Globally, flood frequency increases in 42% and decreases in 18% of the land grid cells.

In many regions in which flood frequency increases in 21C, the consistency of the future flood direction of change among the AOGCMs is high. In particular, Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes show notably high consistency. Of the global land grid cells, 42% showed an increase in flood frequency and more than half of them (corresponding to 23% of the land grid cells) showed relatively high consistency (9 or more of the 11 AOGCMs). In contrast, 6% showed relatively high consistency (9 or more) among the AOGCMs in the regions in which flood frequency decreases in 21C. Only 5%, located mainly in South Asia and Southeast Asia, showed all of the 11 AOGCMs predicting the same decrease or increase direction. In most regions except South America, where flood frequency increases, the frequency of flooding, annual precipitation, annual runoff, heavy precipitation, and annual discharge were all projected to increase (Supplementary Fig. S2).

In addition to the global-scale analysis, future changes in flood frequency and the spread of the AOGCMs were analysed at the outlets of selected river basins (Fig. 2). To illustrate the ranges of the AOGCMs, box plots of the return periods are shown in Fig. 2b. In 21C, the frequency of floods increases in almost all of the selected rivers in South Asia, Southeast Asia, Oceania, Africa and Northeast Eurasia (except for the Ob river basin where the snowmelt peak decreases, similar to rivers in northern Europe).

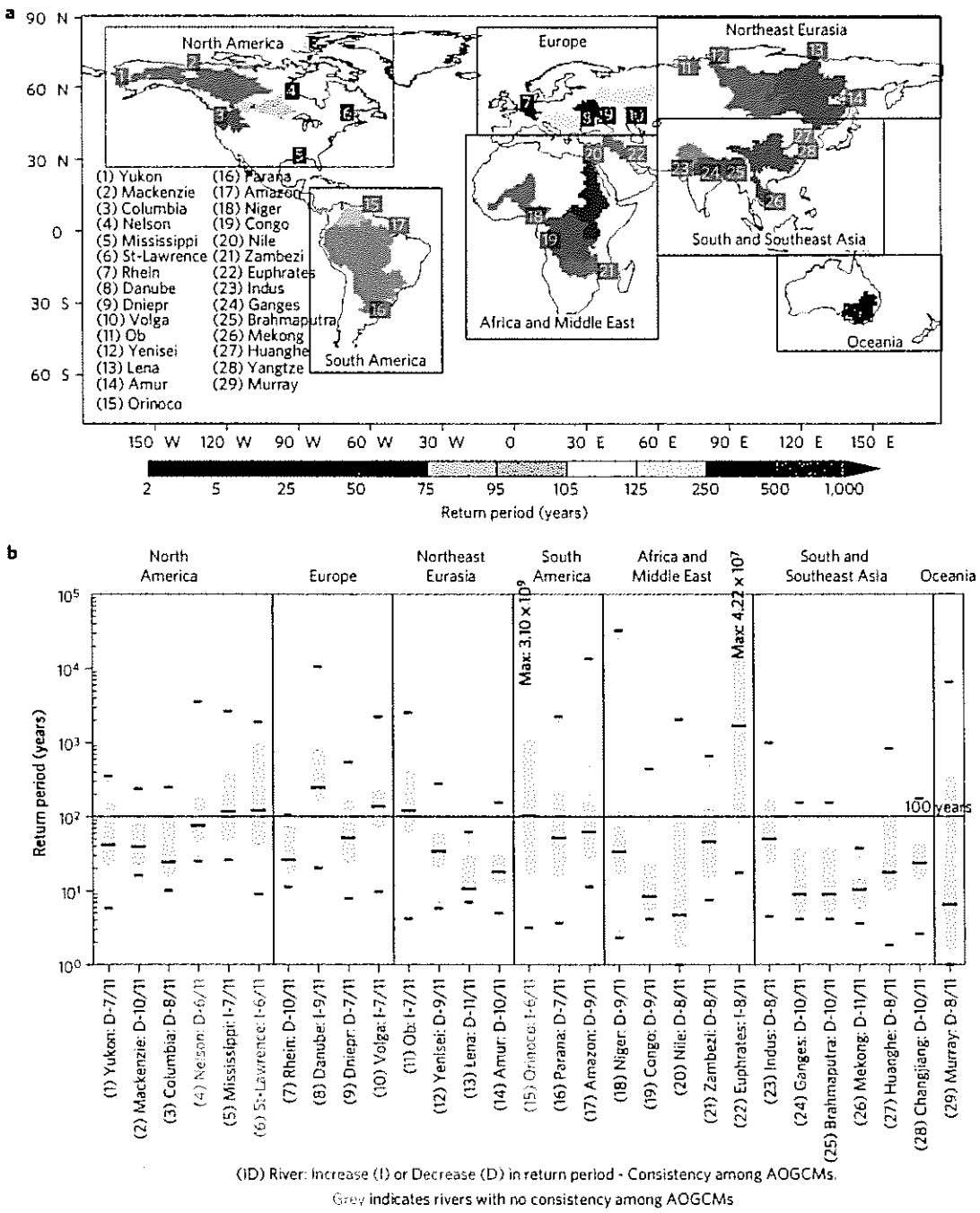

Figure 2 Projected return period of the 20C 100-year flood in 21C at the outlets of 29 selected river basins. a, Basin map with locations and names of the selected rivers with the outlets indicated by the locations of the river numbers. The colour of each basin indicates the multi-model median return period at basin outlets. **b**, The height of the grey box indicates the interquartile range (75th–25th percentile) and the solid line within each box indicates the median value. The dashed lines represent the maximum and minimum return periods for all 11 models. Directions of change (increasing: I and red characters; decreasing: D and blue characters) and model consistencies (numbers after basin names) are also given. Basins with no consistency (6 of 11 AOGCMs showing the same direction of change, increase or decrease) are indicated by grey characters. The case for the RCP8.5 scenario is shown.

The 20C 100-year flood event is projected to occur about every 10–50 years in many of these rivers in 21C. Such a large change in return period is caused by a ~10–30% increase in flood discharge. Similar changes in return period and flood discharge are seen in various parts of the world as shown in Fig. 1 and Supplementary Fig. S4d. In many of these rivers, the consistency of the future flood directions among the AOGCMs, as indicated by the numbers after the basin names in Fig. 2b, was relatively high; 6 of 11 basins within South and Southeast Asia, Oceania and Africa showed a consistency of 9 or more AOGCMs, and 5 basins showed a consistency of 8 AOGCMs. Moreover, most basins in South Asia and Southeast Asia showed relatively similar values of future return periods among the AOGCMs (illustrated as the height of the box and closeness to the multi-model median return period). This indicates that the future return periods in these basins are within a certain range with respect to the magnitude and the direction. The consistency of the direction of change was relatively low in the rivers of North America and South America, because many rivers showed no (6) or low (7)

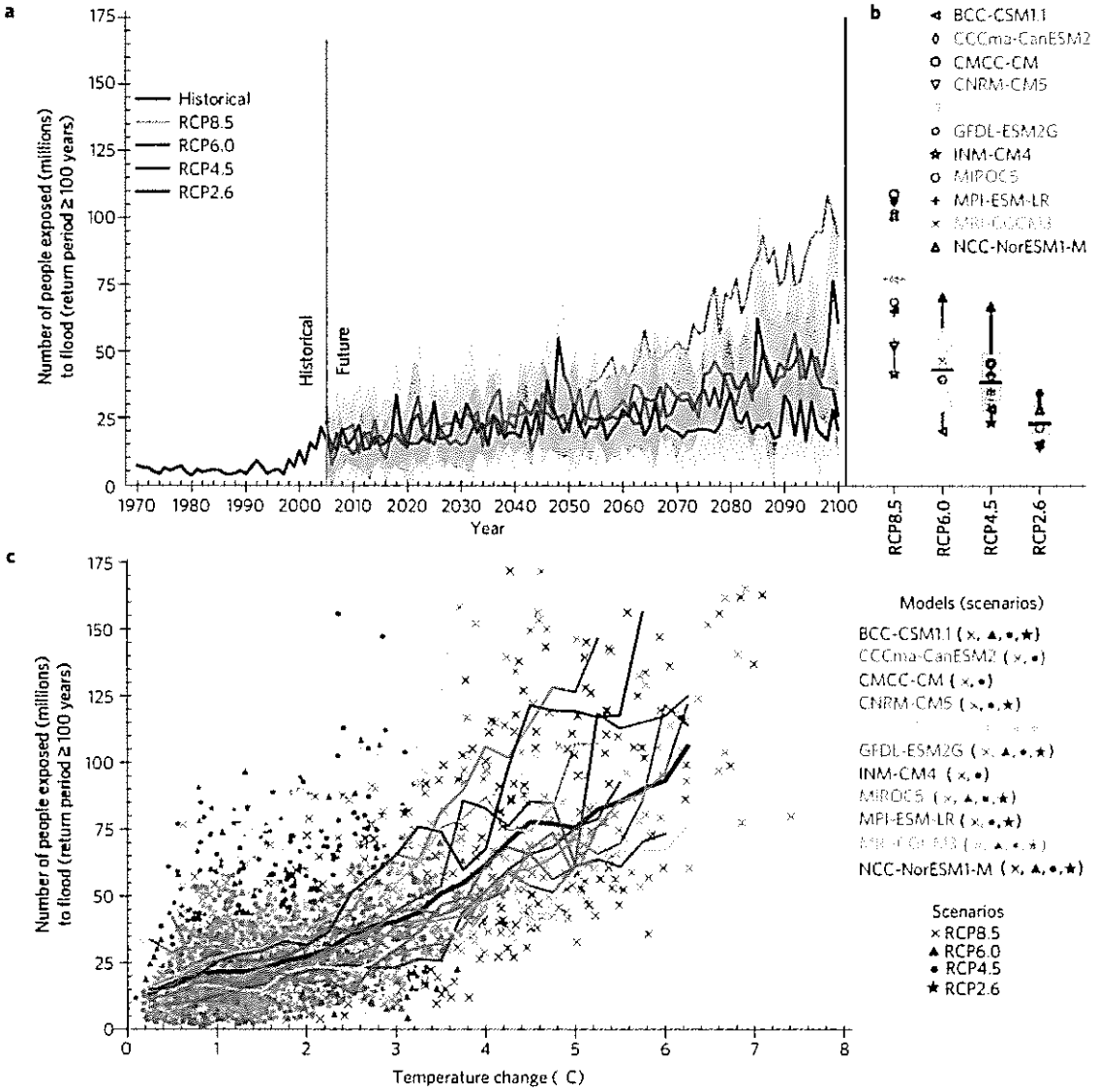

Figure 3 Global flood exposure for the 20C 100-year flood, or above, in millions. a, The ensemble means of the historical simulations (thick black line) and the future simulations for each scenario (coloured thick lines). The shading denotes the ±1 s.d. **b**, The maximum and minimum range (whiskers), mean (horizontal thick lines within each bar), ±1 s.d. (height of box) and individual values among AOGCMs (coloured markers within each bar) averaged over 21C. **c**, Global flood exposure and change in global mean surface air temperature (from the average of 1980–1999). Annual flood exposure for each AOGCM for each scenario (coloured markers), the mean of flood exposure for each 0.5 °C bin of temperature change for each AOGCM (coloured lines) and multi-model mean of them (thick black line) are shown. The population is fixed at the level in the year 2005. All of the individual time series for a selected scenario are provided in Supplementary Fig. S11.

consistency. In Europe, the ranges of the return periods were spread out except for the Rhein.

In all of the selected river basins, except the Mekong and the Lena, the maximum and minimum return periods (marked by the upper and lower whiskers in Fig. 2b, respectively) from the different model simulations show that flood frequency can be projected as a decrease or an increase in 21C depending on the AOGCM used. If only a single AOGCM is used, either a decrease or an increase in the return period might easily be projected, as shown previously[12,14]. This highlights the need to use multiple AOGCMs to analyse the changes in flood frequency.

The implications of the projected changes in floods to human society can be measured by the present and future populations at risk of flooding. Ref. 15, for example, simply estimated the future global affected population from outputs of a single AOGCM, showing that it would increase fivefold by the end of this century. Here, we adopted an index that was frequently used in previous studies[4,5], the flood exposure. We calculated for four RCP scenarios the sum of the population living in the modelled inundation areas in which annual maximum discharge exceeds the 20C 100-year flood, following the flood exposure concept proposed in ref. 4 (see Supplementary Information S7 for details). The realization of the global flood exposure calculation is due to the development of a few very recent global river routing models with inundation dynamics, such as the CaMa-Flood model used in this study. To highlight the impact of climate change, the population was fixed to that of 2005 while calculating the flood exposure. The results show that the annual global flood exposure increases by about 4 ± 3 (RCP2.6), 7 ± 5 (RCP4.5), 7 ± 6 (RCP6.0) and 14 ± 10 (RCP8.5) times (from 0.1% to 0.4–1.2% of the global population) from 20C to 21C (Fig. 3a). We note that the spread of flood projections propagated into the estimation of exposure (see also

Supplementary Information S7). This increase in global flood exposure is due mainly to increased exposure in many low-latitude regions, particularly Asia and Africa, where flood frequency is projected to increase in 21C. When a similar calculation was performed with a future medium population growth scenario[16], the global flood exposure became larger (7–25 times to 20C) than that of the estimation with fixed population (Supplementary Table S2). This was particularly true in Asia and Africa, where the population is projected to increase.

The results shown in Fig. 3a can be converted into a scatter diagram for investigating the relationship between the increase in temperature and the global flood exposure (Fig. 3c). The relationship could be useful to set a greenhouse gas mitigation target. The global flood exposure with the 2 °C increase was 27 million, and that with the 4, 6 °C increase was 62, 93 million, respectively. Figure 3c indicates that the spread of global exposure among the AOGCMs in a scenario (Fig. 3a) can be explained to a certain extent by the difference in temperature increase in the AOGCMs, because the same temperature increase provides similar mean global exposure increases for different AOGCMs although model dependency is not negligible. In addition, there is large interannual variability in Fig. 3a (and also in Supplementary Fig. S11), which should not be neglected in setting an adaptation target.

Despite the limitations in our methodology (see also Supplementary Information S8) and inevitable uncertainty in regional and basin-scale projections, the results of this study signify the necessity for adequate adaptation and mitigation strategies on a global scale: adaptation to intensified floods and mitigation of greenhouse gas emissions. Major attention should be paid to lower-latitude countries where flood frequency and population are both projected to increase.

Methods

River discharge simulation. We calculated discharge from 11 AOGCMs out of the 23 participating in CMIP5 (Supplementary Table S1), which were selected according to the availability of runoff output data at the start time of this study. The AOGCMs were selected from completely independent institutions because different versions of AOGCMs from the same institution may not be considered independent. To calculate river discharge for flood analysis, the runoff output of an AOGCM, generally calculated from the vertical water balance of land surface processes of each AOGCM, must be integrated horizontally along the river network. The daily runoff outputs from 1960 to 2100 were therefore first interpolated from original resolutions (specified in Supplementary Table S1) of each of the 11 selected AOGCMs and then integrated to river discharges through a high-resolution (15′ × 15′) global river network map using a state-of-the-art global river routing model, the Catchment-based Macro-scale Floodplain Model (CaMa-Flood)[6].

CaMa-Flood more reasonably represents temporal variations and peaks of river discharge, as compared with previous global river routing models[3,17], because it can simulate river water levels and hence floodplain inundation hydrodynamics in a realistic manner[18]. Note, however, that CaMa-Flood does not consider the effects of anthropogenic regulation of flood water as was already described.

Calculations of river discharge were carried out for the time period from 1960 to 2100. From the whole simulation period (1960–2100), 30-year periods from 1971 to 2000 (hereafter 20C) and 2071 to 2100 (hereafter 21C) were selected to represent the present and future conditions, respectively. The calculated annual discharges, annual maximum daily discharges and discharges with 100-year return periods were compared against the respective observation-based discharges in 32 river basins. The comparison depicts reasonable consistency of simulation-based and observation-based annual discharges and annual maximum daily discharges (details of the validation are presented in Supplementary Information S1).

Fitting an extreme distribution function. Owing to the relatively small data sample (30 years) of AOGCMs, the two-parameter Gumbel distribution[19], with parameters estimated by using the L-moment method[20], was selected for the extreme distribution function because it provides relatively stable distribution parameters, as compared with other distributions (for example, a generalized extreme value distribution) in small data samples[12]. In ref. 12, it was pointed out that for the case of floods with return periods longer than 50 years in Europe, the two-parameter Gumbel distribution and a three-parameter generalized extreme value distribution showed similar results. Note also that the Gumbel distribution gives potentially higher probabilities of the extremes than those of other extreme distributions in terms of hydrological variables because of lighter tails in a shape parameter[12], but the changes in frequency can be illustrated irrespective of the selection of extreme function. The goodness of fit of the simulation data to the Gumbel distribution using the probability plot correlation coefficient test (PPCC)[21] showed that for all AOGCMs, ~76 ± 5% of the global model grid cells over land had PPCC > 0.96, corresponding to a 95% level of significance. Most grids with a PPCC < 0.96 are located in arid regions of the world, where extreme flood events are relatively rare and flood disasters are probably less significant than extreme drought events. Owing to the low fitting and because of the smaller importance for flood risk analysis, dry regions (32-year mean annual discharge of a retrospective simulation[13] for 1979–2010 of <0.01 mm d^{-1}) were screened out for the further analysis. For more details, see Supplementary Information S2.

The magnitude of river discharge corresponding to the 100-year return period in 20C was first computed using the annual maximum daily discharge of the historical AOGCM simulation fitted to the Gumbel distribution (hereafter referred as 20C 100-year flood). The return period of this calculated discharge in 21C, generally different from 100 years, was then computed for each AOGCM future simulation. The median return period of the 11 AOGCMs was then obtained. We adopted the median rather than the mean because a long return period from a single AOGCM would affect the result if return periods from several AOGCMs were simply averaged. Finally, a consistency among the AOGCMs was calculated by counting the number of AOGCMs showing the same direction of change (increase or decrease).

Although the 30 years (1971–2000 and 2071–2100) of discharge data constitute a relatively short time period for making estimates of events with a return period of 100 years, when the same samples were fitted to the Gumbel distribution, the changes in multi-model median return periods (21C–20C) of other return periods of 20C floods (for example, 10- and 30-year return periods) showed a very similar spatial distribution (Supplementary Figs S7 and S8). We therefore analysed 100-year floods for easier comparisons with previous studies[2,3,12]. In addition, Supplementary Information S4 provides another bootstrap-based uncertainty analysis that examines the effect of limited data periods on uncertainty, although the range of uncertainty in this study is mainly represented by the spread of AOGCMs.

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Author contributions

R.M., S. Koirala, D.Y. and H.K. carried out the simulation and analysis. L.K. and S. Koirala carried out the exposure estimation. S.W. contributed to the data archive. Y.H. and S. Kanae designed the research. Y.H., S. Koirala and S. Kanae co-wrote the paper.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to Y.H. or S.K.

Competing financial interests

The authors declare no competing financial interests.

Tab D

PLOS | ONE

RESEARCH ARTICLE

Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment

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Abstract

Coastal zones are exposed to a range of coastal hazards including sea-level rise with its related effects. At the same time, they are more densely populated than the hinterland and exhibit higher rates of population growth and urbanisation. As this trend is expected to continue into the future, we investigate how coastal populations will be affected by such impacts at global and regional scales by the years 2030 and 2060. Starting from baseline population estimates for the year 2000, we assess future population change in the low-elevation coastal zone and trends in exposure to 100-year coastal floods based on four different sea-level and socio-economic scenarios. Our method accounts for differential growth of coastal areas against the land-locked hinterland and for trends of urbanisation and expansive urban growth, as currently observed, but does not explicitly consider possible displacement or out-migration due to factors such as sea-level rise. We combine spatially explicit estimates of the baseline population with demographic data in order to derive scenario-driven projections of coastal population development. Our scenarios show that the number of people living in the low-elevation coastal zone, as well as the number of people exposed to flooding from 1-in-100 year storm surge events, is highest in Asia. China, India, Bangladesh, Indonesia and Viet Nam are estimated to have the highest total coastal population exposure in the baseline year and this ranking is expected to remain largely unchanged in the future. However, Africa is expected to experience the highest rates of population growth and urbanisation in the coastal zone, particularly in Egypt and sub-Saharan countries in Western and Eastern Africa. The results highlight countries and regions with a high degree of exposure to coastal flooding and help identifying regions where policies and adaptive planning for building resilient coastal communities are not only desirable but essential. Furthermore, we identify needs for further research and scope for improvement in this kind of scenario-based exposure analysis.

Introduction

Coastal zones have always attracted humans because of their rich resources, particularly their supply of subsistence resources; for logistical reasons, as they offer access points to marine trade and transport; for recreational or cultural activities; or simply because of their special sense of place at the interface between land and sea. The development and utilisation of coastal zones has greatly increased during the recent decades and coasts are undergoing tremendous socio-economic and environmental changes—a trend which is expected to continue in future. Further, coastal areas show distinctive patterns of population structures and development, which are partially linked to the global trends of growth and urbanisation. Population density is significantly higher in coastal than in non-coastal areas [1, 2] and there is an ongoing trend of coastal migration, which is associated with global demographic changes [3]. Coastal population growth and urbanisation rates are outstripping the demographic development of the hinterland, driven by rapid economic growth and coastward migration [4, 5]. In China and Bangladesh, for example, the population in the low-elevation coastal zone (LECZ) grew at around twice the rate of the national growth between 1990 and 2000 [5]; the LECZ is commonly defined as the contiguous and hydrologically connected zone of land along the coast and below 10 m of elevation [5, 6]. At the same time, urban areas in the LECZ are growing and expanding faster than in any other area [7]. In China, the growth of coastal urban areas is particularly high at more than three times the national rate, which has been associated with the ongoing economic development and specific policies that drive coastward migration [5].

Most of the world's megacities are located in the coastal zone [8] and many of these are situated in large deltas, where combinations of specific economic, geographic and historical conditions to date attract people and drive coastal migration [9]. This trend, however, is not restricted to mega-deltas: de Sherbinin et al. [10] estimate that globally nearly all coastal ecosystems, as categorised by the Millennium Ecosystem Assessment, experienced net in-migration between 1970 and 2000 despite prevalent coastal hazards. Further, as observed by Seto et al. [7] in a global meta-analysis of urban land-use change, urban land expansion rates in the coastal zone were significantly higher than in the non-coastal hinterland in the same period. These trends are commonly assumed to continue into the future or to even increase [7, 11, 12], making this an important scenario to consider in policy analysis [13]. However, coastal population growth and urbanisation trends are not uniform and can vary significantly between countries and regions: The highest rates of urban land conversion in the coastal zone, i.e. increase of urban extent, occurred in China and Southwest Asia, while the lowest change took place in Europe, North America and Oceania [7].

Population growth and development are critical drivers of change in coastal zones and generate a high pressure on coastal ecosystems and natural resources through increased utilisation and pollution [14, 15]. Coastal growth, land conversion and urbanisation are also related to an increasing exposure of large numbers of people and assets to existing hazards and sea-level rise and related effects, which significantly increases levels of risk and vulnerability along coastlines and in populated deltas. This holds especially true for countries of the developing world [16–18]. Changes in extreme coastal high water levels due to climate change and sea-level rise and the biophysical and socio-economic consequences of such hazards could render living at the coast a high-risk choice [16, 19–21]. Recent studies suggest that mean sea levels could rise by 1 m or more by 2100 [22, 23], which will have severe impacts on coastal environments and ecosystems. Human coastal settlements including infrastructure and economies could be severely impacted by inundation and flooding, coastal erosion, shoreline relocation or saltwater intrusion; and there is the potential for larger disasters [8, 24, 25]. Furthermore, high-impact coastal hazards, such as tsunamis, can devastate whole regions and result in high casualties, as

observed during the 2004 Indian Ocean Tsunami and the Great Eastern Earthquake and Tsunami which hit the northeast coast of Japan in 2011 [20, 26].

At global to regional scales, various studies estimated the population living in the LECZ [1, 5]; assessed the coastal population possibly impacted by a certain rise in sea level [27, 28]; and identified the people living in the storm surge hazard zone that is subject to re-occurring coastal flood events with a specific return rate, with or without consideration of climate change and sea-level rise [18, 29, 30], and adaptation [13, 31–33]. These studies use a range of recognised metrics while working at different spatial and temporal scales and employing various methodological approaches from simple inundation models to more complex vulnerability assessment tools. For reviews of these and other studies and for summaries of commonly employed metrics, data and methods, we refer to Lichter et al. [6], McLeod et al. [34], Mondal and Tatem [35] and Nicholls et al. [36].

The above mentioned studies also differ in the base data used and the scenarios employed. For example, Dasgupta et al. [28, 30] assessed the population of developing countries exposed to sea-level rise and storm surges on the basis of spatially explicit but static population data. Nicholls [13] considered two scenarios of coastal population change in a scenario-based analysis of coastal flooding impacts for the 21st century: First a low-growth scenario, where coastal change was assumed to uniformly follow national change. Second a high-growth scenario, where the coastal population was assumed to grow at twice the rate of the national population in the event of growth, or to decrease at half the rate if declining trends occurred, i.e. people are being relatively attracted to the coast even in the case of falling national population trends. Nicholls et al. [11] tested scenario-driven variations of this "migration factor" with values ranging between one and two and assumed coastward migration to potentially offset falling population trends beyond 2050 for A1 and B1 Special Report on Emissions Scenarios (SRES), resulting in a net increase of population exposed to coastal hazards. Both studies did not differentiate between urban and non-urban population shares.

In this study, we provide more detailed assessments of future coastal population exposure, including accounting for the observed differential growth of coastal areas against the landlocked hinterland, as well as for urbanisation trends and the expansive growth of coastal urban areas [37]. Our key assumption is that the observed trends of coastal growth are likely to continue into the future. We use spatially explicit methods and publicly available global data sets to assess (i) the land area and population distribution in the LECZ and (ii) people living in the 100-year flood plain for three points in time: For a baseline year (2000) and for the years 2030 and 2060. In this context, we develop national projections of the urban and non-urban coastal population on the basis of four environmental and socio-economic scenarios which account for sea-level rise (for the flood plain analysis), population distribution, trends in urbanisation and coastal population growth. Our projections of the LECZ population refer to the extent of LECZ in the baseline year 2000 and do not consider possible displacement due to sea-level rise and other hazards or environmental changes. Further, we apply specific correction factors to account for coastal growth. The underlying scenario narratives, which were developed by the UK Government's Foresight project on Migration and Global Environmental Change (henceforth the Foresight Project), specifically aim at representing possible future developments of migration drivers [38, 39].

This paper is structured as follows: The Material and Methods outline the metrics and methodology chosen, the spatial and demographic base data employed and the projections developed. In the Results section, we present the findings for population development in the LECZ and the 100-year flood plain, while in the Discussion specific issues are addressed such as scenarios of population development and drivers of coastal migration, as well as limitations and uncertainties. Finally, the Summary and Conclusions summarize the study results, which

present new estimates of coastal population trends and exposure and build ground for further and more detailed assessments of exposure and vulnerability of coastal zones.

Material and Methods

There is no uniform definition of the coastal zone. Generally understood as the broader transitional area between the land and the marine environment [40], any geographical delimitation of the "coastal zone" is linked to the questions asked and the specifications of localities and issues under investigation. In the present study, we employed the concept of the LECZ, which constitutes an unambiguous and widely used definition of the coastal zone [5, 6] (see Introduction). In addition to the LECZ metrics, we also used the 100-year flood plain in order to better understand present and future risk. The 1-in-100-year return period is the standard used for coastal protection in many countries and has been employed in many earlier assessments, e.g. in Hanson et al. [18] and Hallegatte et al. [41].

The population projections for 2030 and 2060 are based upon four socio-economic and environmental scenarios formulated by the Foresight Project [38, 39] and involve combining the spatial assessment of present coastal population with UN statistical demographic data sets (see also Fig. 1 and Table 1). Fundamental to our calculations are the following three assumptions: (i) coastal migration leads to higher relative growth of coastal areas as compared to the landlocked hinterland, (ii) urban and non-urban populations in the coastal zone develop differently and (iii) coastal urban growth is expansive, i.e. urban areas are expanding into previous non-urban space. In order to differentiate coastal from inland growth as well as urban from non-urban growth, we applied correction factors to the respective national growth rates.

In total, 187 coastal nations were assessed in this study. It must be noted that Taiwan is not in the UN demographic data sets we employed to build the population projections, so we excluded Taiwan.

Land area and population in the LECZ

Analysis of land area and population in the year 2000. For estimating land and population in the LECZ for the year 2000, we employed the methods of McGranahan et al. [5] and Lichter et al. [6], using an eight-sided connectivity rule to identify the inundation areas that are hydrologically connected to the ocean from the SRTM30 Enhanced Global Map data (Table 2). To differentiate between urban and non-urban population we used the MODIS 500-m Map of Global Urban Extent [42] as proxy for urban areas. For the MODIS urban extent grid, Schneider et al. [42, 43] defined urban areas as „places dominated by built environments", where the „ 'built environment' includes all non-vegetative, human-constructed elements, such as roads, buildings, runways, etc. (i.e. human-made surfaces) and 'dominated' implies coverage greater than 50% of a given landscape unit (the pixel)" (see Uncertainties, limitations and evaluation of results). For our work we opted for the MODIS 500-m urban map because it provides a more recent and more detailed approximation of urban, built-up and settled areas [42, 43], whereas, for example, the GRUMP urban extent grid [45] has been reported to overestimate urban areas [7, 43]. The MODIS urban extent grid captures most areas of high population density from the GRUMP population data set [44] which we utilised to estimate the baseline population in the LECZ (see Table 2). Consequently, the urban population estimates we produced for the baseline year 2000 represent people living in dense urban areas, while the category of non-urban population summarizes people living in rural areas and those in less densely populated suburban or peri-urban areas. In this aspect, our approach differs from the studies of McGranahan et al. [5] and Balk et al. [1] which used the GRUMP urban extent grids as a base layer for mapping the urban footprint.

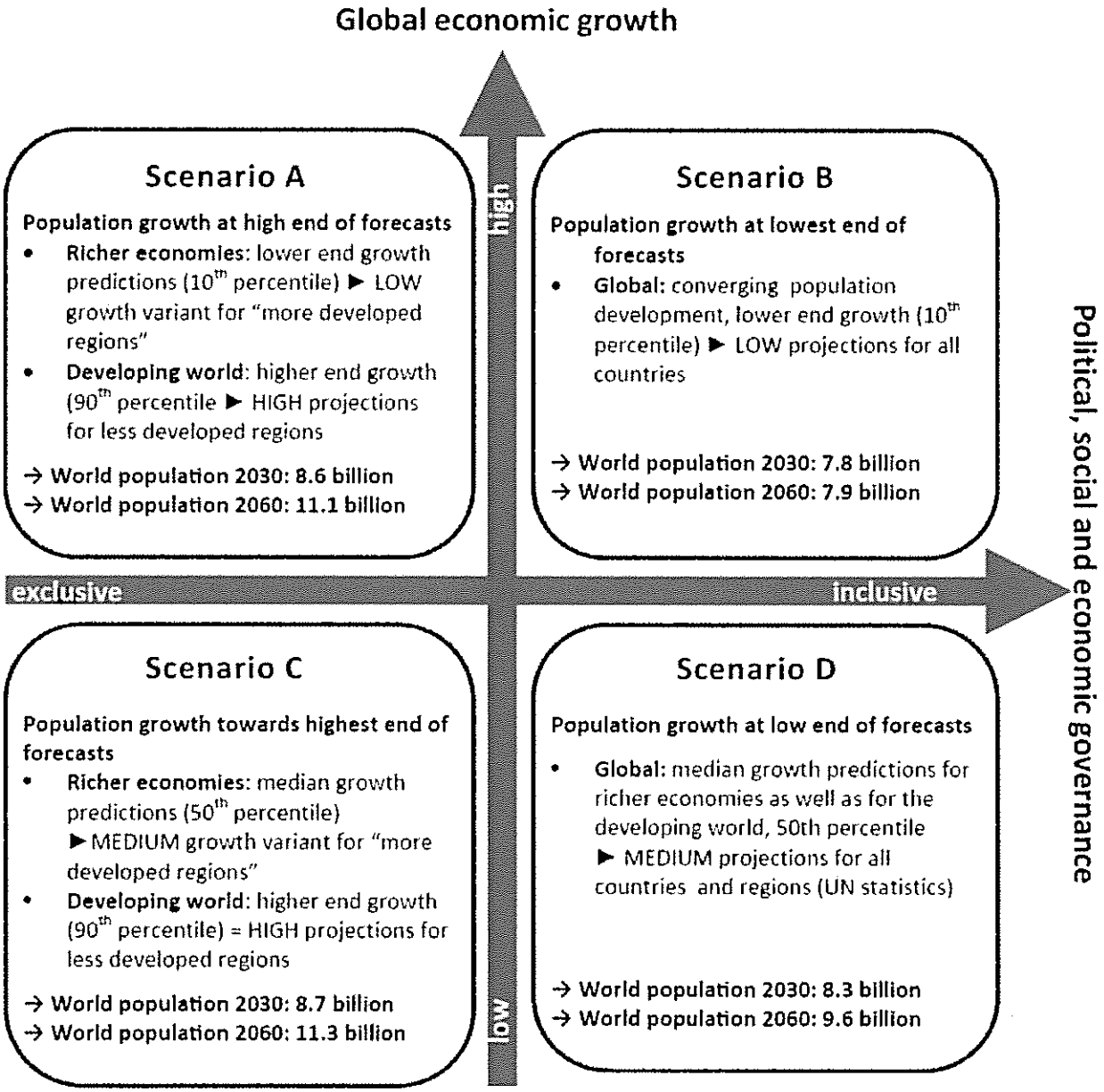

Fig 1. Foresight scenarios A-D of future population growth and implementation through UN demographic variants. Assumptions of future population growth for the Foresight scenarios A-D were taken from [38, 39]. Included in this figure are global scenario results which are based on UN variants of population growth ('LOW', 'MEDIUM', 'HIGH') [46–48] as well as development status.

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We used countries as reporting units (for administrative boundaries see Table 2) and matched the country definitions with the UN classifications [46, 47]. This allowed us to link the spatial population assessments with the population database (see Future LECZ population projections in the years 2030 and 2060). If LECZ population counts and the UN national estimates deviated, which was mostly the case for small island states, corrections were applied adjusting the LECZ counts to match the UN urbanisation and national population data. This

Table 1. Details on the implemented socio-economic scenarios A-D including population growth variants and coastal correction factors (a, b).

Scenario	Population growth variants	Correction factors		Scenario narratives and assumptions
		Urban (a)	Non-urban (b)	
Scenario A	**Population growth AT HIGH END OF FORECASTS:** High global growth; exclusive social, political and economic governance			
Richer economies	10th perc. ▸ LOW	1.7	2.0	Fast growing economy and aging population; high demand for low skilled workers including migrants from developing world to regional economic growth poles; declining population growth rates.
Developing world	90th perc. ▸ HIGH	1.7	2.0	Internal migration in lagging developing countries due to gradual relocation of poverty, rapid migration in faster developing countries.
Scenario B	**Population growth AT LOWEST END OF FORECASTS:** High global growth; inclusive social, political and economic governance			
Richer economies	10th perc. ▸ LOW	1.7	2.0	High global growth limits overall population growth; very fast ageing population in richer economies; increasing demand for labour but largely voluntary migration from poorer economies.
Developing world	10th perc. ▸ LOW	2.0	2.0	Relatively equal distribution of growth in economic activity across the world, implying substantial job creation in the urban areas of the poorer economies; massive migration to regional growth poles.
Scenario C	**Population growth TOWARDS HIGHEST END OF FORECASTS:** Low global growth; exclusive social, political and economic governance			
Richer economies	50th perc. ▸ MEDIUM	1.7	1.7	Stagnant world economic growth; relatively fast aging population; more migration of skilled population from poorer countries; coastal non-urban growth lower compared to the other scenarios, due to stagnant economy and migration to regional growth poles.
Developing world	90th perc. ▸ HIGH	1.8	1.7	Continuing young population in the poorest parts of the world; stagnant economy and migration to regional growth poles; in general limited internal migration opportunities with more rapid internal migration only in a few faster growing developing countries.
Scenario D	**Population growth AT LOW END OF FORECASTS:** Low global growth; inclusive social, political and economic governance			
Richer economies	50th perc. ▸ MEDIUM	1.7	2.0	Slow world economic growth; limited demand for labour; low wage growth; aging population; lower levels of migration but rising demand for migrants.
Developing world	50th perc. ▸ MEDIUM	1.7	2.0	Increased local opportunities for skilled workers in poorer economies; high internal migration in a few faster growing developing countries.

Scenarios and scenario narratives and assumptions are based on the Foresight Project's scenario narratives [38, 39]. Scenarios B and D assume "inclusive governance", in contrast to "exclusive governance" (scenarios A and C). Inclusive governance e.g. respects human rights, is driven by participatory politics and includes migrant and minority groups in governance structures, while inequalities and tensions between communities determines "exclusive governance" [39].

Population growth variants: This column explains the implementation of the Foresight Project's demographic variants (10th percentile, 50th percentile, 90th percentile) through UN variant of population growth ('LOW', 'MEDIUM', 'HIGH') as provided by the UN's demographic data sets [48]. Classified as 'richer economies', or 'more developed regions' in UN terms [46, 47], are Europe, Northern America, Australia/New Zealand (Oceania) and Japan.

Abbreviations: perc. = percentile

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procedure ensured consistency between the data sets and the projected LECZ population numbers not exceeding the UN projection totals for the respective countries.

Future LECZ population projections in the years 2030 and 2060. Our methodology for projecting the urban and non-urban LECZ population in 2030 and 2060 encompassed two steps. First, UN population estimates and projections per country were developed for each of the Foresight scenarios A–D (Fig. 1) on the basis of the demographic descriptors given in the Foresight Project's scenario narratives [38, 39]. We matched the latest national low-, medium- and high-population projections of the United Nations' 2010 Revision of their World Population Prospects [48] to the Foresight scenario assumptions of lower, median and high-end growth predictions (Fig. 1, Table 1 and Table 3). 'Richer economies', as stated in the Foresight scenario narratives, were translated to correspond with 'more developed regions' as classified by the UN (Japan; Europe; North America; Australia/New Zealand), while countries of the

Table 2. Metrics and data employed for the LECZ and 100-year flood plain baseline assessments (year 2000).

Metrics	Base data
Land area and total population in the LECZ and for 1 m elevation increments within the LECZ; urban population in the LECZ	SRTM30 Enhanced Global Map [80],-30 arc sec resolution
	GTOPO30 Global Digital Elevation Model [82],-30 arc sec (for Greenland)
	Population Count Grid, GRUMP, Alpha Version [44], -30 arc sec, re-sampled to 15 arc sec for analysis of urban/non-urban to match the MODIS data resolution (see below): population year 2000
	Land and Geographic Unit Area Grid, GRUMP, Alpha Version [71],-30 arc sec
	Land and Geographic Unit Area Grid, GPWv3 [83],-2.5 minutes, re-sampled to 30 arc sec (for Greenland)
	MODIS 500-m Map of Global Urban Extent [42, 43], -15 arc sec resolution; population year 2009. Available from: http://www.sage.wisc.edu/people/schneider/research/data.html (accessed June 2011)
	National Administrative Boundaries, GPWv3 [81]
	National Administrative Boundaries, Global Administrative Areas GADM, Level 01 [72] (for Greenland)
	NUTS0 national administrative boundaries [82] (for the Netherlands)
People in the 100-year flood plain	**Area extent and total population for 1 m elevation increments within the LECZ (see above)**
	National Administrative Boundaries, Global Administrative Areas GADM[72]

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'developing world' (Foresight) were interpreted to belong to the UN's 'less developed regions' (Africa; Asia except for Japan; Latin America and the Caribbean; Oceania except for Australia/New Zealand) [46, 49]. Based on this interpretation, we computed the total future population for all four scenarios A-D and the years 2030 and 2060 per country. Total population was then split into urban and non-urban on the basis of the United Nations' 2009 Revision of the World Urbanization Prospects [50, 51] and the 2045–2050 trends were used to extrapolate urban and non-urban populations from the latest projection date of the UN urbanisation database (2050) to 2060. Finally, we derived total annual rates of urban (G_{ut}) and non-urban (G_{nt}) population growth per country from the population data for the periods 2000–2030 and 2030–2060, employing exponential growth functions as described in Balk et al. [52] and Gaffin et al. [53].

In a second step, we projected the urban and non-urban population counts of the LECZ (see Analysis of land area and population in the year 2000) from the reference year 2000 to the years 2030 and 2060 for all scenarios using specific annual rates of coastal urban (G_{uc}) and non-urban (G_{nc}) population growth of the respective base year (2000, 2030). These growth rates were based on correction factors (a, b) which we developed to account for faster coastal growth as compared to inland growth and on the derived total rates of urban (G_{ut}) and non-urban (G_{nt}) population growth Equation 1 and Equation 2. This allowed us to differentiate between coastal (G_{uc}, G_{nc}) and inland (G_{ui}, G_{ni}) urban and non-urban growth, while controlling the total population growth.

Table 3. Metrics and data employed for the LECZ and flood plain scenario analyses.

Metrics	Base data
Population in the LECZ projected to 2030 and 2060	Foresight scenario narratives: Scenario narratives and demographic factors [38, 39] (see Fig. 1 and Table 1)
	Total and urban population in the LECZ in 2000 per country (see Table 2)
	World Population Prospects: The 2010 Revision. Total population (both sexes combined) by major area, region and country, annually for 1950–2100 (thousands) [48]
	World Population Prospects: The 2010 Revision. Location list with codes, description, major area, region and development group [47]
	World Urbanization Prospects: The 2009 Revision. Urban Population by Major Area, Region and Country, 1950–2050 [50]
	World Urbanization Prospects: The 2009 Revision. Rural Population by Major Area, Region and Country, 1950–2050 [51]
People in the 100-year flood plain projected to 2030 and 2060	Foresight scenario narratives on sea-level rise 2030: + 10 cm; 2060: + 21 cm [38, 39]
	DIVA 1-in-100-Year Surge Heights [56, 57]
	Total population (year 2000) in the 100-year coastal flood plain in 2000, 2030 and 2060; results per country (see Table 2)
	Coastal population growth rates, country-by-country (intermediate results of LECZ population projections, see above for input data)

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Thus, the **coastal urban growth rate (G_{uc})** is given as a function of inland urban growth and the correction factor (a):

$$G_{uc} = a \times G_{ui};\ \ if\ \ G_{ui} < 0\ \ then\ \ G_{uc} = 0.001 \qquad \text{Equation 1}$$

G_{uc} = coastal urban growth rate for the chosen period, e g. 2000–2030;

a = correction factor for coastal urban growth;

G_{ui} = inland urban growth rate for the chosen period, e.g. 2000–2030.

The total urban growth (G_{ut}) rate is given as a function of the inland urban growth rate (G_{ui}) and the coastal urban growth rate (G_{uc}). Both G_{ui} and G_{uc} are weighted by the proportion of the respective population groups (P_{ui}; P_{uc}) to the total national urban population (P_{ut}):

$$G_{ut} = G_{ui} \times (P_{ui} \div P_{ut}) + G_{uc} \times (P_{uc} \div P_{ut}) \qquad \text{Equation 2}$$

G_{ut} = total urban population growth rate for a period, e.g. 2000–2030;

P_{ui} = inland urban population numbers at beginning of the period;

P_{ut} = total urban population numbers at beginning of the period;

P_{uc} = coastal urban population numbers at beginning of the period.

The coastal urban growth rates (G_{uc}) were then derived by solving Equation 2 for G_{ui} and replacing G_{ui} in Equation 1. This step ensures that the aggregate population growth of a country does not exceed the national UN population estimates. The same equations were used for deriving **coastal non-urban population growth rates (G_{nc})** from total non-urban population growth rates (G_{nt}) and calculating the correction factor for coastal non-urban growth (b).

We also assumed population growth not to decline in the LECZ, even if inland population growth were to be negative. If negative growth occurred, we set $G_{uc} = 0.001$ and $G_{nc} = 0$, which

generally results in very low growth for coastal urban areas and zero growth for coastal non-urban areas. This procedure was applied for small island states and other countries for which the underlying UN data sets assume negative national growth, such as the Republic of Moldova, Bulgaria, Ukraine, Georgia, Lithuania and Dominica.

The **correction factors for coastal urban and non-urban growth (a, b)** (Table 1) were developed on the basis of the Foresight scenario characteristics regarding economic and societal development, population growth and coastal migration [38, 39], as well as on literature review [11, 13] and expert judgement. They account for the three basic assumptions stated above. We set scenario-specific values for these factors that ranged between 1.7 and 2.0, following earlier studies of Nicholls [13] and Nicholls et al. [11]. Urban expansion leads to an increase in population density, to an expansion of built-up areas into non-urban land through suburbanisation and increasingly to peri-urbanisation effects which creates transient boundaries between urban and non-urban zones [54, 55]. Due to methodological, data- and scale-related constraints, modelling the spatial dynamics linked to these aspects of urban growth was not feasible within the scope of this study. We therefore employed a non-spatial approach to compensate for this limitation: By setting the basic correction factors for coastal non-urban growth (b) higher than the ones for coastal urban growth (a), we accounted for urban expansion by allocating a proportion of the coastal urban growth into the non-urban hinterland (see Equation 1 and Table 1).

According to the assumptions on population growth and migration patterns made in the Foresight Project's scenario narratives, we set the correction factors (a, b) as follows (see Table 1): Correction factors of 1.7 and 2.0 (for urban and non-urban growth respectively) were applied for scenarios A (population growth at the high end of forecasts) and D (population growth at the low end of forecasts), both for richer economies and for developing countries. Variations were made for scenario B, where we assumed that both coastal urban and coastal non-urban areas in the developing world will be growing at twice the rate of the hinterland. Though ranging at the lowest end of the population forecasts, resulting in stagnation in growth after 2050, the scenario narratives for scenario B outline substantial job creation in urban areas of the poorer economies and massive migration to regional growth poles, which we assume to include coastal urban areas. For scenario C, we adjusted both the coastal urban and the coastal non-urban correction factors as follows: Stagnant economies and migration to regional growth poles were assumed to reduce coastal non-urban growth in comparison to the other scenarios, which is reflected in a lower correction factor (1.7). At the same time, the correction factor for coastal urban growth in the developing world was set slightly higher (1.8) to express the fact that in this scenario internal migration to coastal urban areas is more rapid in some faster growing countries. For richer economies, we see no change for urban areas in comparison to other scenarios.

It must be noted that the underlying UN data, from which we derived the basic national urban and rural growth rates, already consider differences in urban and non-urban (i.e. rural) growth trends and reflect national trends of urbanisation. Our coastal correction factors (a, b) were applied additionally to the derived rates to account for the assumptions that coastal population growth is higher than national population growth in general and that there is urban expansion from 2000 to 2060 into what has been categorised as non-urban areas in the year 2000. Further, we applied the population projections to the LECZ baseline population estimates (year 2000); we did not consider any displacement of the LECZ from sea-level rise and inundation or coastal erosion.

People in the 100-year flood plain

The number of people living in the 100-year flood plain was assessed through a slightly modified approach. This was due to data processing constraints in developing spatial representations of

the flood plain at a global scale (see Table 2 and Table 3 for base data and metrics). First, we retrieved estimates of the 1-in-100-year extreme water levels from the Dynamic and Interactive Vulnerability Assessment (DIVA) database [56, 57] (Table 2). From these we computed the average 1-in-100-year surge height per level-1 administrative unit (3,366 units in total). Several small coastal countries and island states (i.e. Anguilla, Maldives and Singapore) had no records in the GADM Level-01 data set. For these we employed the GADM Level 0 data set and averaged the storm surge heights per country. The derived average storm surge heights were then displaced upwards by the amount of global mean sea-level rise assumed for the 2030 and 2060 Foresight scenarios [38, 39], 10 cm and 21 cm respectively (Table 3). It must be noted that the actual sea-level rise may vary considerably between regions and scenarios beyond the 2030/2060 narratives [23, 24]. Also, the analysis does not consider possible future climate-induced changes in storm or cyclone activity and resulting effects on flood levels.

We calculated the population in the flood plain based on the distribution of coastal population per 1 m elevation increment (Table 2) assuming that all land below the computed surge heights belongs to the 100-year flood plain. To account for the limited vertical resolution of the employed SRTM30 digital elevation model (multiples of 1 m), we assumed that population distribution within elevation increments is homogeneous. In order to account for differences in the land-ocean boundaries of the employed datasets, we allocated GRUMP population pixels that were falling in the ocean to the nearest GADM administrative units. The derived flood plain population represents the baseline (year 2000) population within the 2000, 2030 and 2060 flood plain. Next, these population estimates were projected into 2030 and 2060 by applying the LECZ's total coastal growth per country. Since the flood plain could not be defined spatially in this study with the methods applied, differentiating between urban and non-urban flood plain population was not possible.

Results

In the following sections, we present the results of our assessments at aggregated continental and regional scales (see Table 4, Table 5 and Table 8; Fig. 2, Fig. 3 and Fig. 4; S1 Table, S2 Table and S3 Table), as well as country-specific results of the top 25 countries in terms of population exposure (Table 6 and Table 7). We focus on two of the four Foresight scenarios assessed, unless the results require further attention: Scenario B (population growth at the lowest end of forecasts) and scenario C (population growth towards the highest end of forecasts). As supporting information, S4 Table lists all assessment results as well as the demographic input data per reporting unit, i.e. per country.

Population in the LECZ in 2000, 2030 and 2060

The LECZ comprised only 2.3% (2,599 thousand km^2) of the total land area of all coastal countries, but 10.9% (625 million) of their population in the year 2000 (Table 4; S1 Table). The majority (83%) of the global LECZ population lived in less developed countries. The average LECZ population density in the year 2000 was 241 people/km^2, which was more than five times higher than the global mean (47 people/km^2). The highest average population densities in terms of development status were found in the LECZ of least developed countries (382 people/km^2). Our results suggest a growth of the population in the LECZ from 625 million (year 2000; global population of 6.1 billion) to between 879 million (scenario B; global population: 7.8 billion) and 949 million people (scenario C; global population: 8.7 billion) in the year 2030 (Table 4 and Table 5; Fig. 2; S3 Table). By 2060, the LECZ population is likely to approach 1.4 billion people (534 people/km^2) under the highest-end growth assumption, which would be 12% of the world's population of 11.3 billion (scenario C). Even when assuming population

Table 4. LECZ population in the year 2000 and projections for 2030/2060 per continent and development status, scenarios A-D.

Region	LECZ population in 2000			LECZ population in 2030				LECZ population in 2060			
	Baseline 2000 [million]	Urban [%]	Non-urban [%]	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]
World	**625.2**	**23.5**	**76.5**	**938.9**	**879.1**	**948.9**	**892.9**	**1,318.3**	**1,052.8**	**1,388.2**	**1,128.1**
More dev. regions	107.5	50.1	49.9	120.6	120.6	125.8	125.9	124.1	124.1	138.4	138.4
Less dev. regions and least dev. countries	517.7	18.0	82.0	818.4	758.6	823.1	767.1	1,194.1	928.6	1,249.8	989.7
Least dev. countries	93.0	7.1	92.9	146.9	132.5	146.5	136.3	231.4	181.9	242.0	192.7
Less dev. regions, excluding least dev. countries	424.7	20.4	79.6	671.5	626.1	676.6	630.7	962.8	746.7	1,007.7	797.0
Less dev. regions, excluding China	373.7	17.9	82.1	619.3	561.4	619.0	574.6	958.8	729.1	1,005.0	785.5
China	144.0	18.1	81.9	199.0	197.2	204.1	192.4	235.4	199.6	244.8	204.2
Sub-Saharan Africa	24.2	17.8	82.2	66.4	63.1	65.7	61.3	160.0	136.5	174.0	126.6
AFRICA	54.2	16.5	83.5	117.6	108.5	116.8	108.9	229.3	190.0	245.2	185.6
ASIA	460.8	20.1	79.9	688.7	640.3	695.0	649.4	943.9	728.6	983.3	792.8
EUROPE	50.0	40.2	59.8	52.8	52.8	54.5	54.5	52.1	52.1	55.7	55.7
LATIN AMERICA AND THE CARIBBEAN	32.2	28.8	71.2	41.7	39.5	42.3	39.8	50.6	40.1	52.3	42.6
NORTHERN AMERICA	24.6	59.6	40.4	33.5	33.5	35.5	35.5	37.0	37.0	45.5	45.5
OCEANIA	3.3	34.7	65.3	4.7	4.6	4.8	4.8	5.5	5.0	6.1	5.8

Classifications by major region and develoment status follow the UN classification scheme [46, 47]. **Abbreviations**: dev. = developed.

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growth at the lowest end of the forecasts (scenario B), we estimate there to be more than one billion people in the LECZ globally by 2060 with an average population density of 405 people/km^2.

Asia had the largest LECZ population in the year 2000 (461 million or 73% of the total LECZ population; Table 4 and Fig. 2; S2 Table), and this will also be the case in 2030 and 2060, under all scenarios. By 2060, between 729 million (scenario B) and 983 million (scenario C) people will be living in the LECZ in Asia, which amounts to around 70% of the world's LECZ population. Within Asia, **Eastern Asia** (China, Hong Kong Special Administrative Region, Macao Special Administrative Region, Democratic People's Republic of Korea, Republic of Korea, Japan) had the largest proportion of population in the LECZ and showed the highest LECZ population density worldwide in the year 2000 (839 people/km^2; Fig. 3 and S1 Table). However, the projections suggest that **South-Central Asia** (Bangladesh, India, Islamic Republic of Iran, Maldives, Pakistan, Sri Lanka) will contribute more to the overall coastal population growth than Eastern Asia in the next decades and is projected to have the highest population

Table 5. Population projections for the LECZ and the 100-year flood plain for 2030/2060 per continent, scenarios A-D.

Region	Baseline population			Scenario	Total population		LECZ population				People in the 100-year flood plain					
	Total 2000 [million]	LECZ 2000 [million]	Flood plain 2000 [million]	Results per scenario and year	2030 [million]	2060 [million]	2030 [million]	% of total pop. 2030	2060 [million]	% of total pop. 2060	2030 [million]	% of total pop. 2030	% of LECZ pop. 2030	2060 [million]	% of total pop. 2060	% of LECZ pop. 2060
World	6,100.8	625.2	189.2	A	8,625.1	11,064.2	938.9	100.0	1,318.3	100.0	282.2	100.0	30.1	392.9	100.0	29.8
				B	7,845.7	7,925.1	879.1	100.0	1,052.8	100.0	268.1	100.0	30.5	315.5	100.0	30.0
				C	8,688.7	11,279.4	948.9	100.0	1,388.2	100.0	285.9	100.0	30.1	411.3	100.0	29.6
				D	8,298.5	9,597.0	892.9	100.0	1,128.1	100.0	271.0	100.0	30.4	339.5	100.0	30.1
AFRICA	811.1	54.2	12.6	A	1,641.4	2,955.3	117.6	12.5	229.3	17.4	26.0	9.2	22.1	46.9	11.9	20.5
				B	1,482.8	2,115.1	108.5	12.3	190.0	18.0	23.5	8.8	21.7	37.9	12.0	20.0
				C	1,641.4	2,955.3	116.8	12.3	245.2	17.7	25.7	9.0	22.0	49.2	12.0	20.1
				D	1,562.0	2,512.2	108.9	12.2	185.6	16.5	24.1	8.9	22.1	38.4	11.3	20.7
ASIA	3,697.1	460.8	137.3	A	5,107.7	6,153.9	688.7	73.4	943.9	71.6	211.1	74.8	30.6	297.6	75.7	31.5
				B	4,571.9	4,174.5	640.3	72.8	728.6	69.2	199.9	74.6	31.2	231.6	73.4	31.8
				C	5,113.0	6,170.3	695.0	73.2	983.3	70.8	213.4	74.7	30.7	309.6	75.3	31.5
				D	4,844.8	5,104.5	649.4	72.7	792.8	70.3	200.7	74.0	30.9	250.7	73.8	31.6
EUROPE	726.8	50.0	28.2	A	704.3	582.5	52.8	5.6	52.1	3.9	30.1	10.7	57.0	30.2	7.7	57.9
				B	704.3	582.5	52.8	6.0	52.1	4.9	30.1	11.2	57.0	30.2	9.6	57.9
				C	741.2	702.3	54.5	5.7	55.7	4.0	31.2	10.9	57.2	32.4	7.9	58.1
				D	741.2	702.3	54.5	6.1	55.7	4.9	31.2	11.5	57.2	32.4	9.5	58.0
LATIN AMERICA AND THE CARIBBEAN	521.4	32.2	6.1	A	743.5	923.0	41.7	4.4	50.6	3.8	8.1	2.9	19.5	10.2	2.6	20.2
				B	660.0	610.6	39.5	4.5	40.1	3.8	7.7	2.9	19.4	7.9	2.5	19.8
				C	743.5	923.0	42.3	4.5	52.3	3.8	8.2	2.9	19.5	10.5	2.6	20.2
				D	701.6	753.2	39.8	4.5	42.6	3.8	7.7	2.9	19.4	8.5	2.5	20.0
NORTHERN AMERICA	313.3	24.6	4.2	A	381.9	393.4	33.5	3.6	37.0	2.8	5.8	2.0	17.2	6.5	1.7	17.7
				B	381.9	393.4	33.5	3.8	37.0	3.5	5.8	2.2	17.2	6.5	2.1	17.7
				C	401.7	466.3	35.5	3.7	45.5	3.3	6.1	2.1	17.2	8.0	1.9	17.5
				D	401.7	466.3	35.5	4.0	45.5	4.0	6.1	2.3	17.2	8.0	2.4	17.5
OCEANIA	31.1	3.3	0.8	A	46.2	56.2	4.7	0.5	5.5	0.4	1.2	0.4	25.6	1.5	0.4	27.2
				B	44.7	49.1	4.6	0.5	5.0	0.5	1.2	0.4	25.2	1.3	0.4	25.9
				C	47.8	62.1	4.8	0.5	6.1	0.4	1.2	0.4	25.3	1.6	0.4	26.5
				D	47.1	58.4	4.8	0.5	5.8	0.5	1.2	0.4	25.2	1.5	0.4	25.8

Total population is based on [47, 48]. Classifications by major region and develoment status follow the UN classification scheme [46, 47]. All LECZ areas and population numbers are based on own assessments. **Abbreviations:** pop. = population.

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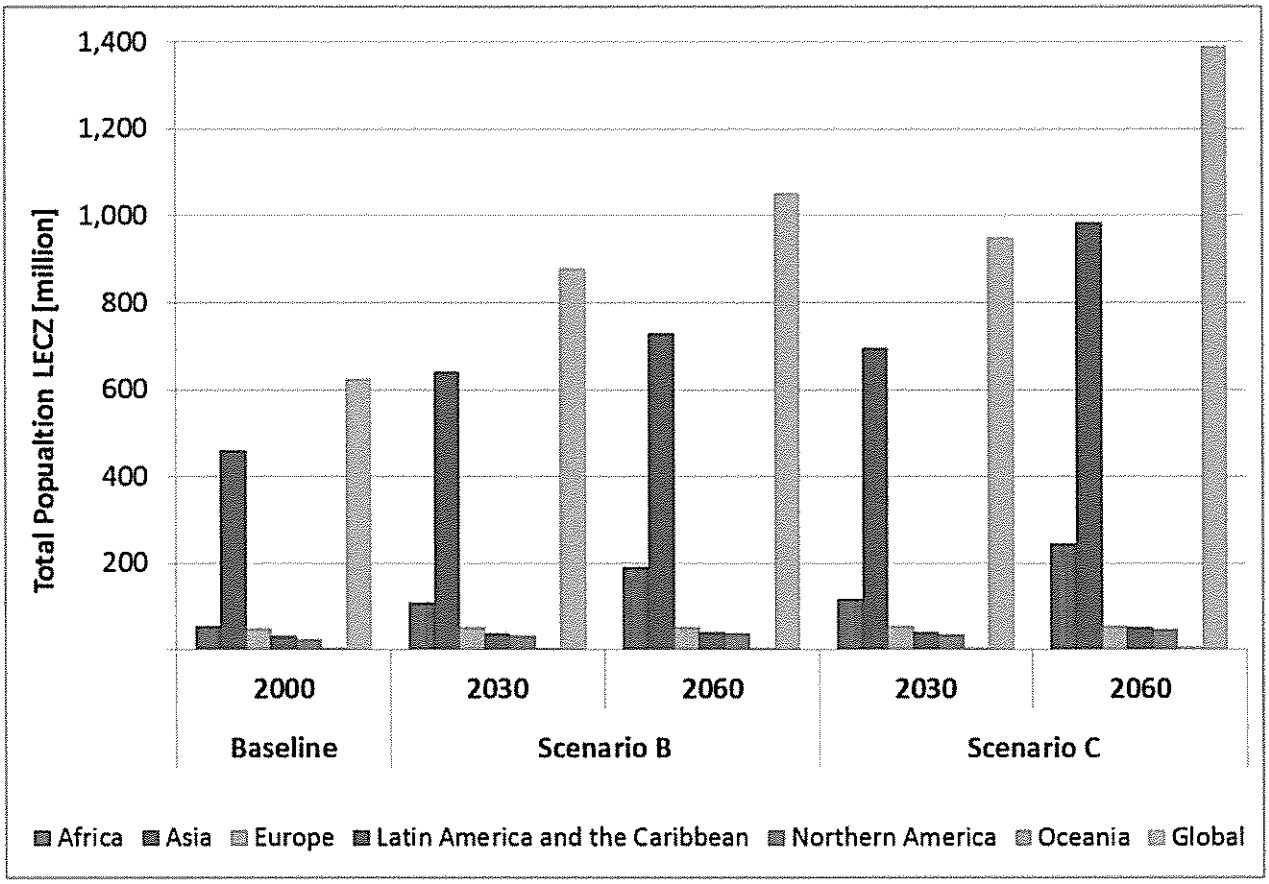

Fig 2. LECZ population in the year 2000 and projections for 2030/2060 per continent, scenarios A-D.

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totals in the LECZ of all Asian regions by 2060 (Fig. 3; S2 Table). This is mainly due to the large populations of Bangladesh, India and Pakistan, in conjunction with significantly higher rates of change as implied in the underlying demographic data sets [48, 50, 51].

Though **China** represented the largest proportion of people in the LECZ in the year 2000 (144 million people, 11.3% of its total population and 23% of the global LECZ population), its population growth is projected to slow down after 2030 (Table 6). Nevertheless, China could still grow to reach between 200 million (scenario B) and 245 million (scenario C; 16.7% of their total population) people in the LECZ by the year 2060, more than any other nation (Table 7; S2 Table). China is closely followed by **India**, which could experience a three-fold increase of its LECZ population between the baseline year 2000 (64 million; 6.1% of its total population) and the year 2060 (216 million; 10.3% of its total population) under the high-growth scenario C (Table 6 and Table 7). The LECZ population of **Bangladesh** (63 million) was similar to India (64 million) in the baseline year 2000 (Table 6). However, the LECZ of Bangladesh comprises over 40% of the country's total land area (India: 2.6% of the total land area) and had a much larger share of the country's total population (49%) than India (6.1%) in 2000. Further, the LECZ population was predominantly non-urban (96%) and the population density was considerably higher (1,154 people/km^2) than the respective of India (777 people/km^2) in the baseline year. Nevertheless, the projections for Bangladesh under scenario C assume a slower growth for its LECZ population, which can be explained by relatively lower non-urban coastal growth

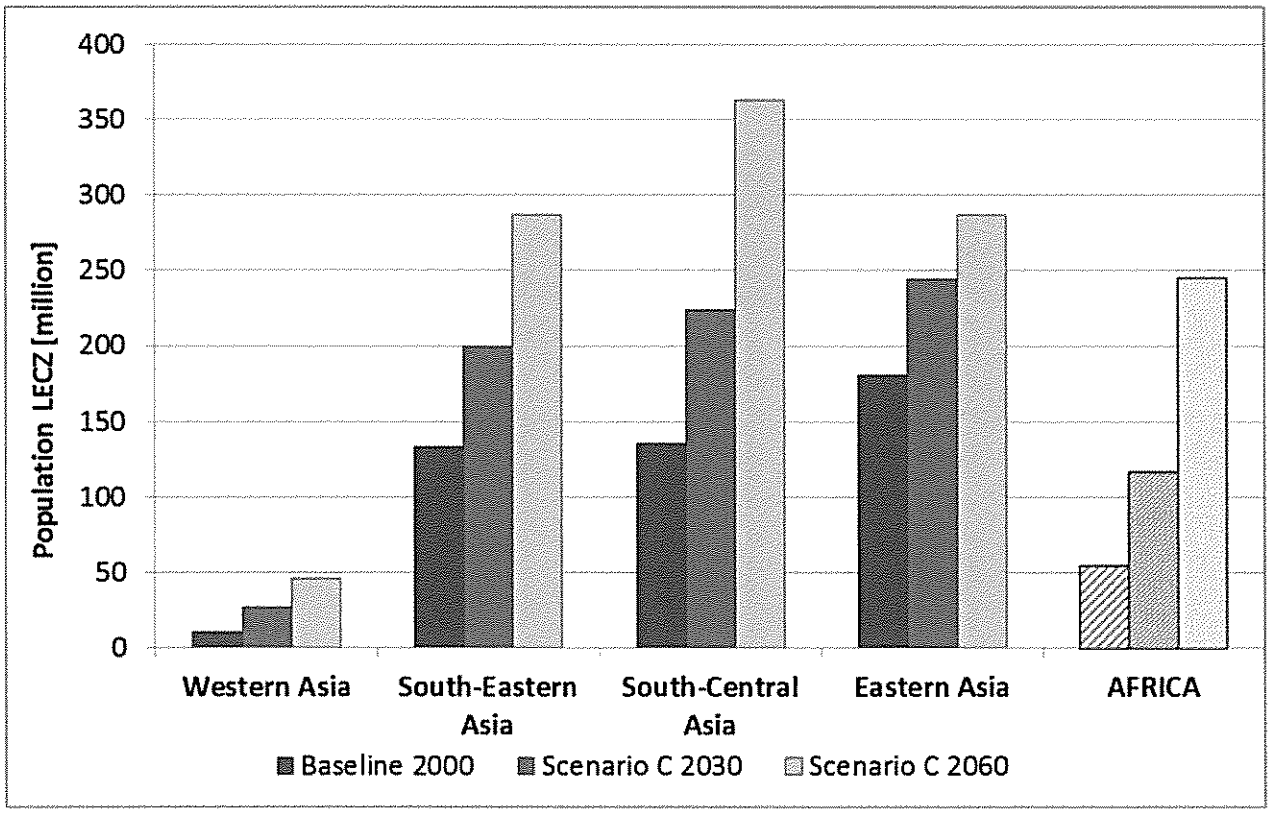

Fig 3. LECZ population in Asia in the year 2000 and projections for 2030/2060 per region, scenario C. Included are totals of LECZ population in Africa for the baseline year 2000 and for 2030/2060.

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(in comparison to other scenarios) in conjunction with the very large share of non-urban population (see Table 1 and Table 7 and Table 1). **Pakistan**, the third country in South-Central Asia that ranks among the top-25 countries in terms of LECZ population both in the 2000 and in 2060, is projected to encounter the strongest population growth in this region under scenario C (Table 6 and Table 7). In the year 2000, not a very large share of the Pakistani population was located in low-lying coastal areas (3.2% or 4.6 million people). However, the LECZ population could increase six-fold to reach 30 million people by 2060.

China, India, Bangladesh, Indonesia and Viet Nam represent the five countries with the largest share of population in the LECZ worldwide (Table 6). All these countries are located in Eastern, South-Central and South-Eastern Asia and belong to the less and least developed nations of the world. Together they accounted for 56% of the global LECZ population in the year 2000 (353 million people; 5.8% of the world population). From these countries, Bangladesh had the highest proportion of people living in low-lying coastal areas (49% of their total population respectively). All countries were characterised by very large extends of non-urban settlements in the LECZ, between 70% (Indonesia) and 96% (Bangladesh). According to our population projections, these countries will maintain the top five positions in the future and count up to 745 million people in the LECZ by 2060, 6.6% of the world population (scenario C; Table 7).

In contrast to Asia, **Africa s** LECZ population (54 million in 2000, 8.7% of the African coastal countries' population) and coastal land area in the LECZ (194 thousand km^2; 0.9% of the

Table 6. Top 25 coastal countries with highest LECZ population in the year 2000, ranked by LECZ population.

Rank LECZ 2000	Country	Region	Development status	Land area and population per country in 2000					LECZ area and population per country in 2000							
				Total land area [km²]	Total pop. [million]	Urban pop. [%]	Non-urban pop. [%]	Pop. density [p/km²]	LECZ area [km²]	LECZ area in % of total area	LECZ pop. [million]	Urban pop. [%]	Non-urban pop. [%]	Pop. density [p/km²]	LECZ pop. in % of total pop.	LECZ pop. in % of global LECZ pop.
1	China	Eastern Asia	less dev.	9,197,930	1,269.1	35.8	64.2	138	181,909	2.0	144.0	18.1	81.9	792	11.3	23.03
2	India	S-Central Asia	less dev.	3,211,220	1,053.9	27.7	72.3	328	82,262	2.6	63.9	16.4	83.6	777	6.1	10.23
3	Bangladesh	S-Central Asia	least dev.	135,986	129.6	23.6	76.4	953	54,679	40.2	63.1	4.4	95.6	1,154	48.7	10.10
4	Viet Nam	S-Eastern Asia	less dev.	328,594	78.8	24.5	75.5	240	66,232	20.2	43.1	12.9	87.1	650	54.7	6.89
5	Indonesia	S-Eastern Asia	less dev.	1,901,200	213.4	42.0	58.0	112	172,092	9.1	39.3	29.7	70.3	228	18.4	6.28
6	Japan	Eastern Asia	more dev.	372,304	125.7	65.2	34.8	338	24,154	6.5	30.2	59.7	40.3	1,250	24.0	4.83
7	Egypt	Northern Africa	less dev.	969,160	67.6	42.8	57.2	70	23,676	2.4	25.5	14.7	85.3	1,075	37.6	4.07
8	U.S.	North. America	more dev.	9,130,850	282.5	79.1	20.9	31	235,336	2.6	23.4	61.4	38.6	99	8.3	3.74
9	Thailand	S-Eastern Asia	less dev.	516,525	63.2	31.1	68.9	122	35,375	6.8	16.4	38.2	61.8	464	26.0	2.63
10	Philippines	S-Eastern Asia	less dev.	295,298	77.3	48.0	52.0	262	20,165	6.8	13.0	11.9	88.1	643	16.8	2.07
11	Myanmar	S-Eastern Asia	least dev.	669,464	45.0	27.8	72.2	67	48,651	7.3	12.5	11.4	88.6	257	27.8	2.00
12	Brazil	S America	less dev.	8,485,010	174.4	81.2	18.8	21	121,668	1.4	11.6	34.7	65.3	95	6.6	1.85
13	Netherlands	Western Europe	more dev.	35,376	15.9	76.8	23.2	448	24,870	70.3	11.6	68.1	31.9	464	72.8	1.85
14	Nigeria	Western Africa	less dev.	904,537	123.7	42.5	57.5	137	14,973	1.7	7.4	16.0	84.0	491	5.9	1.18
15	United Kingdom	Northern Europe	more dev.	247,576	58.9	78.7	21.3	238	21,389	8.6	7.1	30.6	69.4	331	12.0	1.13
16	Mexico	Central America	less dev.	1,942,800	100.0	74.7	25.3	51	93,369	4.8	5.6	7.5	92.5	60	5.6	0.90
17	Italy	Southern Europe	more dev.	299,309	57.0	67.2	32.8	190	16,794	6.3	5.4	26.8	73.2	286	9.4	0.86
18	Malaysia	S-Eastern Asia	less dev.	330,615	23.4	62.0	38.0	71	19,506	5.9	5.2	17.4	82.6	265	22.1	0.83
19	Germany	Western Europe	more dev.	356,104	82.3	73.1	26.9	231	22,600	6.3	4.6	24.1	75.9	203	5.6	0.73
20	Pakistan	S-Central Asia	less dev.	765,150	144.5	33.1	66.9	184	22,835	2.9	4.6	38.0	62.0	200	3.2	0.73
21	Argentina	South America	less dev.	2,736,850	36.9	90.1	9.9	13	52,026	1.9	3.8	58.0	42.0	73	10.3	0.61
22	Russian Fed.	Eastern Europe	more dev.	16,877,500	146.8	73.3	26.7	9	271,546	1.6	3.5	16.1	83.9	13	2.4	0.56
23	Cambodia	S-Eastern Asia	least dev.	179,416	12.4	16.9	83.1	69	13,493	7.5	3.2	2.5	97.5	237	25.7	0.51
24	Spain	South. Europe	more dev.	505,164	40.3	76.3	23.7	80	6,286	1.2	3.2	35.5	64.5	505	7.9	0.51
25	Rep. of Korea	Eastern Asia	less dev.	99,006	46.0	79.6	20.4	464	4,572	4.6	3.0	33.6	66.4	654	6.5	0.48

Total land area was calculated through zonal statistics using the following data sets: land area grids from GRUMP Alpha and GPWv3 (for Greenland), national boundaries from GPWv3, NUTS0 (Netherlands) and Global Administrative Areas (Greenland) (see Table 2). **Total population** including urban/non-urban shares is based on [47, 48, 50, 51]. Classifications by major region and develoment status follow the UN classification scheme [46, 47]. All LECZ areas and population numbers are based on own assessments.
Abbreviations: U.S. = United States of America; Russian Fed. = Russian Federation; Rep. of Korea = Republic of Korea; S. = South; dev. = developed; pop. = population.

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Table 7. Top 25 countries with highest LECZ population and people in the 100-year flood plain in 2030/2060, ranked by LECZ Scenario C 2060.

Rank LECZ Scenario C 2060	Rank LECZ 2000	Country	Total population			LECZ population				People in the 100-year flood plain			
			Baseline 2000 [million]	Scenario C 2030 [million]	Scenario C 2060 [million]	Baseline 2000 [million]	Scenario C 2030 [million]	Scenario C 2060 [million]	Pop. growth 2000–2060 [%]	Baseline 2000 [million]	Scenario C 2030 [million]	Scenario C 2060 [million]	Pop. growth 2000–2060 [%]
1	1	China	1,269.1	1,467.4	1,467.7	144.0	204.1	**244.8**	170	56.0	82.8	103.4	185
2	2	India	1,053.9	1,612.0	2,096.0	63.9	120.8	**216.4**	339	17.1	33.8	63.6	372
3	3	Bangladesh	129.6	193.5	237.7	63.1	85.1	**109.5**	173	6.0	8.8	12.4	207
4	5	Indonesia	213.4	296.5	354.3	39.3	61.9	**93.7**	239	5.4	9.1	14.5	267
5	4	Viet Nam	78.8	107.6	123.1	43.1	58.7	**80.4**	187	26.3	36.4	50.6	192
6	7	Egypt	67.6	112.7	154.6	25.5	45.0	**63.5**	249	7.4	13.8	20.7	281
7	14	Nigeria	123.7	269.3	534.3	7.4	19.8	**57.7**	785	0.1	0.3	0.9	839
8	8	U.S.	282.5	361.7	421.0	23.4	34.0	**43.9**	188	3.5	5.3	7.1	200
9	9	Thailand	63.2	77.4	83.0	16.4	24.7	**36.8**	224	3.5	5.6	9.1	262
10	10	Philippines	77.3	133.7	199.8	13.0	23.8	**34.9**	270	2.0	3.8	5.8	293
11	6	Japan	125.7	120.2	103.2	30.2	32.1	**32.7**	108	8.3	9.2	9.7	117
12	20	Pakistan	144.5	247.8	341.8	4.6	12.7	**30.1**	660	0.7	2.2	5.7	782
13	11	Myanmar	45.0	57.7	66.2	12.5	16.4	**22.8**	182	3.1	4.3	6.3	206
14	27	Senegal	9.5	21.0	38.7	2.9	8.5	**19.2**	655	0.4	1.1	2.7	761
15	12	Brazil	174.4	233.9	268.3	11.6	15.8	**18.7**	162	2.1	2.9	3.5	168
16	29	Iraq	23.9	58.0	114.5	2.7	9.3	**18.1**	679	1.3	4.7	9.3	708
17	40	Benin	6.5	15.3	29.6	1.4	5.4	**15.0**	1,058	0.1	0.6	1.6	1,121
18	57	Un. Rep. of Tanzania	34.0	85.7	200.7	0.6	2.8	**14.0**	2,203	0.2	0.9	4.3	2,302
19	13	Netherlands	15.9	17.3	17.0	11.6	12.3	**11.8**	103	9.5	10.2	9.8	103
20	18	Malaysia	23.4	39.3	54.2	5.2	7.8	**11.3**	218	0.4	0.7	1.1	243
21	64	Somalia	7.4	17.0	40.9	0.6	2.2	**9.8**	1,683	0.2	0.6	2.7	1,695
22	15	United Kingdom	58.9	69.3	73.5	7.1	8.0	**8.8**	124	3.8	4.4	4.8	128
23	47	Côte d'Ivoire	16.6	31.4	54.0	1.2	3.0	**7.6**	644	0.1	0.3	0.7	647
24	21	Argentina	36.9	49.4	62.3	3.8	5.6	**7.6**	200	0.9	1.4	2.0	212
25	31	Mozambique	18.2	37.8	68.1	2.3	4.4	**7.5**	325	0.7	1.4	2.5	360
29	17	Italy	5.4	5.9	6.1	5.4	5.9	**6.1**	112	2.1	2.4	2.7	128
30	23	Cambodia	12.4	18.5	23.4	3.2	4.7	**6.0**	187	0.6	1.0	1.4	224
35	19	Germany	82.3	79.5	72.4	4.6	4.7	**4.7**	101	3.1	3.2	3.2	103
37	24	Spain	40.3	50.0	49.9	3.2	3.9	**4.1**	129	1.3	1.6	1.7	134
42	25	Republic of Korea	46.0	52.9	52.8	3.0	3.5	**3.6**	122	1.3	1.5	1.6	128
44	22	Russian Federation	146.8	136.4	120.8	3.5	3.5	**3.5**	101	1.4	1.4	1.4	104

Total population per country was based on [47, 48]. All LECZ areas and population numbers are based on own assessments (see Material and Methods, Table 2 and Table 3).

Abbreviations: U.S. = United States of America; Un. Rep. of Tanzania = United Republic of Tanzania; pop. = population

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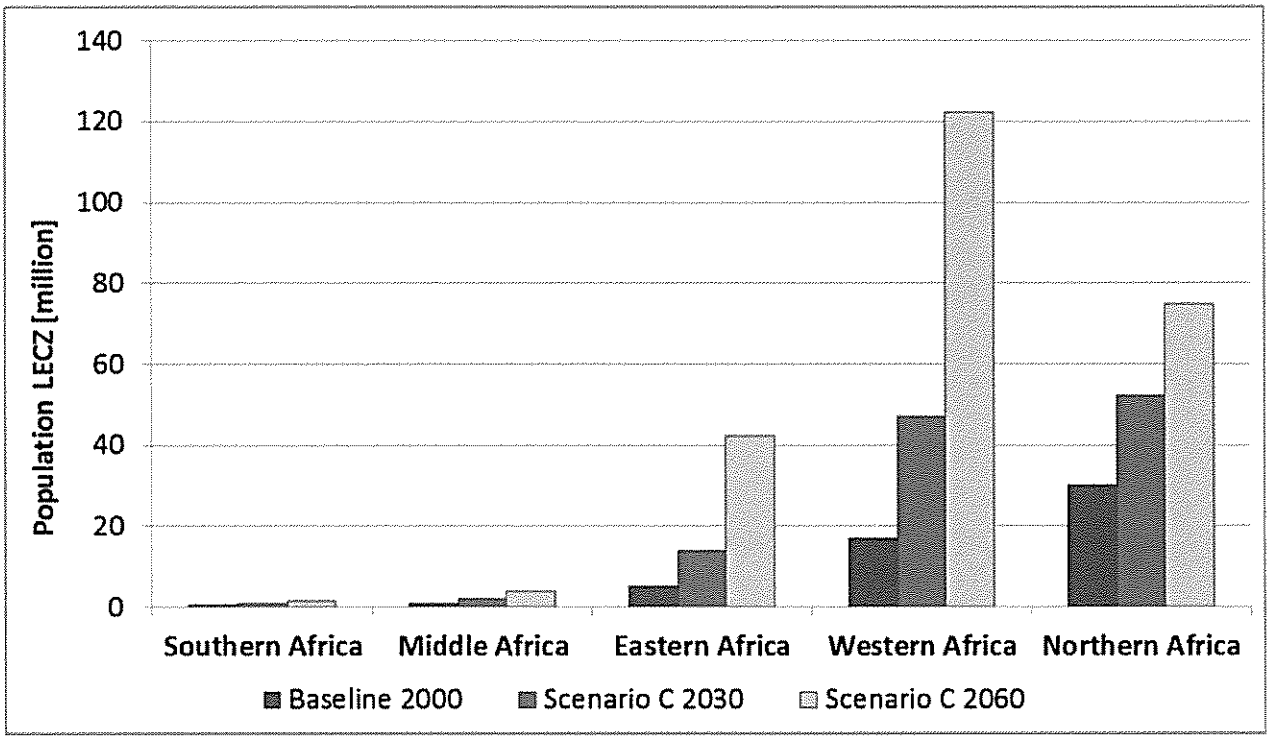

Fig 4. LECZ population in Africa in the year 2000 and projections for 2030/29160 per region, scenario C.

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African coastal countries land area) are considerably smaller (Table 4, Fig. 2 and Fig. 3; S2 Table). However, Africa will be the continent to experience the highest rates of growth and urbanisation in the LECZ across all scenarios. In particular, the LECZ population of **Sub-Saharan Africa** (all of Africa except Northern Africa; includes the Sudan), which represented 45% of the African nations' LECZ population in 2000, could grow from 24 million (2000) to 66 million by 2030 and to 174 million by 2060 (both scenario C) due to an average coastal growth rate of up to 3.3% (2000–2030) and 3.2% (2030–2060). These rates are considerably higher than in Asia, where annual rates of growth are expected to reach 1.4% in the first three decades (2000–2030) and afterwards drop to 1.2% (scenario C).

Among the African regions, coastal population growth is projected to be highest in Eastern and Western Africa, especially in the urban centres of Western Africa where between 72 million (scenario B) and 94 million (scenario C) people will reside by 2060 (Fig. 4; S2 Table). **Northern Africa** (Algeria, Egypt, Libya, Morocco, Sudan, Tunisia, Western Sahara) had the largest LECZ population in the year 2000 (30 million), but will not keep pace with the coastal growth in **Western Africa** where nations like **Nigeria, Benin, Côte d'Ivoire and Senegal** are growing considerably faster. According to our projections, all four countries will be among the top-25 countries in terms of LECZ population totals by 2060 (Table 7), while in the baseline year 2000 only Nigeria was present in this top-25 ranking with 58 million people (11% of its population). All of them will experience a considerable population increase. A characteristic example is Senegal, which had a small LECZ population in the year 2000 (2.9 million) and where 50% of the country's total population could live on low-lying coastal land by 2060 (19 million people; Table 7). In **Eastern Africa**, the countries of **Tanzania, Somalia and Mozambique** boost the regional development through strong coastal growth. These three countries are

expected to feature among the top-25 countries with the highest population in the LECZ by the year 2060 (scenario C; Table 7), in stark contrast with their comparatively low LECZ population in 2000 (Table 6 and Table 7). The United Republic of Tanzania is projected to undergo a 22-fold rise in LECZ population numbers and Somalia a 16-fold increase, while Mozambique is expected to triple its LECZ population (all scenario C). **Southern Africa**, which comprises the coastal countries Namibia and South Africa, exhibited the smallest LECZ population with 0.5 million people in the year 2000, increasing to 1.7 million by 2060 (Scenarios C; Fig. 3).

Egypt (26 million; 38% of its total population) and **Nigeria** (7.4 million; 5.9% of its total population) were the countries with the highest population in the LECZ in the African continent in 2000, ranking at places 6 and 7 globally (Table 6). The Egyptian LECZ along the Mediterranean coast and the Nile delta (1,075 people/km^2) was almost as densely populated as the LECZ of Japan (1,250 people/km^2) or Bangladesh (1,154 people/km^2) in 2000. However, only 15% of the LECZ population actually lived in dense urban areas in the year 2000. By 2030, population density along the Egyptian coast is expected to increase to 1,902 people/km^2 and to 2,681 people/km^2 by 2060.

In **Europe**, the total population in the LECZ (50 million) was similar to that in Africa (54 million) in the year 2000, while the LECZ area was more than double in size (Europe: 471 thousand km^2; Africa: 194 thousand km^2; S1 Table). This resulted in an average population density of only 106 people/km^2 in the in European LECZ, as opposed to the 280 people/km^2 in the LECZ of Africa or to the global average of 241 people/km^2. Also, the proportion of urban population in the LECZ in Europe (40%) was significantly higher than in Asia (20%) or Africa (16.5%) in the year 2000 (Table 4). Among the European regions, Western Europe stands out with about 21 million people living in a LECZ that is quite densely populated (328 people/km^2 respectively), half of which is located in the **Netherlands** (12 million; 73% of its total population). However, the LECZ of Europe, as a region that is characterised by **richer economies,** is projected to experience only low to moderate population growth towards 56 million people by the year 2060, at most (scenario D). In contrast to Europe, Africa could more than quadruple its LECZ population in the same period. From the six European countries with the highest population in the LECZ in the year 2000 (Netherlands, United Kingdom, Italy, Germany, Spain and the Russian Federation), only the Netherlands and the United Kingdom will, according to our projections, rank among the top-25 countries in 2060, though dropping in rank compared to the year 2000 (Table 6 and Table 7). The Russian Federation has the largest LECZ (272 thousand km^2) of all countries worldwide. In 2000, 3.51 million people (2.4% of the national total; Table 6) were living in the Russian LECZ, but little change is expected here with LECZ population reaching at maximum 3.55 million by 2060 (scenario C). In accordance with the UN's classification, the Russian Federation is assigned to Eastern Europe [46].

Northern America (Bermuda, Canada, Greenland, Saint Pierre and Miquelon, United States of America) has the second largest extent of LECZ after Asia with over 507 thousand km^2 (see S2 Table). However, the overall number of people in the LECZ was significantly lower than in most other continents in the year 2000 (24 million or 3.7% of the global LECZ population). Compared to Europe, coastal growth is expected to be higher in Northern America with rates of up to 1.2% (2000–2030), dropping to 0.8% in the decades thereafter (2030–2060), while Europe shows growth rates of 0.3% to 0.1%, respectively (scenario C). The Northern American LECZ population is growing faster than the Latin American one and by 2060 up to 46 million people could be living in the LECZ of Northern America (S2 Table). The U.S. had the largest share of coastal population with 23 million in 2000, rising to 44 million in 2060 (scenario C), ranking eighth among LECZ countries in both years (Table 6 and Table 7). Canada, despite having a much larger LECZ, is sparsely populated along its long northern coastline. Here, a maximum of 1.6 million people could be living below 10 m of elevation by 2060. An

interesting feature of the Northern American LECZ is the high number of people in dense urban areas, which reached already almost 60% in 2000 (Table 4).

In **Latin America and the Caribbean,** the LECZ area is about half the size of the Asian LECZ with 424 thousand km^2 in total, whereas the LECZ population was only about 7% (32 million) of that in Asia in the year 2000. **South America** (Argentina, Brazil, Chile, Colombia, Ecuador, Falkland Islands/Malvinas, French Guiana, Guyana, Suriname, Uruguay, Venezuela) contributed the largest share of coastal population in the year 2000 and is also expected to do so in future: Starting from 22 million in the year 2000, the population in the LECZ could reach between 28 million (scenario B) and 38 million (scenario C) by 2060. In this region, Brazil and Argentina are the two nations with the highest number of people in the LECZ, both in the year 2000 and in future projections (Table 6 and Table 7). In **Brazil**, 12 million people were living in the LECZ (1.4% of the land area) in the year 2000, corresponding to 6.6% of its total population (Table 6). At the same time **Argentina** had about 3.6 million people living the LECZ (about 1.9% of the land area). By 2060, the LECZ population of the two nations could grow to 19 million (Brazil) and 7.6 million (Argentina) (Table 7).

The smallest portion of the global LECZ population is found in **Oceania**. In the year 2000, the LECZ population amounted to 0.5% of the global LECZ population (Table 4; S1 Table). However, this represents at least 11% of the total population of the region, making the proportion higher compared to other regions. Most of these people were living in the LECZ of Australia and New Zealand (2.7 million or 80% of Oceania's LECZ population in 2000). Growth is projected to be comparatively low in Oceania and could lead to LECZ population totals between 5.0 million and 6.1 million people by 2060 (Scenarios B and C respectively; Table 4). We must note that the results for Oceania do not include data for Tokelau (total population in 2000 [48]: 1,552), Pitcairn (included in Polynesia in the UN data [48], but no separate population records) and for the Federated State of Micronesia (total population in 2000 [48]: 107,103), both for the LECZ and the flood plain analysis. This is due to missing information in the employed data sets, as explained in the section Uncertainties, limitations and evaluation of results. Nevertheless, although highly significant for the respective nations, these numbers would have no major impact on our results at continental or global scale.

People in the 100-year flood plain in 2000, 2030 and 2060

Our results show that about one third (30%; 189 million) of the global LECZ population was living in the 100-year flood plain in the year 2000 (see Table 5 and Table 8; S3 Table). The number of people at risk from coastal flooding could reach between 268 million and 286 million in 2030, globally (scenarios B and C, respectively). By 2060, up to 411 million people could be affected by extreme flooding events (Scenario C). However, large regional variations exist.

Asia had the highest number of people living in the flood plain: 30% (137 million) of Asia's LECZ population resided in the 100-year flood plain in the baseline year 2000, which made 73% of the total global flood plain population. Our results suggest a rapid population growth for the flood plain population in Asia to between 200 million and 213 million people by 2030 (scenarios B and C; Table 5 and Table 8). By 2060, this number could range between 232 million (scenario B) and 310 million (scenario C), despite slowing growth rates. **Africa**, at the same time, could experience a two-fold increase from 13 million in 2000 to 26 million by 2030 and a further growth to 49 million people in the flood plain by 2060 (scenario C; Table 5 and Table 8; S3 Table).

Europe and Northern America are expected to exhibit a relatively moderate increase (Table 5 and Table 8). In **Europe**, 56% of the LECZ population (28 million people) lived within the 100-year flood plain in the year 2000. The exposed population could grow by 3 million

between 2000 and 2030 and an additional 1.2 million by 2060 to reach 32.4 million under scenario D. Scenario D proved to be the highest-end-of-growth scenario for "richer economies", which is due to the underlying assumptions made in the scenarios (see Table 1). In **Northern America**, the number of people in the flood plain could increase from 4.2 million (year 2000) to about 8.0 million by 2060 (scenario D), with the United States being the country with the largest share of exposed population (Table 5 and Table 8; S4 Table). In **Latin America and the Caribbean**, more than a quarter (19%; 6 million) of the people living in the LECZ were located within the 100-year flood plain in the year 2000. The proportion will remain stable in future, but the total number will reach up to 11 million people in the flood plain by 2060 (scenario C).

According to our results, **Oceania** only has a minor contribution to the global total of people exposed to 1-in-100 year flood events, both in the baseline year 2000 and in the future. However, since Oceania partly consists of a large number of small island states, the impacts of sea-level rise and increasing storm surge heights will affect a large portion of these countries' inhabitants, as a high percentage of their population and infrastructure is concentrated within a few kilometres of the coast [58]. By 2060, at least 1.6 million people could be at risk from flooding, an increase of up to 100% compared to the year 2000, with more than one third of these people being citizens of small island nations.

Discussion

Coastal population development and aspects of coastal migration

Our projections show that, even under the lowest growth assumptions, the global LECZ population could rise by more than 50% between the baseline year 2000 and 2030 (scenario B), from 625 million to 880 million; by 2060, more than a billion people worldwide could be living in the LECZ. Under scenario C the world would face an overall high population growth due to stagnant economic development and exclusive social, political and economic governance (see Fig. 1 and Table 1). In this scenario, the global LECZ would bear 763 million additional people by 2060, compared to the situation in the year 2000, which would be an increase of 122%. For the same scenario between 315 million and 411 million people would be living in the 100-year flood plain by 2060, compared to 189 million in the year 2000. It must be noted that considering for subsidence in deltaic areas and in cities prone to subsidence due to drainage and groundwater pumping would further enhance these numbers [59, 60]. However, this factor was not considered in the present study.

The results also demonstrate that the less developed countries outnumber the more developed regions in terms of population in the LECZ and in the flood plain, with Asia having had the highest land area, total number of people and urban population in the LECZ in the year 2000 and prevailing in the future (Fig. 5). In Africa, we see a rapid coastal development in terms of overall population growth and urbanisation, which will exacerbate the already high vulnerability of many African coastal countries [33]. By 2060, Egypt and Nigeria are expected to rank in the top ten countries globally, following directly the five Asian countries with the highest exposure: China, India, Bangladesh, Indonesia and Viet Nam. Hanson et al. [18] identified twelve port cities located in these Asian coastal countries to be among the top 20 of the world's large port cities exposed to 100-year flood levels by 2070 in terms of population. In an assessment of 136 coastal cities by Hallegatte et al. [25], several of these cities were also rated as being highly vulnerable in terms of expected annual damages (flood risk) in 2005 as well as under future scenarios (2050). However, Hanson et al. [18] found 40 million people in urban locations in the 100-year flood plain, considering all coastal cities with more than one million people in 2005. Comparing these figures to our total flood plain population estimates of

Table 8. People in the 100-year flood plain in the year 2000 and projections for 2030/2060 per continent and development status, scenarios A-D.

Region	Total population	LECZ population	People in the 100-year flood plain										
	2000	2000	2000			2030				2060			
	Baseline [million]	Baseline [million]	Baseline [million]	% of LECZ pop.	% of flood plain pop.	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]
WORLD	**6,100.8**	**625.2**	**189.2**	**30.3**	**100.0**	**282.2**	**268.1**	**285.9**	**271.0**	**392.9**	**315.5**	**411.3**	**339.5**
More developed regions	1,188.8	107.5	41.2	38.4	21.8	45.4	45.4	47.3	47.3	46.9	46.9	51.0	51.0
Less developed regions and least developed countries	4,912.0	517.7	147.9	28.6	78.2	236.8	222.6	238.6	223.7	346.0	268.6	360.3	288.4
Least developed countries	662.0	93.0	12.6	13.6	6.7	22.9	20.9	22.6	21.3	41.6	33.8	43.8	34.2
Less developed regions, excluding least developed countries	4,250.0	424.7	135.3	31.8	71.5	213.9	201.7	215.9	202.5	304.5	234.8	316.5	254.2
Less developed regions, excluding China	3,642.9	373.7	91.9	24.6	48.6	156.0	142.6	155.7	145.6	246.7	184.4	256.9	202.2
China	1,269.1	144.0	56.0	38.9	29.6	80.8	80.0	82.8	78.1	99.4	84.3	103.4	86.2
Sub-Saharan Africa	669.1	24.2	3.4	14.2	1.8	9.6	9.0	9.4	8.9	23.6	20.0	25.3	18.6
AFRICA	811.1	54.2	12.6	23.3	6.7	26.0	23.5	25.7	24.1	46.9	37.9	49.2	38.4
Eastern Africa	251.6	5.2	1.4	28.1	0.8	4.3	4.0	4.0	3.9	11.8	10.4	12.7	9.3
Middle Africa	96.2	1.1	0.2	13.9	0.1	0.3	0.3	0.3	0.3	0.5	0.4	0.5	0.4
Northern Africa	176.2	30.3	9.2	30.3	4.9	16.3	14.6	16.3	15.2	23.3	18.1	24.0	19.9
Southern Africa	51.4	0.5	0.1	21.1	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.2
Western Africa	235.7	17.1	1.7	10.1	0.9	4.8	4.5	4.8	4.5	11.0	8.9	11.7	8.7
ASIA	3,697.1	460.8	137.3	29.8	72.6	211.1	199.9	213.4	200.7	297.6	231.6	309.6	250.7
Eastern Asia	1,473.3	180.9	67.2	37.1	35.5	93.4	92.3	95.8	90.9	113.3	97.2	117.7	99.9
South-Central Asia	1,515.6	135.7	25.0	18.4	13.2	46.9	40.7	46.3	42.6	79.2	58.2	83.5	63.8

(*Continued*)

Table 8. (*Continued*)

Region	Total population	LECZ population	People in the 100-year flood plain										
	2000	2000	2000			2030				2060			
	Baseline [million]	Baseline [million]	Baseline [million]	% of LECZ pop.	% of flood plain pop.	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]	Scenario A [million]	Scenario B [million]	Scenario C [million]	Scenario D [million]
South-Eastern Asia	523.8	133.2	41.4	31.1	21.9	60.3	57.1	61.0	57.4	86.4	61.8	89.0	71.9
Western Asia	184.4	11.1	3.8	34.0	2.0	10.6	9.8	10.3	9.9	18.8	14.4	19.3	15.0
EUROPE	726.8	50.0	28.2	56.3	14.9	30.1	30.1	31.2	31.2	30.2	30.2	32.4	32.4
Eastern Europe	304.2	6.8	2.7	39.7	1.4	2.8	2.8	2.8	2.8	2.9	2.9	2.9	2.9
Northern Europe	94.3	11.2	5.1	45.6	2.7	5.6	5.6	5.8	5.8	5.6	5.6	6.2	6.2
Southern Europe	145.1	10.6	4.3	40.2	2.3	5.0	5.0	5.1	5.1	5.3	5.3	5.7	5.7
Western Europe	183.1	21.4	16.1	75.2	8.5	16.7	16.7	17.5	17.5	16.4	16.4	17.6	17.6
LATIN AMERICA AND THE CARIBBEAN	521.4	32.2	6.1	18.9	3.2	8.1	7.7	8.2	7.7	10.2	7.9	10.5	8.5
Caribbean	38.4	3.5	0.7	19.1	0.4	0.8	0.8	0.8	0.8	1.0	0.8	1.1	0.9
Central America	135.6	6.8	1.0	14.4	0.5	1.2	1.1	1.2	1.1	1.3	1.2	1.4	1.2
South America	347.4	21.9	4.4	20.2	2.3	6.1	5.8	6.2	5.8	7.8	5.9	8.1	6.4
NORTHERN AMERICA	313.3	24.6	4.2	17.1	2.2	5.8	5.8	6.1	6.1	6.5	6.5	8.0	8.0
OCEANIA	31.1	3.3	0.8	24.4	0.4	1.2	1.2	1.2	1.2	1.5	1.3	1.6	1.5
Australia/New Zealand	23.0	2.7	0.5	20.5	0.3	0.7	0.7	0.8	0.8	0.8	0.8	1.0	1.0
Melanesia	7.0	0.4	0.1	31.9	0.1	0.3	0.2	0.2	0.2	0.4	0.3	0.4	0.3
Micronesia	0.5	0.2	0.1	55.5	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2
Polynesia	0.6	0.1	0.1	40.2	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Total population is based on [47, 48]. Classifications by major region and develoment status follow the UN classification scheme [46, 47]. All LECZ areas and population numbers are based on own assessments. **Abbreviations:** pop. = population; flood pl. = flood plain.

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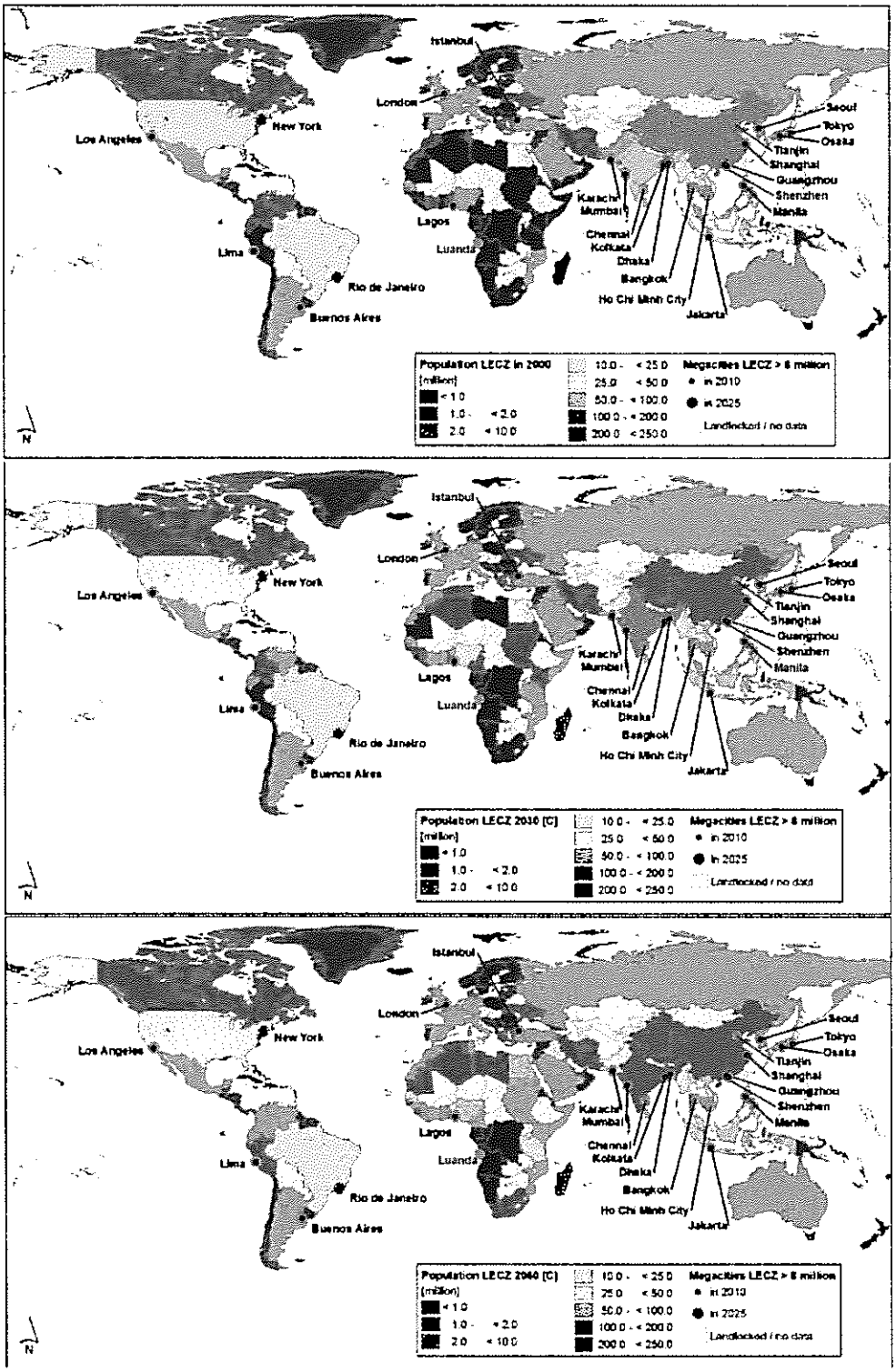

Fig 5. LECZ Population in the year 2000 and for 2030/2060 per country, scenario C. Population estimates (year 2010) and projections (year 2025) for selected megacities (> 8 million people) located in the LECZ were derived from the UN's World Urbanization Prospects [79].

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189 million (in the year 2000) suggests that most of the flood plain population is actually located in smaller coastal cities, less densely populated urban areas and rural settings.

Nevertheless, among the 25 countries we project to have the largest portion of people in the LECZ in 2060, there are also several developed countries, including the United States of America. The U.S. was already among the 25 countries with the highest LECZ population in the year 2000. Due to the large number of people living in the LECZ (23 million in 2000) and the fact that 61% of these were located in dense urban areas, the U.S. exhibit a relatively strong growth of the total LECZ population in comparison to other developed countries. The U.S. recently encountered major coastal disasters with the Hurricanes Katrina in 2005 and Sandy in 2012, indicating the—possibly increasing—vulnerability and risks associated with settling in low-lying coastal areas of the U.S. [20, 25, 61].

Our projections reflect the scenario assumptions made concerning the socio-economic development pathways of the coastal regions and coastal migration, as well as the underlying low, medium and high growth variants of the UN's population prospects (see Fig. 1 and Table 1). Scenario B with its lowest-end-of-growth assumptions (10^{th} percentile or low growth variant) produces the lowest projections of coastal growth, despite a coastal correction factor of 2.0 assigned to coastal urban areas in the developing world to account for massive migration to regional growth poles. The scenarios A and C project the highest population growth in the LECZ for the "less developed regions". Nevertheless, assumptions of increased migration from poorer countries to richer countries in combination with a high population growth variant for the developing world (90^{th} percentile or high growth variant) in scenario C result in overall higher coastal growth compared to scenario A. In this scenario, we translated the assumed patterns of more rapid internal migration in faster growing developing countries into slightly higher coastal urban growth, while coastal non-urban growth is reduced due to stagnant economy and migration to regional growth poles in comparison to scenario A. Only Africa exhibits a different behaviour in the period between 2000 and 2030 with strongest growth under scenario A. This is explained by a high percentage of non-urban coastal population in the African countries and the assumption that developing countries partially experience rapid coastal migration with expansive urban growth. In contrast to this, the "richer economies" in Europe, Northern America, Japan and Australia/New Zealand would face the highest coastal growth under scenario D. Although in this scenario inclusive governance is assumed to keep the global population growth at the low end of forecasts (50^{th} percentile or medium growth variant), richer economies exhibit relatively strong coastal growth due to an increased demand for migrants to fill in the labour market for the aging population [39]. It has to be noted, though, that due to the methodology employed, we cannot explicitly differentiate between urban and non-urban population numbers in our projections, as the latter also include a certain proportion of urban population. This is due to the fact that we did not account spatially for transitions between dense urban, suburban and rural areas. However, these transitions are considered implicitly through our assumptions of coastal urban growth. We are therefore confident that the total numbers produced in this study constitute reliable projections of people in the LECZ and in the 100-year flood plain.

Net migration from developing to developed countries, as well as assumptions on fertility, are inherently included in the employed UN's population prospect variants [46]. General effects of environmental pressures and disasters on migration are considered in the Foresight Project's socio-economic scenarios [39]. However, possible out-migration and displacement as a response to increased flood risks or inundation was not considered spatially in our assessment. More explicit consideration of these factors in future work is important, especially when considering that the areas at risk, i.e. coastal flood plains and deltaic areas, are at the same time a "major migrant destinations since they offer better economic opportunities through their

concentration of industry and services" [62]. The UK's Government Office for Science [38] concludes that environmental change in the LECZ, such as sea-level rise and increasing occurrence extreme events, will affect the existing structural drivers of migration through the induced socio-economic impacts. However, as Black et al. [63] and Warner [64] point out, the factors that drive environmental migration are complex and multi-layered, and migration as well as displacement are some of the possible responses. The role of adaptation to coastal flooding and sea-level rise will also need to be considered [16, 21, 25, 65]. Curtis and Schneider [66] stress that migration networks between coastal and inland areas or between inundated and not-inundated coastal counties may be another essential factor to account for when assessing future coastal population. Socio-demographic, economic and environmental characteristics as well as the political setting of a coastal area or region determine the response to coastal hazards. Yet, such a level of detail is hard to achieve in global to regional scale studies.

Uncertainties, limitations and evaluation of results

Our estimates of total land area and population in the LECZ for the year 2000 are in agreement with the findings of previous studies [1, 5], with deviations being in the order of 4% for the global total and between 1% and 10% when comparing continental totals (see Table 9). However, our assessments suggest a significantly smaller proportion of urban population within the LECZ. This deviation can be explained by the different data used for the identification of urban areas and the resulting differences in the definitions of "urban". While McGranahan et al. [5] and Balk et al. [1] used the urban extent grids of the Global Rural-Urban Mapping Project GRUMP (GRUMP alpha), we employed the higher resolution MODIS 500-m Map of Global Urban Extent (see Material and Methods; Table 2). This decision was based on the work of Potere and Schneider [67], Schneider et al. [42] and Seto et al. [7] who found GRUMP to overestimate urban land in comparison to other global urban maps and the MODIS 500-m map to have the highest overall accuracy [42, 67]. In addition, we conducted extensive visual checks of urban areas to compare their representation in both data sets, also using satellite imagery for validation (Google Earth; ArcGIS World Imagery). For most regions, the urban extent of the MODIS data set appeared to be considerably more representative of built-up urban areas than GRUMP. The latter seems to overestimate urban extent and city size but captures other types of settlements such as urban slums, which the MODIS grid excludes. We also observed that both MODIS and GRUMP urban extent grids are likely to include non-residential built-up areas such as industrial districts or commercial centres. At the same time, by using the MODIS urban extent grid in combination with the GRUMP population count grid to approximate urban population, specific types of possibly densely populated residential areas within urban administrative units, such as informal settlements and urban slums, might have been classified as non-urban population in our assessment.

Further uncertainties may have been introduced when combining the MODIS urban extent data [42, 43] with the GRUMP population data [44], where resampling may have led to incorrect allocation of population into urban and non-urban classes. These uncertainties could not be quantified in the context of this work, but we expect them to have only minor influence on the population figures. Overall we are confident to have produced representative global estimates of LECZ population, though we have to stress that our urban population refers to people living in dense urban areas (see Material and Methods). We may underestimate urban population for less densely built-up urban areas, for cities with large vegetated areas or for urban settlements in less developed countries with structures that resemble rural areas, such as dirt roads. For this reason our baseline estimates of urban population are likely to be at the lower

Table 9. Comparison of different studies estimating the LECZ land area and population for the year 2000.

Region	Study	Employed land use data	Total area LECZ [km^2]	Total pop. LECZ [million]	Urban pop. LECZ [million]
Global	This study	MODIS-500m [42, 43]	2.598.623	625.2	146.9
	McGranahan et al. [5]	GRUMP alpha [84]	2.700.000	634.0	360.0
Africa	This study	MODIS-500m [42, 43]	193.658	54.2	8.9
	McGranahan et al. [5]	GRUMP alpha [84]	191.000	56.0	31.0
	Balk et al. [1]	GRUMP alpha [84]	NA	NA	31.5
Asia	This study	MODIS-500m [42, 43]	859.215	460.8	92.8
	McGranahan et al. [5]	GRUMP alpha [84]	881.000	466.0	238.0
	Balk et al. [1]	GRUMP alpha [84]	NA	NA	253.7
Latin America	This study	MODIS-500m [42, 43]	423.863	32.2	9.3
	McGranahan et al. [5]	GRUMP alpha [84]	397.000	29.0	23.0
	Balk et al. [1]	GRUMP alpha [84]	NA	NA	17.7
India	This study	MODIS-500m [42, 43]	82.262	63.9	10.5
	McGranahan et al. [5]	GRUMP alpha [84]	NA	63.2	NA
	Balk et al. [1]	GRUMP alpha [84]	NA	NA	37.3

Abbreviations: pop. = population.

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bound for the year 2000, compared to e.g. the results of McGranahan et al. [5] and Balk et al. [1].

As discussed by Balk et al. [68], amongst others, there are further issues related to the criteria and methods whereby populations and the respective areas are identified as urban or non-urban in spatial data and census data. For census data, there is no common set of criteria and definitions for classifying urban and non-urban (or rural) population between countries [69, 70]. In a similar way, spatial population and urban extent data are also based on specific (but possibly different) criteria and methods for differentiating between urban and non-urban areas and for spatially allocating people [42, 43, 67, 70]. These issues need to be considered when combining spatial population and urban extent data with census-based data. Nevertheless, we are confident that by combining spatial and non-spatial population data we did not introduce additional uncertainty. The UN's population and urbanisation data were used to derive annual rates of coastal urban and non-urban growth, as explained in Material and Methods. These rates were then applied to the mapped urban and non-urban baseline population shares.

As a result of the resolution and scale of this analysis, some issues with small coastal countries occurred, such as missing information and mis-registration issues between spatial data layers. This became particularly evident when analysing data of small islands and island states

in this global approach. Several of these could not be considered in this study because of missing information in the GRUMP population count grid [44] (St. Helena, French Southern Territories, Tokelau and Pitcairn Islands) and in the land area data set [71] (Norfolk Island and the Federated State of Micronesia). In the flood plain analysis we identified spatial mis-matches between the GRUMP data sets [44, 71] and the more detailed GADM boundaries [72]. Similar issues due to mismatches between elevation and population data sets had been reported by McGranahan et al. [5] and Lichter et al [6].

Nevertheless, despite addressing those mis-matches (see Material and Methods), we may still underestimate the number of people in the flood plain. For instance, we estimated 189 million people to have been living in the 100-year flood plain in the year 2000, globally, while Jongman et al. [73] estimated 271 million people exposed to 1-in-100-year coastal flood events in 2010. They projected 345 million people to be living in the 100-year flood plain in 2050, based on the Medium Fertility projections of the United Nations' 2006 Revision of the World Population Prospects, while our results suggest a coastal growth to 340 million people by 2060 under a medium growth variant (scenario D). Although these numbers do compare well, we must note that there is a difference of ten years between the baseline years and the projections and that Jongman et al. [73] did not account for upward displacement of the flood plain from sea-level rise. The observed differences between their study and our assessment can further result from variations in the base data employed: Jongman et al. [73] used a finer resolution SRTM grid at 3 arc sec resolution but coarser resolution population density data at 5 arc min resolution and, as mentioned earlier, an older version of the UN's demographic data.

The issues discussed above constitute inherent characteristics of analysis that integrate global data sets from different sources, as discussed by several authors [6, 27, 56, 68, 74]. Despite these common uncertainties and limitations, we are confident that our results present improved first order estimates of the population development and exposure of land and people in coastal regions. These estimates can provide a reliable basis for exploring and comparing future development trends and pathways at regional, continental and global levels. However, we also see scope for improvement regarding the differential projection of urban and non-urban population in the coastal zone. The use of dynamic spatial models of land-use change in the analysis would allow for explicit consideration of the expansive dimension of urban growth and the spatial transitions between different land use categories. Such a model could then be combined with more detailed scenarios and country-specific coastal correction factors to spatially differentiate between urban growth in density, urban expansion including peri-urbanisation and rural population change.

However, as outlined above, the categorisation of urban and non-urban (or rural) areas and populations currently suffers from a lack of unambiguous and consistent definitions of the respective classes, or other forms of land use and settlement structures, and their representation in global land use/land cover maps, population maps and census data. Thus, looking at the importance of global data sets for assessing global- and climate-change related impacts and with the encountered limitations and uncertainties in mind, we strongly support Mondal and Tatem [35] in their pleading for "spatial population datasets built on accurate, contemporary and detailed census data". In fact, there is an urgent need for a more detailed approximation of population and settlement structures. These could possibly be based upon existing data models such as GRUMP and MODIS for improved and consistent global population and land use data. Further, we recommend detailed explorations of both data sets with respect to capturing settlements of different types and the respective population shares, for example introducing a third class of peri-urban and comparing different combinations of global urban extent data and population data. Also, when analysing the future flood plain population, the role of subsidence should be considered in addition to sea-level rise. Finally, this first-order assessment

could also be improved in future studies by accounting for migration and displacement due to environmental changes and climate change-related effects such as sea-level rise. Yet, this would require employing other spatial assessment methods in order to relocate people from the flood plain and consider migration networks, as discussed by Curtis and Schneider [66].

As outlined above, our results are based on a series of assumptions (e.g. with regard to coastal growth) and data sets (e.g. MODIS urban extent data, GRUMP population count data and the UN's 2009 and 2010 urbanisation and population data), and the overall assessment is confined by certain limitations and uncertainties. We recommend that continued studies on this topic are needed. By employing more recent or improved data and refining methods and scenarios or accounting for the discussed uncertainties and limitations, the results will inevitably evolve. For example, new population projections and scenarios come to different conclusions whether population growth will level off before 2100 [75, 76] or continue to grow [77] and how population will change in China or in fast-growing countries of Africa. But for the time being, our assessment represents plausible scenarios of future population exposure in coastal zones.

Summary and Conclusions

This study has produced new estimates of the number of people living in the low-elevation coastal zones (LECZ) and the 100-year flood plain. We have constructed plausible futures of the LECZ population and of people in the flood plain in 2030 and 2060 and highlighted regions of high exposure. These estimates are based on a series of scenario-dependent assumptions on climate change effects relating to sea-level rise, future socio-economic development and coastal migration and are more detailed than previous work. The population projections for the LECZ and the coastal flood plain are, to our knowledge, the only quantitative global estimates that account for (i) the faster growth of coastal regions in comparison to the landlocked hinterland and (ii) differential population growth of coastal urban areas as opposed to coastal non-urban areas.

The results show significant increases in coastal population living in the LECZ and of people being potentially exposed to coastal flood events. They highlight regions that will most likely experience rapid increases in exposure, such as Africa, and depict that Asia is the continent that has had the largest number of total and of urban population in the LECZ and the 100-year flood plain in the year 2000 and will continue to do so in the future. Our results emphasise that less developed countries are more exposed to flooding than more developed regions. Africa and Asia are expected to become increasingly exposed to sea-level rise and coastal hazards and thereby many countries that already now experience high vulnerability to such hazards. The five Asian countries China, India, Bangladesh, Indonesia and Viet Nam accounted for more than half of the global LECZ population in the year 2000 and will continue to do so under future scenarios, despite the rapid coastal growth of several African coastal nations. Further, our study suggests that densely-populated urban areas are less prevalent in the LECZ than expected, as our baseline assessment produced a significantly smaller urban population than previous studies. We need to stress, however, that earlier studies relate 'urban' areas to urban agglomerations that encompass densely populated urban areas and suburban and even peri-urban areas population. This is a topic for further investigation.

Our assessments provide useful information for better understanding future coastal development and exposure to coastal flooding and submergence at global, regional and national scales. Further, they can be used as inputs to impact models for different scenarios of change. These new projections of coastal population build ground for further analyses beyond the scope of the study presented here. These could, for example, consider the spatial dynamics of urbanisation, the current limitations and inconsistencies related to global data sets or the

interactions and feedbacks between environmental change and migration. One aspect rarely discussed, but strongly related to the theme of environmental migration, is a possible reversion of the coastward migration trend due to increasing impacts from climate change, subsidence and extreme events. Furthermore, considering adaptation and mitigation processes would allow for a more in-depth analysis of the actual exposure, vulnerability and risk of coastal nations and regions. Hence, further research is required to better understand the human-environment interactions in coastal regions, improve forecasts of impacts and responses for a better management of coastal change and to build resilient and sustainable coastal communities now and into the future [78].

Supporting Information

S1 Table. Land area and population globally, of coastal countries and in the LECZ, baseline year 2000, per development status, continent and region.
(DOCX)

S2 Table. Population in the LECZ projected for 2030 and 2060, scenarios A-D, per development status, continent and region.
(DOCX)

S3 Table. People in the 100-year flood plain in 2000 and projected to 2030 and 2060, scenarios A-D, per development status, continent and region.
(DOCX)

S4 Table. Demographic base data and assessment results per region and reporting unit (countries).
(XLSX)

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Author Contributions

Conceived and designed the experiments: BN ATV RJN. Performed the experiments: BN ATV JZ. Analyzed the data: BN ATV JZ. Contributed reagents/materials/analysis tools: BN ATV JZ RJN. Wrote the paper: BN ATV RJN JZ.

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Tab E

FACT SHEET

Sea Level Rise in Rhode Island

TRENDS AND IMPACTS

COASTAL FLOODING, like this in Pawtuxet Cove, will become more common.
IMAGE CREDIT: FRED FULLERTON

JANUARY 2013 This fact sheet provides an overview of the current science from peer-reviewed information as well as impacts and actions compiled by the University of Rhode Island (URI) Climate Change Collaborative, scientists, and managers in Rhode Island.

Sea levels have been rising over the last century on both global and local scales. This increase is a result of several major factors, two of which are most influential. First, the increase in water temperatures in recent decades has led to higher sea levels because warmer water takes up more space than cooler water (thermal expansion). Second, warmer air and water temperatures have increased melt rates for the Greenland and Antarctic ice sheets and mountain glaciers, adding more water to the ocean.

THE UNIVERSITY OF RHODE ISLAND
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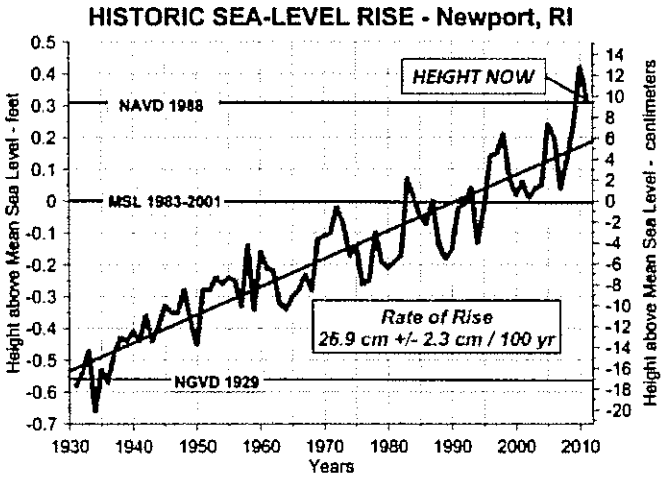
RI's Climate Challenge Waves of Change

FLOODING IN WICKFORD
During post-tropical storm Sandy of 2012, Wickford had over three feet of storm surge.
CREDIT: MELISSA DEVINE

SEA LEVEL RISE FACTS

+ Average global sea level has increased by 7 inches since 1900, which threatens low-lying coastal communities.
+ Since 1930, sea level in Rhode Island has increased by an average of 1 inch per decade.
+ Over the past half century, sea levels in the Northeast have been increasing 3 to 4 times faster than the global average rate, resulting in a 6-inch rise between 1970 and 2012.
+ With accelerating rates, sea level is projected to increase by 3 to 5 feet above 1990 levels in Rhode Island by 2100, with a potential for 1 foot of sea level rise by 2050.



Difference between mean sea level at Newport, R.I., from 1983 to 2001 and mean annual sea level plotted for each year between 1930 and 2012. The blue trend line shows a 8.7 inch rise through 2012, which is equalto a 10.6 inch (26.9 cm) increase in sea level per century. GRAPH COURTESY OF JON BOOTHROYD, 2012.

STORM TIDES AND SEA LEVEL RISE

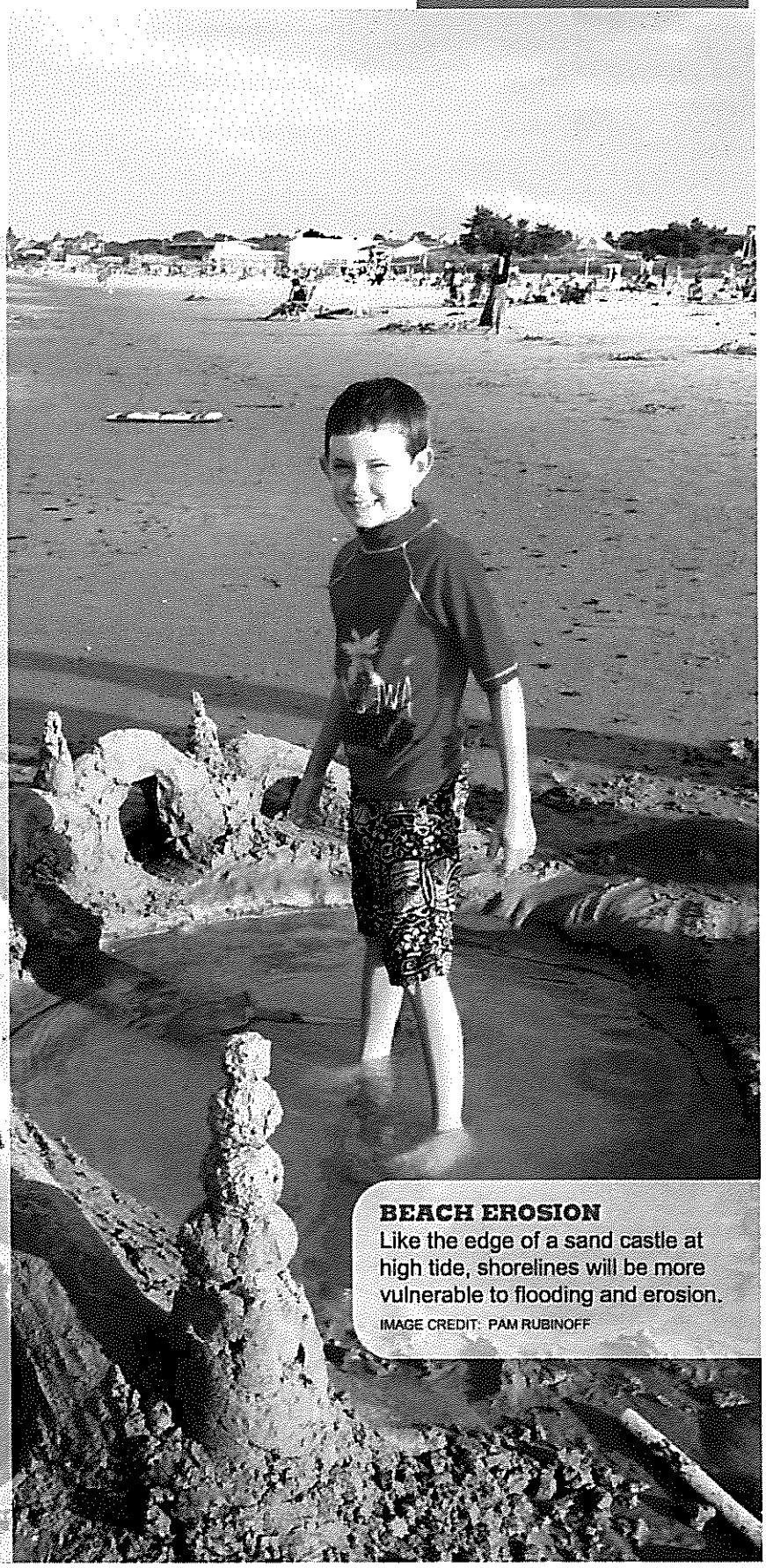
+ A storm tide is the increase in water level generated by a storm combined with the influence of astronomical tides.
+ Increased activity of extratropical storms (Nor'easters) on top of an already higher sea level will increase coastal flooding and erosion.
+ In some areas of the Northeast, storm surges associated with future hurricanes could be 2 to 4 feet higher than present conditions.
+ Damaging storm surges and higher tides in the Northeast are predicted to occur more frequently in the future. Evidence shows this is happening already.

TAKING **ACTION:**

FACT SHEET

+ New Shoreham is evaluating the potential impacts of sea level rise on ferry terminal operations and access to Block Island.
+ North Kingstown is identifying impacts, actions and infrastructure retrofits to adapt to rising seas, with the goal of targeting funding and integration to its comprehensive plan; this provides a template for Statewide Planning Program guidance available for other communities.
+ Bristol is looking at alternatives to critical road access impacted by storms.
+ Government and non-government organizations are monitoring saltmarsh impacts of sea level rise and evaluating alternative shoreline protection techniques to determine how best to protect future salt marsh and valuable ecosystem services.
+ Statewide maps are available depicting sea level rise inundation scenarios of 1, 3, and 5 feet and the 1938 hurricane http://seagrant.gso.uri.edu/climate/slr_tools.html

The URI Climate Change Collaborative is an interdisciplinary project funded by Rhode Island Sea Grant that draws on communication and behavioral science as well as climate change research to promote adaptation to sea level rise and the impacts of climate change. Learn more at seagrant.gso.uri.edu/climate.



BEACH EROSION
Like the edge of a sand castle at high tide, shorelines will be more vulnerable to flooding and erosion.
IMAGE CREDIT: PAM RUBINOFF

SEA LEVEL RISE IMPACTS COMMUNITIES BY **INUNDATING LOW-LYING COASTAL AREAS AND INCREASING RISKS FROM STORM TIDES.**

BUILT ENVIRONMENT:

+ Structures and roads will need to be raised or relocated above increasing coastal flood elevations. There are already locations where roads flood during extreme high tides.
+ Causeways, such as the Galilee Escape Road, or bridge approaches in low-lying areas will need to be elevated.
+ An estimated 2,700 housing units are within an elevation of one meter (3.3 feet) above sea level in Rhode Island. Residential and business properties in low-lying areas will likely be inundated permanently or during more frequent extreme high tides.
+ Ten at-risk coastal wastewater treatment facilities will need to be evaluated to determine risk, and options to reduce damage and disruption to service; other sectors with critical coastal infrastructure such as port facilities and energy and gas networks will also need to evaluate potential impacts and adaptation options.

NATURAL RESOURCES:

+ Rising sea level may drown salt marshes as rising tides outpace marsh growth, affecting their productivity and the fish and wildlife that depend on them.
+ Salt marshes seeking higher ground may not be able to migrate inland if they are constrained by hardened shorelines, elevated landforms, or coastal development.
+ Beaches will also migrate landward and if impeded by development will narrow or disappear altogether, reducing the area available for public recreation and tourism, and affecting habitats for plants and birds migrating or nesting on shore.

PUBLIC HEALTH AND WELFARE:

+ Drinking water systems will be impacted. Saltwater intrusion to groundwater may affect numerous homes with wells near the shore.
+ Coastal properties with septic systems will likely see reduced treatment of waste, and potential failure, with elevated groundwater and saltwater intrusion. This also may increase coastal pond contamination.
+ Increased flooding of coastal roads, evacuation routes, and bridges during high tides and storm surge events may leave coastal populations trapped with no means of accessing emergency services.

For more information and detailed references, visit Rhode Island Sea Grant's page on climate change at http://seagrant.gso.uri.edu/climate/