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SHOCK WAVES: MANAGING THE IMPACTS OF CLIMATE CHANGE ON POVERTY

Background Paper

Climate Change Impacts on Rural Poverty in Low-Elevation Coastal Zones

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WORLD BANK GROUP

Abstract

This paper identifies the low-elevation coastal zone populations and developing regions most vulnerable to sea-level rise and other coastal hazards, such as storm surges, coastal erosion, and salt-water intrusion. The focus is on the rural poor in the low-elevation coastal zone, as their economic livelihoods are especially endangered directly by coastal hazards and indirectly through the impacts of climate change on key coastal and near-shore ecosystems. Using geo-spatially referenced malnutrition and infant mortality data for 2000 as a proxy for poverty, this study finds that just 15 developing countries contain over 90 percent of the world's low-elevation coastal zone rural poor. Low-income countries as a group have the highest incidence of poverty, which declines somewhat for lower-middle-income countries, and then is much lower for upper-middle-income economies. South Asia, East Asia and the Pacific, and Sub-Saharan Africa account for most of the world's low-elevation coastal zone rural poor, and have a high incidence of poverty among their rural low-elevation coastal zone populations. Although fostering growth, especially in coastal areas, may reduce rural poverty in the low-elevation coastal zone, additional policy actions will be required to protect vulnerable communities from disasters, to conserve and restore key coastal and near-shore ecosystems, and to promote key infrastructure investments and coastal community response capability.

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Climate Change Impacts on Rural Poverty in Low-Elevation Coastal Zones

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Keywords: coastal zone, rural poverty, climate changes, rural development, coastal countries

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1. Introduction

The coastal areas of the world are the frontlines of climate change, and the most vulnerable populations are the poor living in the low-elevation coastal zone (LECZ) of developing countries, which is the contiguous area along the coast with less than 10 meters (m) elevation. The purpose of this paper is to review and assess how climate change could affect poor people living in LECZs by identifying the populations and developing regions most vulnerable to sea-level rise and other coastal hazards, such as storm surges, coastal erosion and saltwater intrusion. Where possible, discussing how these climate change impacts may be influenced by the status and management of coastal and near-shore ecosystems will be highlighted. In this paper, the focus will be on the rural poor in the LECZ, as their economic livelihoods are especially endangered both directly by coastal hazards and indirectly through the impacts of climate change on key coastal and near-shore ecosystems.

Approximately 38% of the world's population lives in coastal areas, defined as areas within 100 kilometers of the coast (UNEP 2014b). Over the past three decades, coastal populations have increased globally from 1.6 billion to over 2.5 billion (see Figure 1). In 2007, over three-quarters (1.9 billion) were in developing countries.

The expansion of coastal populations, economic activity and settlement growth in developing countries has resulted in growing pressures on coastal and near-shore ecosystems, such as mangroves, marsh, coral reefs, oyster reefs, seagrass beds and barrier islands (Barbier and Cox 2002; Barbier et al. 2011; Beck et al. 2011; Lotze et al. 2006; Wilkinson and Salvat 2012; Worm et al. 2006). As these ecosystems disappear or are degraded, there will be less protection against short-lived natural disasters with immediate and often extreme impacts, such as flooding and storm surge, as well as long-term climatic changes with more gradual impacts, such as sea-level rise, saline intrusion and erosion (Barbier 2014; Barbier et al. 2011; Gedan et al. 2011; IPCC Working Group II 2014; Spalding et al. 2014; Temmerman et al. 2013). In addition, the changes in precipitation, temperature and hydrology accompanying climate change are likely to threaten remaining coastal and near-shore ecosystems (Dasgupta et al. 2011; Doney et al. 2012; Erwin 2009; IPCC Working Group II 2014; Spalding et al. 2014; Webb et al. 2013).

Figure 1. Population within 100 kilometers of coast, 1975-2007
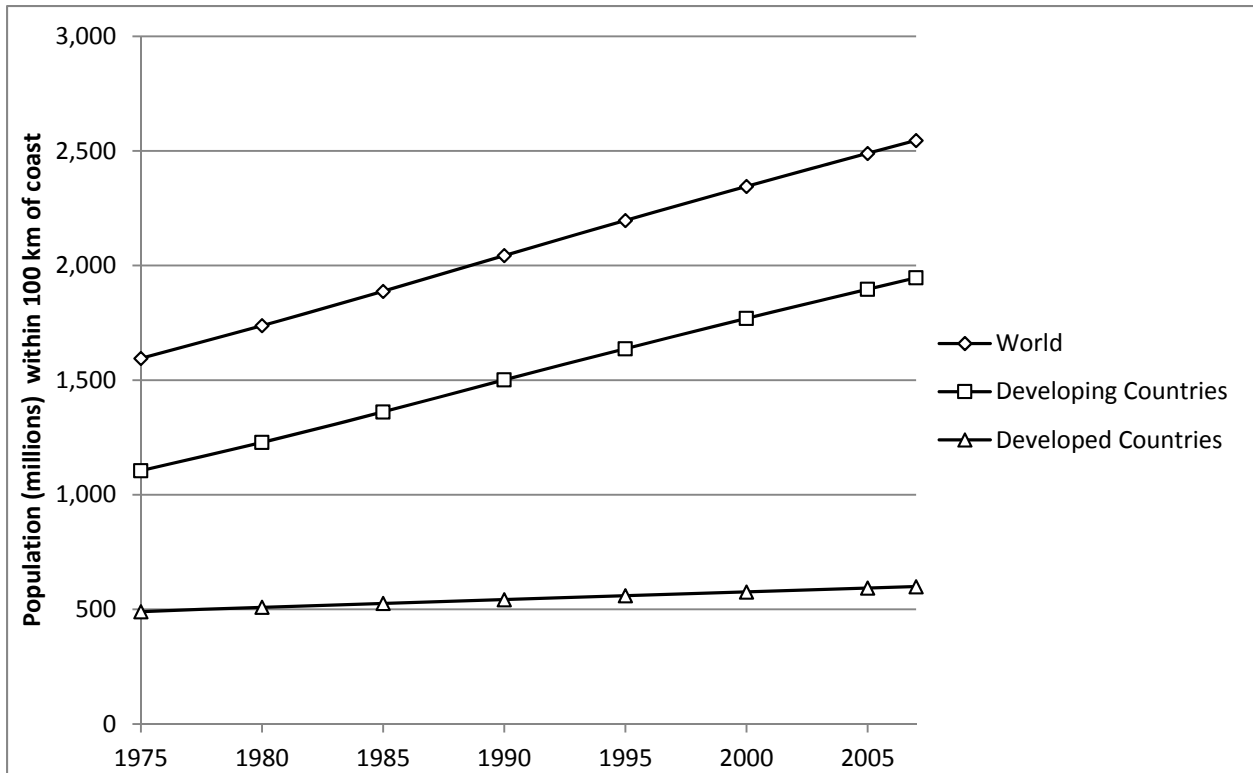
Source: United Nations Environment Programme (UNEP). 2014b. The UNEP Environmental Data Explorer, as compiled from UNEP/DEWA/GRID-Geneva. UNEP, Geneva. http://geodata.grid.unep.ch.

Previous studies have emphasized that the increasing concentration of populations in the LECZ are vulnerable to sea-level rise and other coastal hazards such as storm surges (Brecht et al. 2012; Dasgupta et al. 2011; IPCC Working Group II 2014; McGranahan et al. 2007; Moser et al. 2012; Nicholls and Cazenave 2010; Nicholls et al. 2007 and 2010). Although the LECZ covers only 2% of the world's land area, in developing countries it contains 14% of the population and 21% of urban dwellers (McGranahan et al. 2007). As a consequence, about 40 million urban residents globally are exposed to a 1-in-100-year coastal flooding event, and by 2070, it will be 150 million people (Nicholls et al. 2007). A 1 meter (m) sea-level rise accompanied by a10% intensification of storm surges would threaten an additional 31 million people in developing countries with inundation – approximately doubling the exposed population – and would increase the extent of coastal urban area exposed from 7% to 12.6% (Dasgupta et al. 2011). It is estimated that 10 cities in developing countries will account for 67% of the future coastal population exposure to the risks from sea-level rise and storm surge (Brecht et al. 2012).

There is little doubt that, as the LECZ in developing countries becomes more densely settled, these growing urban areas will become more vulnerable to the future risks resulting from

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coastal hazards. However, this paper focuses on another crucial aspect of the vulnerability of coastal populations in developing countries to climate change, which is its impact on poor rural LECZ populations. This impact has three channels. First, in the poorest developing countries, LECZ populations remain predominantly rural and have a high incidence of poverty. These poor rural LECZ populations can least afford to adapt to or protect themselves against sea-level rise and other coastal hazards, such as storm surges, coastal erosion and saltwater intrusion. Second, the disruptions and losses caused by such coastal hazards impact *directly* the livelihoods of many rural coastal households, such as agriculture and fishing. Finally, rural coastal populations and their livelihoods are also affected *indirectly*, as they are supported and protected by coastal and near-shore ecosystems, such as mangroves, marsh, coral reefs, seagrass beds and barrier islands, which are disappearing rapidly in many developing countries and are also threatened by climate change.

The purpose of this paper is to review and assess these three channels of the impact of climate change on poverty in coastal areas of developing countries. First, the paper reviews the main trends in LECZ coastal populations worldwide. Second, using spatially referenced data for infant mortality and child malnutrition reveals the extent and incidence of poverty among rural LECZ populations in specific developing regions and countries. Third, based on this spatial analysis, the vulnerability of the rural LECZ poor to the impacts of climate change is analyzed, including examining the specific effects on their main coastal livelihoods. The paper concludes by summarizing the findings and discussing their policy implications for improving the protection and adaptation of poor rural LECZ populations given future climate change hazards.

2. Population Trends in the Low Elevation Coastal Zone

Approximately 28% of the population living within 100 km of the coast globally can be found in the LECZ (see Table 1). This share is almost one-third for developing countries, and around 47% for low-income economies. East Asia & Pacific has around 40% of its coastal population in LECZ, followed by 35% in South Asia and 27% in Middle East & North Africa.

Although about 29% of the rural coastal population of developing countries is in the LECZ, this share is almost one-half for low-income economies (Table 1). In South Asia, 35% of the rural coastal population is located in the LECZ, 33% for East Asia & Pacific, and 28% for Middle East & North Africa.

Table 1. Low Elevation Zone Coastal Share of Coastal Population, 2000

	LECZ Share (%) of Total Coastal Population	LECZ Share (%) of Urban Coastal Population	LECZ Share (%) of Rural Coastal Population
Developing Country	**30.9%**	**33.4%**	**28.5%**
By Income:			
Low Income	46.5%	43.0%	48.1%
Lower Middle Income	26.0%	30.3%	23.2%
Upper Middle Income	32.8%	34.6%	29.5%
By Region:			
East Asia & Pacific	40.2%	48.5%	33.0%
Europe & Central Asia	7.5%	8.6%	5.8%
Latin America & Caribbean	12.1%	13.7%	9.1%
Middle East & North Africa	26.9%	25.5%	28.4%
South Asia	35.0%	34.6%	35.2%
Sub-Saharan Africa	18.4%	24.4%	12.6%
Developed Country	**18.7%**	**19.8%**	**13.9%**
World	**27.5%**	**28.1%**	**26.7%**

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level. The estimates of LECZ populations are from Center for International Earth Science Information Network (CIESIN)/Columbia University. 2013. Urban-Rural Population and Land Area Estimates Version 2. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/lecz-urban-rural-population-land-area-estimates-v2. Population and land area estimates are subdivided by elevation zone as derived from Shuttle Radar Topographic Mission (SRTM) elevation data at ~90m (3 arc seconds) resolution.

Coastal populations are those living within 100 kilometers (km) of the coast, and excluding countries without territory within 100 km of a coastline measured using an Azimuthal Equidistant (world) projection. See the appendix for details on the spatial methods in calculating these coastal population distributions.

Low-income economies are those in which 2013 per capita income was $1,045 or less, lower-middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, upper-middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745, and developed countries are those in which 2013 per capita income was more than $12,745 , based on the Atlas conversion factor instead of simple exchange rates, as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

As indicated in Figure 2, there are two notable trends from the current and projected future distribution of populations in the LECZ. First, both the total and rural populations in the world's LECZ have risen rapidly over the past 15 years, and are projected to continue increasing through 2100. Second, nearly all the world's rural LECZ population is in developing countries, which will also likely be the case through 2100.

In 1990, there were 528 million people living in the LECZ worldwide; by 2010, this number had increased to 704 million (see Figure 2). By 2100, the global LECZ population is estimated to be 1.06 billion. Developing countries continue to account for most of the LECZ population. In 1990, the total population in the LECZ of developing countries was 418 million, rising to 578 million in 2010. By 2100, nearly all the global LECZ population (926 million) will likely be in countries that are currently low- and middle-income economies.

The rural population in the LECZ of developing countries is also increasing, albeit at a slower rate (see Figure 2). In 1990, this population was 212 million, and rose to 267 million in 2010. By 2100, the rural population in the LECZ of today's low- and middle-income economies is projected to be 459 million, and will account for almost the entire global total (477 million).

Figure 2. Population in Low Elevation Coastal Zones, 1990-2100

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 meters above sea level.

Developing countries are low and middle-income economies with 2013 per capita income of $12,745 or less, as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.
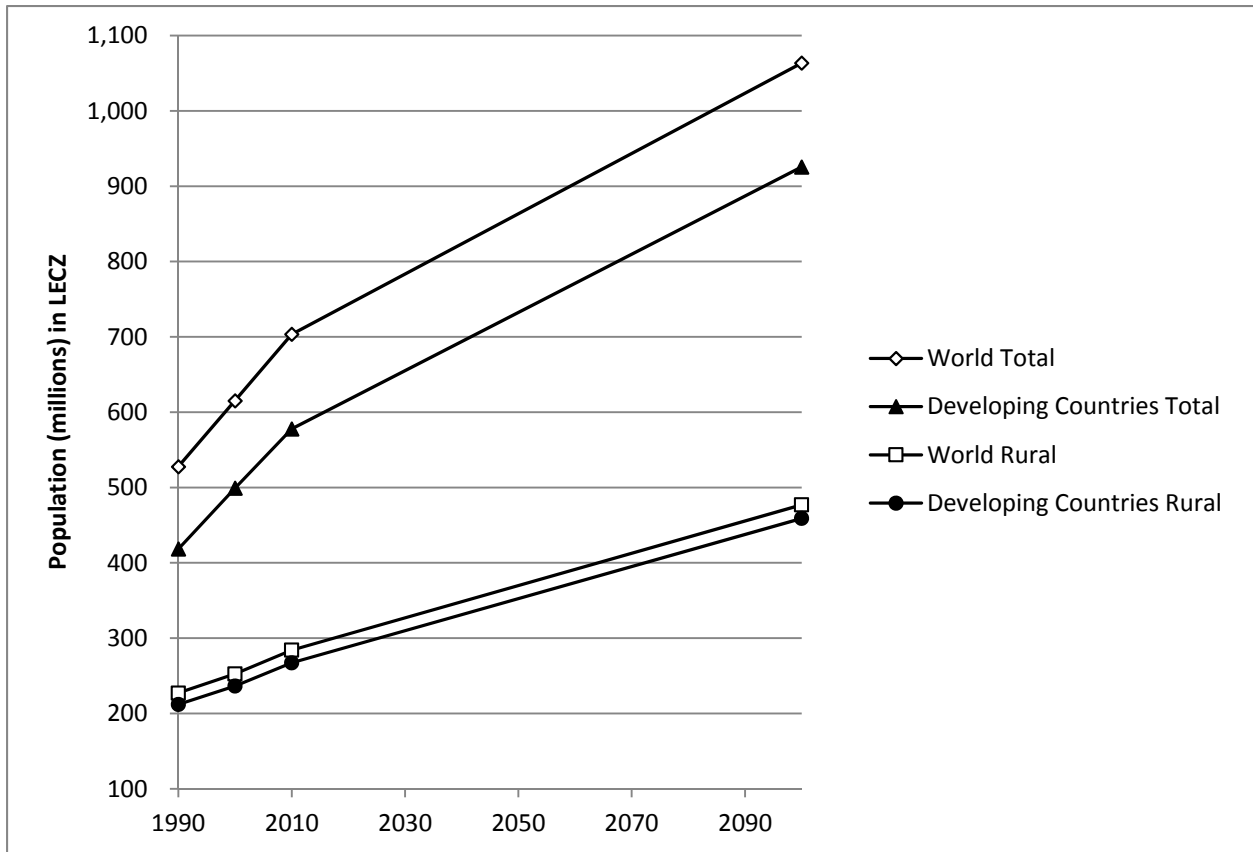
The estimates of LECZ populations are from Center for International Earth Science Information Network (CIESIN)/Columbia University. 2013. Urban-Rural Population and Land Area Estimates Version 2. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/lecz-urban-rural-population-land-area-estimates-v2. Population and land area estimates are subdivided by elevation zone as derived from Shuttle Radar Topographic Mission (SRTM) elevation data at ~90m (3 arc seconds) resolution.

Although in developed countries only 13% of the LECZ population is rural, this share is 46% for developing countries (see Table 2). However, the latter share varies considerably by income and region. For low-income economies, around 71% of the LECZ population is rural; for lower-middle-income economies, 52%; and for upper middle-income economies, 28%. The largest rural LECZ populations in developing countries are in East Asia & Pacific (133 million) and South Asia (93 million). In South Asia, 60% of the LECZ population is rural, 52% in the Middle East & North Africa, and 42% in East Asia & Pacific.

In sum, the rural population in the LECZ of developing countries is continuing to increase, and the share of LECZ population that is rural is especially large in poorer economies. Among developing regions, South Asia has a particularly large share of rural LECZ population, and along with East Asia & Pacific, accounts for 85% of the rural LECZ population across all developing countries. These population distributions by income and regions have important implications for determining the most vulnerable regions and countries to climate change impacts on coastal poverty.

Table 2. Population in Low Elevation Coastal Zones, 2000 and 2010

	Total LECZ Population (millions)		Rural LECZ Population (millions)		Rural Share (%)	
	2000	**2010**	**2000**	**2010**	**2000**	**2010**
Developing Country	**499.2**	**577.9**	**236.3**	**267.2**	**47.3%**	**46.2%**
By Income:						
Low Income	80.8	93.6	58.0	66.2	71.8%	70.8%
Lower Middle Income	210.2	252.5	112.6	132.1	53.5%	52.3%
Upper Middle Income	208.2	231.8	65.8	68.9	31.6%	29.7%
By Region:						
East Asia & Pacific	279.9	313.8	123.2	133.0	44.0%	42.4%
Europe & Central Asia	4.7	4.7	1.5	1.5	31.6%	30.9%
Latin America & Caribbean	28.9	33.1	7.5	8.3	25.8%	25.1%
Middle East & North Africa	32.4	39.6	16.8	20.5	51.7%	51.7%
South Asia	129.5	155.2	79.2	93.3	61.1%	60.1%
Sub-Saharan Africa	23.7	31.4	8.2	10.6	34.5%	33.8%
Developed Country	**116.1**	**125.6**	**16.2**	**16.9**	**13.9%**	**13.4%**
World	**615.2**	**703.5**	**252.5**	**284.1**	**41.0%**	**40.4%**

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

Low-income economies are those in which 2013 per capita income was $1,045 or less, lower-middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, upper-middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745, and developed countries are those in which 2013 per capita income was more than $12,745, based on the Atlas conversion factor instead of simple exchange rates, as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

The estimates of LECZ populations are from Center for International Earth Science Information Network (CIESIN)/Columbia University. 2013. Urban-Rural Population and Land Area Estimates Version 2. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/lecz-urban-rural-population-land-area-estimates-v2. Population and land area estimates are subdivided by elevation zone as derived from Shuttle Radar Topographic Mission (SRTM) elevation data at ~90m (3 arc seconds) resolution.

3. Coastal Populations and Poverty

By using spatially referenced data sets for infant mortality and child malnutrition, which are available for 2000, it is possible to estimate the extent of poverty among coastal populations, including those in the LECZ (see appendix). In the absence of globally gridded data sets for income or consumption-based measures of poverty, infant mortality and child malnutrition rates serve as a useful proxy for overall poverty levels because they are highly correlated with many poverty-related metrics, such as income, education levels and health status. Infant mortality rates measure the number of deaths of infants under age 1 per 1,000 live births in a given year. Child malnutrition counts are the product of malnutrition rates and population counts, with malnutrition rates based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population. The globally gridded data sets of infant mortality and child malnutrition used here as proxies for poverty have been employed in other studies of the geographical extent of poverty by country (de Sherbinin 2008 and 2011; Turner et al. 2012).

As indicated in Table 3, among populations within 100 km of the coast in developing countries, there were approximately 408 million people living in areas with high levels of infant mortality in 2000.[1] Nearly 58% of this population was rural, or around 235 million people. Overall, approximately 28% of the rural coastal population in 2000 was in areas with high rates of infant mortality. In 2000, around 340 million coastal people were also in locations with malnourished children. Around 61%, or 206 million of this population, lived in rural coastal areas. They accounted for approximately one-quarter of the rural coastal population in developing countries.

However, poverty, as proxied by infant mortality and malnutrition, among rural coastal populations in developing countries varied considerably by income level (see Table 3). Most of the rural coastal populations that lived in areas with high infant mortality and malnourished children in 2000 were in low- and lower-middle-income countries. The share (%) of rural coastal population in poverty also declined with income level. For example, 67% of the rural coastal population in low-income countries lived in areas with high infant mortality, compared to 28% in lower-middle-income and 8% in upper-middle-income countries. Similarly, 37% of the rural coastal population in low-income countries was in areas with malnourished children, 30% in lower-middle-income countries, and 6% in upper-middle-income countries.

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[1] Although child malnutrition is directly association with poverty, it is necessary to designate a threshold for infant mortality, above which the number deaths of infants per 1,000 live births is associated with conditions of poverty. As indicated in Table 3, the threshold used here is 50 or more deaths. Although somewhat conservative, this threshold is consistent with other studies that use the CIESN globally gridded data set of infant mortality to designate areas with different degrees of poverty. For example, in his spatial analysis of poverty in areas surrounding national parks in developing countries, de Sherbinin (2008) considers areas with infant mortality rates < 15 deaths per 1,000 live births to be not poor, in the range of 15-32 deaths to be moderately poor, 32-65 to be poor, 65-100 to be very poor, and > 100 to be extremely poor.

Table 3. Poverty among Coastal Populations, 2000

	Population in Areas with High Infant Mortality (millions)		Rural Share (%)	Population in Areas with Malnourished Children (millions)		Rural Share (%)	Share (%) of Rural Coastal Population in Areas with High Infant Mortality	Share (%) of Rural Coastal Population in Areas with Malnourished Children
	Total	**Rural**	**(%)**	**Total**	**Rural**	**(%)**		
Developing Country	**408.5**	**235.5**	**57.6%**	**339.9**	**205.6**	**60.5%**	**28.4%**	**24.8%**
By Income:								
Low Income	117.7	80.3	68.2%	62.5	45.1	72.1%	66.5%	37.4%
Lower Middle Income	249.2	136.5	54.8%	243.3	147.2	60.5%	28.1%	30.3%
Upper Middle Income	41.6	18.7	44.9%	34.0	13.3	39.0%	8.4%	6.0%
By Region:								
East Asia & Pacific	39.3	29.5	75.1%	123.3	79.8	64.7%	7.9%	21.4%
Europe & Central Asia	0.0	0.0	--	3.2	1.4	43.1%	0.0%	5.3%
Latin America & Caribbean	24.3	14.5	59.7%	17.4	7.6	43.5%	17.7%	9.2%
Middle East & North Africa	22.3	14.7	66.0%	9.8	5.7	58.6%	25.0%	9.7%
South Asia	204.0	113.3	55.5%	158.2	95.2	60.2%	50.4%	42.4%
Sub-Saharan Africa	118.5	63.4	53.5%	28.0	15.8	56.7%	97.4%	24.3%
Developed Country	**0.3**	**0.3**	**76.9%**	**3.4**	**0.7**	**20.9%**	**0.2%**	**0.6%**
World	**408.9**	**235.7**	**57.7%**	**343.3**	**206.3**	**60.1%**	**24.9%**	**21.8%**

Coastal populations are those living within 100 kilometers (km) of the coast, and excluding countries without territory within 100 km of a coastline measured using an Azimuthal Equidistant (world) projection.

High infant mortality is 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births).

Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population.

See the appendix for details on the spatial methods in calculating these coastal population distributions.

Low-income economies are those in which 2013 per capita income was $1,045 or less, lower-middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, upper-middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745, and developed countries are those in which 2013 per capita income was more than $12,745 , as defined by the World Development Indicators, available at
http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

Poverty among rural coastal populations in 2000 appeared concentrated in a few developing country regions (see Table 3). The largest rural coastal populations in areas with high levels of infant mortality were found in South Asia (113 million), Sub-Saharan Africa (63 million) and East Asia & Pacific (30 million). South Asia had 95 million rural coastal people living in areas with malnourished children, East Asia & Pacific 80 million, and Sub-Saharan Africa 16 million. Over 97% of the rural coastal population in Sub-Saharan Africa in 2000 was in areas with high infant mortality, and more than half in South Asia. The share of rural coastal population in locations with malnourished children in 2000 was also highest in South Asia (42%), followed by Sub-Saharan Africa (24%) and East Asia & Pacific (21%).

Similar patterns emerge for poverty among LECZ populations in developing countries in 2000 (see Table 4). Across all developing countries, 119 million people in the LECZ lived in areas with high infant mortality, of which nearly 54% (64 million) was in rural LECZ areas. The total LECZ population in locations with malnourished children in 2000 was 107 million, of which over 62 million (58%) were rural. Around 27% of the rural LECZ population in developing countries lived in areas with high infant mortality, and 26% in locations with malnourished children.

Nearly all of the LECZ rural poor in 2000 were in low- and lower-middle-income countries (see Table 4). The incidence of rural LECZ poverty also fell with income level. For example, 59% of the rural LECZ population in low-income countries lived in areas with high infant mortality, compared to 24% in lower-middle-income and 5% in upper-middle-income countries. Similarly, 43% of the rural LECZ population in low-income countries was in locations with malnourished children, 30% in lower-middle-income countries, and 5% in upper-middle-income countries.

South Asia and East Asia & Pacific had by far the largest poor rural LECZ populations in 2000, followed by Sub-Saharan Africa (see Table 4). The largest rural LECZ populations in areas with high infant mortality were in South Asia (40 million), East Asia & Pacific (13 million) and Sub-Saharan Africa (8 million). South Asia had 35 million rural LECZ people in areas with malnourished children, East Asia and Pacific 80 million and Sub-Saharan Africa 2 million. Over 98% of the rural coastal population in Sub-Saharan Africa lived in locations with high infant mortality, and 51% in South Asia. The share of rural coastal population in areas with malnourished children was also highest in South Asia (44%), followed by Sub-Saharan Africa (24%) and East Asia & Pacific (20%).

Table 4. Poverty among Low Elevation Coastal Zone Populations, 2000

	Population in Areas with High Infant Mortality (millions)		Rural Share (%)	Population in Areas with Malnourished Children (millions)		Rural Share (%)	Share (%) of Rural LECZ Population in Areas with High Infant Mortality	Share (%) of Rural LECZ Population in Areas with Malnourished Children
	Total	Rural	(%)	Total	Rural	(%)		
Developing Country	**119.3**	**64.3**	**53.9%**	**106.8**	**62.4**	**58.4%**	**27.2%**	**26.4%**
By Income:								
Low Income	50.8	34.3	67.5%	33.5	25.0	74.6%	59.2%	43.1%
Lower Middle Income	61.0	26.8	43.9%	63.7	34.2	53.6%	23.8%	30.3%
Upper Middle Income	7.6	3.3	43.2%	9.6	3.2	33.6%	5.0%	4.9%
By Region:								
East Asia & Pacific	18.4	12.9	70.3%	41.0	24.0	58.5%	10.5%	19.5%
Europe & Central Asia	0.0	0.0	--	0.2	0.1	36.2%	0.0%	6.0%
Latin America & Caribbean	2.9	1.2	41.3%	1.9	0.6	31.0%	16.1%	7.9%
Middle East & North Africa	4.0	1.9	47.4%	1.7	0.8	49.8%	11.4%	4.9%
South Asia	71.1	40.3	56.6%	56.8	34.9	61.4%	50.8%	44.1%
Sub-Saharan Africa	22.9	8.0	35.1%	5.2	2.0	38.1%	98.4%	24.1%
Developed Country	**0.02**	**0.02**	**86.1%**	**0.7**	**0.1**	**14.5%**	**0.2%**	**0.6%**
World	**119.4**	**64.4**	**53.9%**	**107.5**	**62.5**	**58.1%**	**25.5%**	**24.7%**

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

High infant mortality is 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births).

Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population.

See the appendix for details on the spatial methods in calculating these coastal population distributions.

Low-income economies are those in which 2013 per capita income was $1,045 or less, lower-middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, upper-middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745, and developed countries are those in which 2013 per capita income was more than $12,745 , as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

To provide a context for the poverty estimates in Table 4 for LECZ populations, Table 5 depicts the general poverty patterns in 2000 for the same coastal countries. Overall, much the same pattern of rural poverty and its incidence occurs across developing countries as in the LECZ. However, there are some important differences.

Across all developing countries, the rural share of populations in areas with high infant mortality was around 71% in 2000, which is much higher than in the LECZ of these countries (see Tables 4 and 5). Similarly, the rural share of populations in locations with malnourished children was almost 70% across all developing countries compared to 58% in the LECZ. Overall, this pattern was similar by income group and regions, with the exceptions for Middle East & North Africa, which had a larger rural share of populations in areas with high infant mortality in the LECZ, and Europe & Central Asia, which had a greater rural share of populations in locations with malnourished children in the LECZ.

As in the case of the LECZ, nearly all the rural poor across developing countries in 2000 were located in low- and lower-middle-income countries (see Table 5). In addition, the incidence of rural poverty fell with income level. Compared to the LECZ, the share of rural population living in areas of high infant mortality was generally higher across all developing countries, including by income group and region, except for in Latin America & Caribbean and Sub-Saharan Africa (see Tables 4 and 5). However, the share of rural population in areas of child malnutrition was slightly higher in the LECZ of developing countries than across these countries generally. The same is true for low-income countries, East Asia & Pacific and Europe & Central Asia.

Overall, in developing countries, the LECZ in 2000 accounted for 5% of the rural population in areas with high infant mortality and over 9% of the locations with malnourished children (see Table 5). But these shares varied considerably by income group and region. In low-income economies, the LECZ contained 13% of the rural population in areas with high infant mortality and almost 22% in locations with malnourished children. In East Asia & Pacific, the LECZ had about 8% of the rural population in areas with high infant mortality and over 19% in locations with malnourished children, and in South Asia these shares were more than 5% and 8%, respectively.

Table 5. Poverty in Countries with Coastal Populations, 2000

	Population in Areas with High Infant Mortality (millions)		Rural Share (%)	Population in Areas with Malnourished Children (millions)		Rural Share (%)	Share (%) of Rural Population in Areas with High Infant Mortality	Share (%) of Rural Population in Areas with Malnourished Children	LECZ Share (%) of Rural Population in Areas with High Infant Mortality	LECZ Share (%) of Rural Population in Areas with Malnourished Children
	Total	Rural		Total	Rural					
Developing Country	**1,818.2**	**1,287.5**	**70.8%**	**977.7**	**680.0**	**69.5%**	**48.7%**	**25.7%**	**5.0%**	**9.2%**
By Income:										
Low Income	337.8	265.2	78.5%	145.5	116.0	79.7%	83.0%	36.3%	12.9%	21.5%
Lower Middle Income	1,192.2	844.8	70.9%	717.7	506.5	70.6%	63.0%	37.8%	3.2%	6.7%
Upper Middle Income	288.2	177.5	61.6%	114.5	57.4	50.1%	18.0%	5.8%	1.8%	5.6%
By Region:										
East Asia & Pacific	234.4	168.8	72.0%	187.5	123.9	66.1%	17.1%	12.5%	7.6%	19.4%
Europe & Central Asia	0.0	0.0	--	4.4	1.4	32.3%	0.0%	1.9%	0.0%	6.2%
Latin America & Caribbean	42.5	27.8	65.4%	34.2	15.9	46.6%	14.3%	8.2%	4.3%	3.7%
Middle East & North Africa	94.0	44.3	47.1%	26.9	13.5	50.1%	36.7%	11.1%	4.3%	6.1%
South Asia	1,026.0	752.9	73.4%	595.3	432.3	72.6%	79.6%	45.7%	5.3%	8.1%
Sub-Saharan Africa	421.2	293.6	69.7%	125.0	90.4	72.3%	92.5%	28.5%	2.7%	2.2%
Developed Country	**0.5**	**0.4**	**85.3%**	**9.2**	**2.8**	**30.5%**	**0.2%**	**1.0%**	**4.3%**	**3.5%**
World	**1,818.7**	**1,287.9**	**70.8%**	**987.0**	**682.8**	**69.2%**	**44.1%**	**23.4%**	**5.0%**	**9.2%**

Coastal populations are those living within 100 kilometers (km) of the coast, and excluding countries without territory within 100 km of a coastline measured using an Azimuthal Equidistant (world) projection.

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

High infant mortality is 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births).

Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population.

See the appendix for details on the spatial methods in calculating these coastal population distributions.

Low-income economies are those in which 2013 per capita income was $1,045 or less, lower-middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, upper-middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745, and developed countries are those in which 2013 per capita income was more than $12,745 , as defined by the World Development Indicators, available at
http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

Table 6 indicates that there are 15 developing countries that contain over 90% of the world's LECZ rural poor. The countries are: India, Bangladesh, Myanmar, Cambodia, Nigeria, Pakistan, Iraq, Mozambique, Senegal, Brazil, China, Indonesia, the Philippines, Vietnam and Thailand. For example, in 2000 these 15 economies accounted for around 59.2 million, or 92%, of the LECZ rural population living in areas with high infant mortality across all developing countries. In 2000 the 15 countries of Table 6 also contained 59.1 million, or almost 95%, of all LECZ rural population in areas with malnourished children throughout the developing world.

The 15 countries listed in Table 6 also had a slightly higher incidence of rural LECZ poverty in 2000 compared to the poverty rate across all developing economies. Around 29% of the rural LECZ population for the 15 countries lived in areas of high infant mortality in 2000, whereas the rate was just over 27% in the LECZ across all developing economies. However, some countries in Table 6 had much higher infant mortality incidence; all or almost all of the rural LECZ populations in Myanmar, Cambodia, Nigeria, Pakistan, Iraq, Mozambique and Senegal were located in areas of high infant mortality. India (55%), Bangladesh (47%) and Brazil (39%) also had a very high rate of poverty, based on the location of their rural LECZ populations in areas of high infant mortality. Similarly, 29% of the rural LECZ population for the 15 countries lived in areas of child malnutrition, whereas this rate was about 26% in the LECZ of all developing countries. Again, some of the countries in Table 6 had even a higher share of their rural LECZ population located in areas child malnutrition, such as Pakistan (50%), Bangladesh (46%), India (42%), Cambodia (42%), Myanmar (38%) and Vietnam (33%).

In sum, rural poverty among LECZ populations is clearly a developing country problem. In addition, rural LECZ poverty is distinguishable by income level. Low-income countries as a group have the highest incidence of poverty, which declines somewhat for lower-middle-income countries, and then is much lower for upper-middle-income economies. South Asia, East Asia and the Pacific and Sub-Saharan Africa account for most of the world's LECZ rural poor, and have a high incidence of poverty among their rural LECZ populations. Fifteen countries appear to contain nearly all the world's rural LECZ poor. These countries tend to have greater concentrations of the rural poor in these zones, and many have much higher incidence of rural poverty compared to the rates across all developing countries.

Table 6. Countries with High Rural Low Elevation Coastal Zone Poverty, 2000

	Areas of High Infant Mortality				Areas of Malnourished Children		
Country	Rural LECZ Population in Areas of High Infant Mortality ('000)	Share (%) of Rural LECZ Population in Areas of High Infant Mortality	LECZ Share (%) of Rural Population in Areas of High Infant Mortality	Country	Rural LECZ Population in Areas with Malnourished Children ('000)	Share (%) of Rural LECZ Population in Areas with Malnourished Children	LECZ Share (%) of Rural Population in Areas with Malnourished Children
India	19,419.9	55.4%	3.3%	Bangladesh	19,092.3	46.4%	33.2%
Bangladesh	19,143.5	46.5%	27.1%	India	14,635.0	41.7%	4.3%
Myanmar	7,791.0	99.7%	21.1%	Vietnam	10,764.0	33.0%	53.7%
Cambodia	3,306.5	99.5%	30.6%	Indonesia	4,466.6	26.3%	12.8%
Nigeria	2,175.1	100.0%	2.7%	Myanmar	3,001.2	38.4%	22.9%
Pakistan	1,694.1	99.5%	1.8%	Philippines	1,564.4	27.9%	10.5%
Iraq	1,324.3	99.3%	11.9%	Cambodia	1,384.5	41.7%	27.8%
Mozambique	1,041.2	100.0%	7.8%	China	1,117.5	2.3%	5.1%
Senegal	802.9	100.0%	14.0%	Thailand	955.0	18.6%	11.8%
Brazil	759.6	38.6%	4.0%	Pakistan	842.9	49.5%	2.3%
China	624.7	1.3%	0.6%	Nigeria	450.5	20.7%	1.9%
Indonesia	416.0	2.4%	13.5%	Mozambique	265.7	25.5%	6.6%
Philippines	359.6	6.4%	10.5%	Iraq	211.2	15.8%	12.0%
Vietnam	314.5	1.0%	24.7%	Senegal	194.7	24.2%	13.2%
Thailand	9.4	0.2%	0.4%	Brazil	127.4	6.5%	3.1%
Total 15	**59,182.3**	**28.9%**	**5.7%**		**59,072.9**	**28.8%**	**10.2%**
All Developing	**64,335.1**	**27.2%**	**5.0%**		**62,360.1**	**26.4%**	**9.2%**

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

High infant mortality is 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births). The above 15 countries account for 92.0% of all rural LECZ populations with high infant mortality in developing countries.

Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population. The above 15 countries account for 94.7% of all rural LECZ populations with malnourished children in developing countries.

See the appendix for details on the spatial methods in calculating these coastal population distributions.

4. Vulnerability to Climate Change

Because of the extensive poverty among rural populations in the LECZ of developing countries, these populations are highly vulnerable to the impacts of climate change. The Intergovernmental Panel on Climate Change concludes, with high confidence, that low-lying coastal areas and ecosystems will increasingly experience adverse impacts such as submergence, coastal flooding and coastal erosion due to sea-level rise (IPCC Working Group II 2014). Past studies that have projected these impacts have analyzed mainly the implications for coastal urban populations and major cities (Brecht et al. 2012; Dasgupta et al. 2009 and 2011; IPCC Working Group II 2014; McGranahan et al. 2007; Nicholls et al. 2007 and 2010). The exception is the scenarios for sea-level rise and storm surges developed by Dasgupta et al. (2009 and 2011), which include impacts on coastal gross domestic product (GDP), agriculture and wetlands that are more likely to affect the rural poor in LECZ.[2] These three impacts are more relevant to the three channels of climate change impacts discussed in the Introduction that are likely to affect the coastal rural poor: As coastal GDP rises, poverty among LECZ rural populations diminishes, and they are better able to cope with and adapt to the hazards associated with climate change; agriculture is an important livelihood for the coastal rural poor that is directly impacted by coastal hazards; and finally, mangroves and similar coastal wetlands support and protect the rural poor and their livelihoods, which are therefore indirectly impacted by the loss of these beneficial habitats.

Flooding associated with cyclones and other major coastal storms are likely to increase as a result of accelerated sea-level rise (IPCC Working Group II 2014; Woodruff et al. 2012). Table 7 summarizes the implications of a possible 1 meter (m) sea-level rise accompanied by a 10% intensification of storm surges in terms of coastal GDP, agricultural area exposed, and wetlands area impacted in the LECZ of 84 developing countries, as analyzed by Dasgupta et al. (2011).[3] As indicated in the table, across these countries, the percentage of coastal GDP, agricultural area and wetlands area exposed to flooding would increase significantly with sea-level rise and storm surge intensification.

Of particular concern are the predicted large increases in exposure to storm surges in South Asia and in East Asia & the Pacific, which are the regions with the largest poor rural LECZ populations (see Table 4). As shown in Table 7, in South Asia, a 1 m sea-level rise accompanied by 10% storm surge intensification would increase the flooding exposure of coastal GDP from 7.9% to 14.4%, LECZ agricultural area from 4.2% to 10.7%, and wetlands area from

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[2] In a separate but related study, Blankespoor et al. (2014) quantify the impact of a 1 m sea-level rise on coastal wetlands in 86 developing countries and territories and find that around 68% of the wetlands in these countries are at risk.

[3] There were no developing countries from Europe and Central Asia in the analysis conducted by Dasgupta et al. (2011).

12.2% to 22.0%. In East Asia and Pacific, the threat from flooding to coastal GDP would rise from 5.9% to 11.1%, to agriculture from 4.6% to 9.0%, and to wetlands from 11.3% to 18.1%.

Table 7. Exposure of the LECZ in Developing Countries to Sea-Level Rise and Storm Surge Intensification

	% of Coastal GDP (2005) Exposed		% of Coastal Agricultural Area Exposed		% of Coastal Wetlands Area Impacted	
	Current Storm Surge	Intensified Storm Surge	Current Storm Surge	Intensified Storm Surge	Current Storm Surge	Intensified Storm Surge
Developing Country	**7.0%**	**12.5%**	**4.3%**	**8.9%**	**10.1%**	**17.1%**
East Asia & Pacific	5.9%	11.1%	4.6%	9.0%	11.3%	18.1%
Latin America & Caribbean	5.5%	9.9%	1.7%	4.1%	5.5%	9.9%
Middle East & North Africa	15.1%	23.8%	1.0%	4.1%	18.9%	29.3%
South Asia	7.9%	14.4%	4.2%	10.7%	12.2%	22.0%
Sub-Saharan Africa	3.9%	8.6%	1.3%	3.5%	7.6%	14.6%

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

The table compares current exposure to inundation from a 1-in-100 year storm surge with exposure to a 1 meter (m) sea-level rise accompanied by a 10% intensification of storm surges.

Adapted from Dasgupta, S. Laplante, B., Murray, S. and Wheeler, D. 2011. "Exposure of developing countries to sea-level rise and storm surges." *Climatic Change* 106:567-579, Tables 2 and 3.

Table 8 indicates the climate change vulnerability of the 15 countries with the largest poor rural LECZ populations in 2000 (see Table 6). For each country, the table shows the share (%) of coastal GDP (in 2005), agricultural area and wetlands in the LECZ that could be exposed to future inundation from a 1 m sea-level rise accompanied by a 10% intensification of storm surges. In addition, the rural LECZ population growth for each country from 2000 to 2010 is included.

Across all 15 countries with large poor rural LECZ populations, around 31% of coastal GDP, 22% of agricultural area and 32% of wetlands are likely to be exposed to future inundation from sea-level rise and storm surges. In addition, in these countries, rural LECZ population has expanded on average by 18% from 2000 to 2010.

Table 8. Climate Change Vulnerability of Countries with the Largest Poor Rural LECZ Populations

Country	Rural LECZ Population in Areas with High Infant Mortality ('000)	Rural LECZ Population in Areas with Malnourished Children ('000)	% of Coastal GDP Exposed	% of Coastal Agricultural Area Exposed	% of Coastal Wetlands Area Impacted	Growth (%) of Rural LECZ Population 2000-2010
India	19,419.9	14,635.0	27.7%	23.6%	32.3%	20.5%
Bangladesh	19,143.5	19,092.3	19.0%	17.5%	24.3%	15.7%
Myanmar	7,791.0	3,001.2	48.9%	22.9%	50.2%	0.2%
Cambodia	3,306.5	1,384.5	2.7%	1.0%	1.5%	12.0%
Nigeria	2,175.1	450.5	22.0%	100.0%	38.8%	35.8%
Pakistan	1,694.1	842.9	38.6%	2.7%	61.4%	22.9%
Iraq	1,324.3	211.2	..	..	..	31.1%
Mozambique	1,041.2	265.7	55.0%	23.6%	47.1%	33.0%
Senegal	802.9	194.7	21.1%	2.0%	22.0%	22.6%
Brazil	759.6	127.4	28.5%	16.5%	11.5%	10.1%
China	624.7	1,117.5	17.1%	11.7%	39.8%	1.7%
Indonesia	416.0	4,466.6	38.7%	26.1%	27.0%	13.4%
Philippines	359.6	1,564.4	52.3%	30.7%	45.0%	25.0%
Vietnam	314.5	10,764.0	31.7%	23.8%	29.4%	11.3%
Thailand	9.4	955.0	31.6%	11.6%	14.7%	12.4%
Total	**59,182.3**	**59,072.9**	**31.1%**	**22.4%**	**31.8%**	**17.5%**

The low elevation coastal zone (LECZ) is the contiguous area along the coast that is less than 10 m above sea level.

High infant mortality is 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births). Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population. See the appendix for details on the spatial methods in calculating these coastal population distributions. Across all developing countries, the 15 countries in this table account for 92.0% of all rural LECZ populations in areas with high infant mortality in 2000 and 94.7% of all rural LECZ populations in locations with malnourished children.

Data for % of coastal GDP, agricultural area and wetlands exposed to a 1 meter (m) sea-level rise accompanied by a 10% intensification of storm surges are from Dasgupta, S., Laplante, B., Murray, S. and Wheeler, D. 2009. "Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts in Developing Countries." Policy Research Working Paper 4901, the World Bank, Washington, D.C. April. Available at http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:22270368~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html

Many individual countries show alarmingly high vulnerability to these climate change impacts. Nearly half the coastal GDP of Myanmar is exposed to the risk of future flooding, 52% of the coastal GDP of the Philippines, and 55% of the coastal GDP of Mozambique. All of Nigeria's LECZ agriculture is vulnerable to inundation, over 30% of the agriculture in the Philippines, and over a quarter of the agriculture in Indonesia. Over 61% of the wetlands in Pakistan, 50% in Myanmar, 47% in Mozambique, 45% in the Philippines, and 40% in China are at risk. From 2000 to 2010, rural LECZ population in Nigeria grew 36%, in Mozambique 33%, in Iraq 31%, and in the Philippines 25%.

India and Bangladesh also show considerable vulnerability to the risk of future flooding from sea-level rise and storm surge intensification. For example, 24% of the coastal GDP and agriculture of India, and 32% of its wetlands are at risk from inundation. For Bangladesh, 19% of its LECZ GDP, 18% of agriculture, and 24% of its wetlands may be impacted by future flooding. In addition, the rural LECZ populations of both countries have expanded substantially over 2000 to 2010, by 21% in India and 16% in Bangladesh.

A further problem is that, in many coastal regions, the disappearance and degradation of many coastal and near-shore ecosystems means less protection against sea-level rise, storm surge, saline intrusion and erosion (Barbier 2014; Barbier et al. 2011; Gedan et al. 2011; IPCC Working Group II 2014; Spalding et al. 2014; Temmerman et al. 2013). For example, for many of the 15 countries with large numbers of LECZ rural poor, mangroves are an important natural barrier that provides protection against these hazardous events. In many remote and rural coastal areas, they may be the only form of protection against storms available for the poor. Yet, as indicated in Table 9, the remaining mangroves in these countries are under considerable threat not only from the potential impacts of climatic change but also population growth and economic development.

The 15 countries with the largest poor rural LECZ populations also contain the majority of the world's remaining mangroves. Yet mangrove deforestation continues to be a problem in their coastal areas, which on average lost 2% of their mangroves from 2000 to 2012 (see Table 7). Myanmar experienced an 8.4% decline in its mangroves, Cambodia 4.5%, India 3.3%, and Indonesia 3.1%. As indicated in Table 9, the increased exposure to flooding is also likely to affect coastal wetlands such as mangroves, as will the disruptions in precipitation, temperature and hydrology accompanying climate change (Doney et al. 2012; Erwin 2009; IPCC Working Group II 2014; Spalding et al. 2014; Webb et al. 2013). Finally, continued growth of rural LECZ population and GDP per capita will continue to put pressure on the remaining mangroves, as these factors have proven to be significant in past mangrove conversion (Barbier and Cox 2003). Overall across these 15 countries, rural LECZ population expanded by 18% and GDP per capita by 6% from 2000 to 2012.

Table 9. Mangrove Extent and Threats in Countries with the Largest Poor Rural LECZ Populations

Country	2012 Mangrove Forest Area (km2)	Mangrove Loss (%) 2000-2012	% of Coastal Wetlands Area Impacted	Growth (%) of Rural LECZ Population 2000-2010	Annual GDP per capita Growth (%) 2000-2012
India	797.8	3.3%	32.3%	20.5%	7.9%
Bangladesh	1,773.0	0.1%	24.3%	15.7%	5.9%
Myanmar	2,557.4	8.4%	50.2%	0.2%	..
Cambodia	323.2	4.5%	1.5%	12.0%	8.7%
Nigeria	2,654.0	0.1%	38.8%	35.8%	7.2%
Pakistan	11.7	0.3%	61.4%	22.9%	2.5%
Iraq	..	..	..	31.1%	1.7%
Mozambique	1,223.7	0.2%	47.1%	33.0%	6.4%
Senegal	155.3	0.0%	22.0%	22.6%	1.1%
Brazil	7,674.9	0.6%	11.5%	10.1%	2.5%
China	33.8	1.9%	39.8%	1.7%	16.5%
Indonesia	23,324.3	3.1%	27.0%	13.4%	5.0%
Philippines	2,064.2	1.3%	45.0%	25.0%	3.5%
Vietnam	708.2	1.1%	29.4%	11.3%	7.1%
Thailand	1,886.3	2.4%	14.7%	12.4%	4.5%
Total	**45,187.9**	**2.0%**	**31.8%**	**17.5%**	**5.7%**

Data on mangrove extent and loss is from Hamilton (2014) "Creation of a high spatiotemporal resolution database of continuous measures of global mangrove tree cover for the 21st Century (CGMFC-21): A big-data fusion approach." Available at https://docs.google.com/spreadsheets/d/1wy6uBL8XVXb7wbQ6bzkbZdxWVy50EMr6vmc5NB3z-5A/edit?usp=sharing. Total global mangrove extent in 2012 was 81,848.8 km^2; the above countries account for 55.2% of this total.

Data for % of coastal GDP, agricultural area and wetlands exposed to a 1 meter (m) sea-level rise accompanied by a 10% intensification of storm surges are from Dasgupta, S., Laplante, B., Murray, S. and Wheeler, D. 2009. "Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts in Developing Countries." Policy Research Working Paper 4901, the World Bank, Washington, D.C. April. Available at http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:22270368~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html

Data on GDP per capita is from the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

In sum, the 15 developing countries that account for more than 90% of the global rural LECZ populations in poverty are highly vulnerable to the future risks to coastal GDP, agriculture and wetlands from sea-level rise and storm surge intensification. In addition, these countries are generally low and lower middle-income economies, and have been experiencing rapid growth in their rural LECZ populations. For these populations, coastal and near-shore ecosystems, such as mangroves, are important natural barriers that provide protection against the increased hazardous events associated with climate change. Yet, not only are mangroves and other coastal ecosystems likely to be impacted by the risk of greater inundation and other hazards associated with climate change, they are also under pressure from population expansion and the coastal development accompanying increased economic growth.

5.   Climate Change Impacts on the Economic Livelihoods of the Rural Coastal Poor

For the rural poor living in LECZ, the climate change impacts on coastal agriculture and wetlands will adversely affect their economic livelihoods. Many rural coastal households depend on agriculture and fishing, which are highly susceptible to the disruptions and losses caused by sea-level rise and other coastal hazards, such as storm surges, coastal erosion and saltwater intrusion. Already, there is some evidence of what some of these impacts might entail for rural coastal populations.

Many poor households in rural coastal communities undertake a range of activities in order to cope financially and reduce the risks associated with high economic dependency on a single activity. In this regard, this coastal poor face similar constraints as the rural poor do generally in developing countries (Barbier 2010 and 2012). That is, the poorest rural households in developing economies have very few productive assets (Banerjeee and Duflo 2007). First, land is one of the few productive assets owned by the rural poor, and almost all households engage in some form of agriculture, but the size of landholdings tends to be very small. Second, poor rural households tend to rely on selling their only other asset, which is generally unskilled labor. Agriculture is generally not the mainstay of most these households; instead, they generally obtain most of their income from off-farm work as agricultural laborers or in unskilled paid work or occupations outside of agriculture. However, when households do engage in outside employment, they tend to migrate only temporarily and for short distances. Permanent migration over long distances for work is rare for most poor rural households (Banerjee and Duflo 2007). Thus, given the lack of ownership of assets by the rural poor, and their tendency to stay where they are located, it is not surprising that the livelihoods of the "assetless" poor are often the most dependent on their surrounding natural environments. In the case of coastal households, exploitation of marine and coastal resources – collection of products from local forests, such as mangroves, and small-scale fishing – seems to predominate.
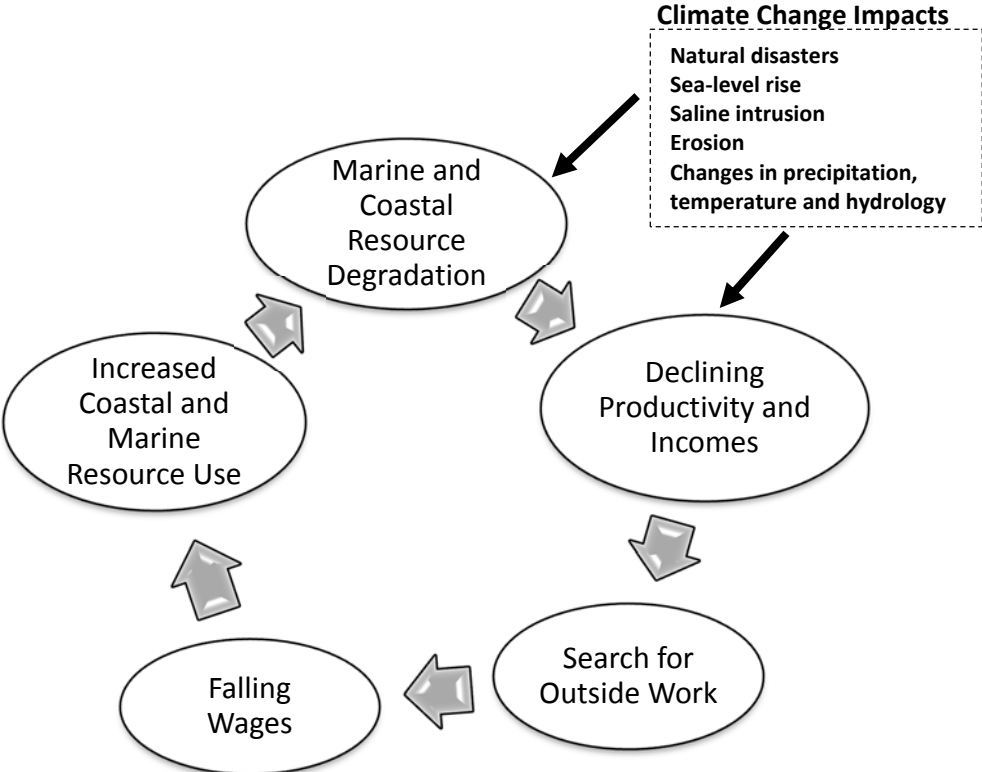
Surveys of poor rural coastal households confirm this diversified livelihood strategy. In Bangladesh, the most dominant primary occupation of households surveyed is fishing (34%), followed by agriculture (29%) and daily wage laborer (15%); however, more than half (52%) of the respondents do not own any farmland and 64% are illiterate (Paul and Routray 2011). In Tanzania and Zanzibar, 34% of coastal households identified fishing as their most important economic activity, and 38% responded farming/livestock keeping – but 73% identified both activities as important to their livelihoods (Tobey and Torell 2006). In Thailand, although only a few coastal households surveyed engage in agriculture, 31% reported having at least one male member undertaking outside work and 17% reported one female member (Barbier 2008). All the households engaged in some form of mangrove-dependent activity for their main livelihoods, such as offshore fishing or aquaculture (16%), 31% collected wood and other mangrove products (31%), and more than half (52%) engaged in both activities.

Marine fisheries, especially small-scale fisheries, are an importation source of nutrition, employment and income for many of the world's coastal and rural poor. For example, the small-scale fisheries sector is responsible for half of the catch in developing countries, employs 25-27 million full or part-time people in fishing, and another 68-70 million in post-harvest activities (World Bank 2008). Fishing households are some of the poorest in coastal areas, and for many other poor coastal households, fishing provides an important source of food and occasional income (Béné et al. 2010; Campbell et al. 2006; Mills et al. 2011; Kronen et al. 2012; Nayak et al. 2014; Solaymani and Kari 2014; World Bank 2008).

Because of their lack of assets, their dependence on exploiting marine and coastal resources, and their need for diversified sources of income, the rural coastal poor are susceptible to a *poverty-environment trap* that is commonly faced by rural poor households in less favored areas of developing countries (Barbier 2010 and 2012). Figure 3 illustrates the elements of the trap that can be a vicious cycle for poor households in rural coastal areas.

Increased use of coastal and marine resources, including available agricultural land, causes extensive degradation. The result is falling productivity and incomes for the households dependent on these resources. This leads to more people searching for available outside work to boost or supplement incomes. If there are large numbers of households seeking outside employment in coastal areas, the supply of labor for paid work could exceed demand. The market wage for hired labor will decline. For some households, the wage rate will fall to the level of the reservation wage or even lower, and these households would now forego outside employment opportunities and instead allocate all of their labor back to production activities dependent on coastal and marine resources. The danger for these households is that, if this process degenerates into a vicious cycle, then the dynamics of a poverty-environment trap may ensue (see Figure 3).

Figure 3. The Poverty-Environment Trap and Climate Change in Coastal Areas

Climate Change Impacts

Natural disasters
Sea-level rise
Saline intrusion
Erosion
Changes in precipitation,
temperature and hydrology

Marine and Coastal Resource Degradation

Declining Productivity and Incomes

Increased Coastal and Marine Resource Use

Search for Outside Work

Falling Wages

The rural coastal households susceptible to this poverty-environment trap are therefore highly vulnerable to the increase in coastal hazards induced by climate change, which either threaten directly their livelihoods or indirectly through impacting the key coastal and near-shore ecosystems on which their livelihoods depend. Two types of climate change impacts especially affect the poor: short-lived natural disasters with immediate and often extreme impacts, such as flooding and storm surge, and long-term climatic changes with more gradual impacts, such as sea-level rise, saline intrusion and erosion. These hazards either degrade the coastal and marine systems and resources on which households depend or inflict losses in income and productivity on the households (see Figure 3). Thus, climate change impacts can reinforce the poverty-environment trap faced poor coastal households, and for many others, tip them into the trap.

The rural poor in coastal areas are especially vulnerable to natural disaster shocks, such as hurricanes, tsunamis, floods and other extreme coastal events (Badola and Hussein 2005; Barbier 2008; Carter et al. 2007; Das and Vincent 2009; Laso Bayas et al. 2011; McSweeney 2005). In addition, the inadequate protection infrastructure in rural areas, such as storm shelters, seawalls and embankments, means that poor rural households are often reliant on "natural barriers", such as mangroves, for protection. For example, two studies based on the 1999 cyclone that struck Orissa, India found that mangroves significantly reduced the number of deaths as well as damages to property, livestock, agriculture, fisheries and other assets (Badola and Hussain 2005; Das and Vincent 2009). Statistical analysis indicates that there would have been 1.72 additional deaths per village within 10 km of the coast if the mangrove width along shorelines had been reduced to zero (Das and Vincent 2009). Losses incurred per household were greatest ($154) in a village that was protected by an embankment but had no mangroves compared to losses per household ($33) in a village protected only by mangrove forests (Badola and Hussain 2005). However, evidence from Thailand indicates that poor coastal households are less willing to participate in mangrove replanting schemes, even though they are aware of the storm protection benefits of mangroves, because of the high opportunity cost of their labor and lack of community control over the management of the restored mangroves (Barbier 2008). In many developing regions, poor households rely on natural resources not for protection against storms and other environmental shocks but as insurance and coping strategies for avoiding the income and subsistence losses associated with such disasters (Carter et al. 2007; McSweeney 2005).

Many areas of coastal Bangladesh are suffering from the effects of saltwater intrusion on agriculture (Dasgupta et al. 2014; Haque and Jahan 2013; Rabbani et al. 2013; Shameem et al. 2014). In the southwest coastal region of Bangladesh, saltwater intrusion into surface and ground water is already causing impacts on livelihoods, land holdings and land use change. In one study area, over a period of 10 years 70% of farmers partially or fully abandoned agriculture due to saline soil and either converted their fields to shrimp ponds or sold land to richer farmers. Nearly three-quarters of the households also gave up cattle raising, due to lack of animal feed in the area from saltwater intrusion impacts on fodder production (Shameen et al. 2014). In other

coastal areas, although all households involved in rice cultivation have been affected by salinity intrusion, the poor have been disproportionately impacted. In the aftermath of the saltwater intrusion caused by the 2009 Cyclone Aila, the loss incurred by the extreme poor was about 74% of their annual income from rice production, compared to 40-45% for the poor and non-poor households (Rabbani et al 2013). However, the non-poor recovered much faster than even the poor or extremely poor. By 2010, only 20% of the rice income of the non-poor households were affected, and by 2011 just 10%. In contrast, in 2010 52% of the income of the extremely poor was still impacted by salinity intrusion, and in 2011 28% of rice income was still affected.

Climate change may disrupt the fishing activities by poor coastal households in two principal ways. First, the changes in ocean temperature, acidity, freshwater inputs, circulation and stratification will cause physical changes in marine ecosystems that will alter the populations and community structures of many important commercial and subsistence fisheries (Brander 2010; Doney et al. 2012; Drinkwater et al. 2010; IPCC Working Group II 2014; Ottersen et al. 2010; Sumaila et al. 2011). The likely result will be changes in primary productivity, shifts in distribution and changes in the potential yield of many fisheries important to the livelihoods of coastal households (Brander 2010; Sumaila et al. 2011). Second, the disruptions in precipitation, temperature and hydrology accompanying climate change are also likely to impact coastal and near-shore ecosystems, such as wetlands, mangroves, coral and oyster reefs, and seagrass beds (Doney et al. 2012; Erwin 2009; IPCC Working Group II 2014; Spalding et al. 2014; Webb et al. 2013). These habitats are important for supporting fisheries, which would be adversely affected by the loss and degradation of such vital marine ecosystems (Barbier et al. 2011). Mangroves are especially valuable coastal habitats that support marine fisheries in developing countries (Hutchison et al. 2014).

At the same time, fisheries in developing countries and the marine systems supporting them are under extreme pressure from over-exploitation and habitat degradation. There is evidence that the stresses on fisheries from human exploitation are reducing their capacity to withstand climate variability and change (Planque et al. 2010). Due to coastal development, population growth, pollution and other human activities, 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses have already been lost or degraded worldwide (Barbier et al. 2011; Doney et al. 2012). As much as 89% of oyster reefs may also have been lost globally (Beck et al. 2011).

As indicated in Table 10, the 15 countries with the largest poor rural LECZ populations have fisheries that are highly vulnerable to climate change. These economies are also experiencing mangrove loss, and their coastal wetlands are likely to be impacted by sea-level rise and associated storm intensification. The fisheries for almost all of the 15 countries in Table 10 display high or moderate vulnerability to climate change impacts. The only exceptions are the Philippines and Thailand, which show low vulnerability. Given that fishing is likely to be an important economic livelihood for the many rural LECZ poor in these countries, its vulnerability to climate change is of great concern.

Table 10. Climate Change Vulnerability of Fisheries and Coastal Habitats in Countries with the Largest Poor Rural LECZ Populations

Country	Mangrove Loss (%) 2000-2012	% of Coastal Wetlands Area Impacted	Vulnerability to Climate Change Impacts on Fisheries
India	3.3%	32.3%	Moderate
Bangladesh	0.1%	24.3%	High
Myanmar	8.4%	50.2%	..
Cambodia	4.5%	1.5%	High
Nigeria	0.1%	38.8%	High
Pakistan	0.3%	61.4%	High
Iraq	..	..	..
Mozambique	0.2%	47.1%	High
Senegal	0.0%	22.0%	High
Brazil	0.6%	11.5%	Moderate
China	1.9%	39.8%	Moderate
Indonesia	3.1%	27.0%	Moderate
Philippines	1.3%	45.0%	Low
Vietnam	1.1%	29.4%	High
Thailand	2.4%	14.7%	Low
Total	**2.0%**	**31.8%**	

Data on mangrove extent and loss is from Hamilton (2014) "Creation of a high spatiotemporal resolution database of continuous measures of global mangrove tree cover for the 21st Century (CGMFC-21): A big-data fusion approach." Available at https://docs.google.com/spreadsheets/d/1wy6uBL8XVXb7wbQ6bzkbZdxWVy50EMr6vmc5NB3z-5A/edit?usp=sharing. Total global mangrove extent in 2012 was 81,848.8 km^2; the above countries account for 55.2% of this total.

Data for % of coastal GDP, agricultural area and wetlands exposed to a 1 meter (m) sea-level rise accompanied by a 10% intensification of storm surges are from Dasgupta, S., Laplante, B., Murray, S. and Wheeler, D. 2009. "Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts in Developing Countries." Policy Research Working Paper 4901, the World Bank, Washington, D.C. April. Available at http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:22270368~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html

Data on vulnerability of fisheries from Allison, E.H., Perry, A.L., Badjeck, M-C., Adger, W.N., Brown, K., Conway, D., Halls, A.S., Pilling, G.M., Reynolds, J.D., Andrew, N.L. and Dulvy, N.K. 2009. "Vulnerability of national economies to the impacts of climate change on fisheries." *Fish and Fisheries* 10:173-196. For the 132 countries, "high" is for the upper quartile (highest vulnerability), "moderate" for the second quartile, "low" for the third quartile, and "very low" for the bottom quartile.

Coral reef fisheries are especially important to the economic livelihoods of the rural coastal poor in many developing countries, yet these reef fisheries are threatened by both overexploitation and climate change impacts, such as temperature changes, ocean acidification and coral bleaching (Badjeck et al. 2010; Cinner et al. 2012; Doney et al. 2012; Planque et al. 2010; Sumalia et al. 2011). For example, Cinner et al. (2012) examine the vulnerability of 29 coastal communities to the impacts of coral bleaching on fishery returns across five western Indian Ocean countries – Kenya, Madagascar, Mauritius, the Seychelles and Tanzania. They found vulnerability to vary considerably both within and among countries. Across countries, Kenya was the most vulnerable, followed by Tanzania, Madagascar, Seychelles, and Mauritius. At the site level, Sahamalaza in Madagascar had the highest vulnerability, but seven of the ten most vulnerable sites were from Kenya. Some sites in Madagascar also had the lowest vulnerability. Given that coral reef vulnerability to climate change is highly variable, appropriate policy and adaptive responses must be not only country but location-specific.

Coastal and near-shore habitats such as wetlands, mangroves, coral and oyster reefs, and seagrasses, not only benefit the coastal rural poor by supporting fishing or protecting agriculture through buffering coastlines from erosion and saltwater intrusion, but also protect against storm surge and other coastal hazards, provide raw materials, food and forage, and filter sediment and pollutants (Barbier et al. 2011; Doney et al. 2012; Erwin 2009; Spalding et al. 2014; Wilkinson and Salvat 2012). These benefits, as well as the cultural value of these marine ecosystems, can be significant to poor coastal households.

For example, estimates from Thailand suggest that the net present value (in 1996 $) over 1996-2004 arising from the net income to local communities from collected forest products from coastal mangroves range from $484 to $584 per hectare (ha). The net present value of mangroves as breeding and nursery habitat in support of off-shore artisanal fisheries ranged from $708 to $987 per ha, and the storm protection service was $8,966 to $10,821 per ha (Barbier 2007). Such benefits are considerable when compared to the average incomes of coastal households; a survey of four mangrove-dependent communities in two different coastal provinces of Thailand indicates that the average household income per village ranged from $2,606 to $6,623 per annum, and the overall incidence of poverty (corresponding to an annual income of $180 or lower) in all but three villages exceeded the average incidence rate of 8% found across all rural areas of Thailand (Sarntisart and Sathirathai 2004). The authors also found that excluding the income from collecting mangrove forest products would have raised the incidence of poverty to 55.3% and 48.1% in two of the villages, and to 20.7% and 13.64% in the other two communities.

The Thailand example is not unusual; poor households across the developing world typically benefit from a wide range of protection and support of their economic livelihoods from mangroves (Badola and Hussain 2005; Bandaranayake 1998; Barbier et al. 2011; Das and

Vincent 2009; Laso-Bayas et al. 2011; Naylor and Drew 1998; Nfotabong Atheull et al. 2009; Rönnbäck, et al. 2007; UNEP 2014a; Walters et al. 2008; Walton et al. 2006). However, there is also evidence that coastal people hold important cultural values associated with mangroves. A contingent valuation study of mangrove-dependent coastal communities in Micronesia demonstrated that the communities "place some value on the existence and ecosystem functions of mangroves over and above the value of mangroves' marketable products" (Naylor and Drew 1998, p. 488).

In addition to supporting near-shore fisheries harvested by poor coastal communities, coral reefs also provide valuable shoreline protection against storms. For example, Cesar (2000) estimates the losses, in net present value per square kilometer (km^2), in terms of support for near-shore artisanal fisheries and coastal protection from the destruction of coral reefs in Indonesia. The main threats to coral reefs are from poison fishing, blast fishing, coral mining, sedimentation from logging onshore and overfishing. Together, these threats account for present value losses in coastal fisheries of around $0.41 million per km^2 of coral reef destroyed, and present value losses in coastal protection of $0.011 to $0.453 million per km^2 of coral reef destroyed. Evidence from Kenya indicates that coral reefs may also be critical to larval dispersal to fishing areas, which could affect the effectiveness of marine reserves and closed fishing grounds in inducing stock recovery and thus eventual re-opening to fishing (Rodwell et al. 2003). Coral reefs also have important cultural and non-use value to neighboring coastal communities; many cultural and religious traditions have evolved in tropical coastal zones that honor the dependence of local communities on adjacent reefs and reflect the "bequest value" of preserving this way of life into the future (Moberg and Folke 1999). Studies from other regions show that these coral reef fishery, protection and cultural benefits are significant for many poor coastal rural communities (Badjeck et al. 2012; Barbier et al. 2011; Campbell et al. 2006; Moberg and Folke 1999; van Zanten et al. 2014; White et al. 2000; Zeller et al. 2007).

6. Conclusion

Recent studies indicate that a handful of developing countries contain most of the urban low-elevation coastal zone (LECZ) populations at high risk from the hazards of climate change; for example, 10 cities in developing countries will account for 67% of the future coastal population exposure to the risks from sea-level rise and storm surge (Brecht et al. 2012). This study finds that the global distribution of rural LECZ poverty is also concentrated; in 2000, just 15 developing countries contained more than 90% of the world's LECZ rural poor.

In addition, rural LECZ poverty is distinguishable by income level. Low-income countries have the highest incidence of poverty among their LECZ rural populations, which declines somewhat for lower-middle-income countries, and then is much lower for upper-middle-income economies. South Asia, East Asia and the Pacific and Sub-Saharan Africa

account for most of the world's LECZ rural poor, and have a high incidence of poverty among their rural LECZ populations.

The 15 developing countries that account for over 90% of the global rural LECZ poor are highly vulnerable to the future risks to coastal GDP, agriculture and wetlands from sea-level rise and storm surge intensification.   These countries are generally low- and lower-middle-income economies, and have been experiencing rapid growth in their rural LECZ populations.   Many of the coastal rural poor depend on agriculture and fishing, which are at risk from the disruptions and losses caused by sea-level rise and other coastal hazards, such as storm surges, coastal erosion and saltwater intrusion. Coastal and near-shore habitats such as wetlands, mangroves, coral and oyster reefs, and seagrasses, not only benefit the coastal rural poor by supporting fishing or protecting agriculture through buffering coastlines from erosion and saltwater intrusion, but also protect against storm surge and other coastal hazards, provide raw materials, food and forage, and filter sediment and pollutants. But these ecosystems are also vulnerable to greater inundation and other hazards associated with climate change, while simultaneously under pressure from population expansion and the coastal development accompanying increased economic growth in developing countries.

Consequently, the rural poor in LECZ are exposed to both the risks of climate change and the ongoing losses associated with marine and coastal resource degradation. As indicated in Figure 3, these risks are self-reinforcing. Climate change impacts could easily push many more rural LECZ populations into a poverty-environment trap.

Because of the high incidence of rural LECZ poverty among low-income countries, fostering economic growth, especially in coastal areas, may be one of the most effective ways over the long-term in reducing the vulnerability of the LECZ rural poor to the impacts of climate change. However, growth alone may be necessary but not sufficient to address this problem. As discussed in this paper, the persistent threat of a poverty-environment trap faced by many coastal rural households leaves them vulnerable to the short and long-term risks posed by climate change (see Figure 3). In short, to address problem of rural LECZ with extensive poverty may require policy measures in addition to promoting growth in these coastal areas.

First, there is strong evidence that the persistence of rural poverty in developing countries, including in coastal regions, needs to be addressed by more location-specific targeting of these disadvantaged populations (Barbier 2012; Badjeck et al. 2010; Campbell et al. 2006; Cinner et al. 2012). For example, actions that can be targeted to specific coastal communities and LECZ regions include improved information about weather events and early-warning systems, evacuations from highly vulnerable areas, development of social safety nets, and diversification within coastal livelihoods, such as agriculture and fishing. Further actions include strengthening community groups responsible for managing coastal resources, improvements in coastal infrastructure, and policies and investments to encourage the most vulnerable migrate to non-coastal areas. Over the long term, actions targeted to specific coastal communities and

LECZ include livelihood diversification out of fishing, agriculture and other coastal resource-based activities, investments in health and education, and broader investments in local governance and institutions.

Second, although the poverty-reducing effects of increasing GDP per capita are important, economic growth and the expansion of populations and economic activity in coastal areas have been associated with the loss or degradation of important habitats, such as mangroves, marsh, coral reefs, oyster reefs, seagrass beds and barrier islands (Barbier and Cox 2002; Barbier et al. 2011; Beck et al. 2011; Lotze et al. 2006; Wilkinson and Salvat 2012; Worm et al. 2006). In addition, the disruptions in precipitation, temperature and hydrology accompanying climate change are likely to threaten remaining coastal and near-shore ecosystems (Dasgupta et al. 2011; Doney et al. 2012; Erwin 2009; IPCC Working Group II 2014; Spalding et al. 2014; Webb et al. 2013). Finally, coastal GDP itself will be heavily impacted by future sea-level rise and any accompanying storm surge intensification (Dasgupta et al. 2011). For example, as this study has shown, the 15 developing countries that account for more than 90% of the global rural LECZ poor are highly vulnerable to the future risks to coastal GDP and wetlands (see Table 8). This suggests that specific measures need to be taken, beyond promoting economic growth, both to protect the rural LECZ poor and to conserve and restore key coastal and near-shore ecosystems.

A global strategy for protecting coastal populations, especially the vulnerable rural poor in LECZ, should have two objectives: (i) protecting coastlines and populations from risks posed by damaging storms and (ii) restoring valuable coastal systems - such as salt marshes, oyster and coral reefs, mangroves, seagrass beds, and beaches - that act as natural barriers (Barbier 2014; IPCC Working Group II 2014; Erwin 2009; Gedan et al. 2011; Spalding et al. 2014; Temmerman et al. 2013). Comprehensive plans to reduce coastal vulnerability should also include key infrastructure investments - such as seawalls, dikes, barrages, and diversions – and improved institutional and coastal community response capability. For example, studies of the current capacity, infrastructure and coping strategies of communities in coastal Bangladesh reveal that they are inadequate to deal with the likely increase in coastal cyclone and storm surge hazards associated with climate change (Dasgupta et al. 2010; Paul and Routray 2011). Although the estimated additional investment necessary to cope with these hazards in Bangladesh is around $2.4 billion with an annual recurrent cost of $50 million, these costs are likely to be half of the additional financial costs of future damages, deaths and injuries from the increased hazards associated with climate change (Dasgupta et al. 2010). As this study has identified 15 developing countries that contain almost all of the global rural LECZ poor, these countries should be the priority for such a strategy to protect these vulnerable populations – although all developing countries with significant shares of their rural poor in LECZ should also be included in this strategy.

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Appendix. Geospatial Methods Used to Estimate Poverty among Coastal and Low Elevation Coastal Zone Populations[4]

The analysis of poverty among coastal and low elevation coastal zone (LECZ) populations in 2000 employed a variety of global spatially referenced data sets.

The **Coastlines, v1 (2000)** dataset was used to identify national coastlines:

> *Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Coastlines. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4CR5R8J. Accessed 15 10 2014.*

Populations within 100km of those coastlines and in non-landlocked countries were identified as "coastal" using population data from **GRUMPv1**

> *Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Population Count Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4VT1Q1H. Accessed 15 10 2014.*

Populations that are within 100km of a coastline but in a landlocked country were not considered coastal. Those countries without populations within 100km of a coastline are also denoted as "non-coastal". The use of a 100 km buffer is a threshold standard in the literature to identify coastal areas.[5] This buffer was calculated using an Azimuthal Equidistant (world) projection.

Urban coastal populations are those within the GRUMPv1 **Urban extents grid:**

> *Center for International Earth Science Information Network - CIESIN - Columbia University, International Food Policy Research Institute - IFPRI, The World Bank, and Centro Internacional de Agricultura Tropical - CIAT. 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4GH9FVG. Accessed 15 10 2014.*

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[4] I am grateful to Jacob P. Hochard for technical assistance i+ conducting this spatial analysis of poverty among coastal and low elevation coastal zone populations.

[5] See, for example,
http://www.un.org/esa/sustdev/natlinfo/indicators/methodology_sheets/oceans_seas_coasts/pop_coastal_areas.pdf.

Rural populations are therefore defined as those that are non-urban.

Impoverished populations were identified using geo-spatially referenced malnutrition and infant mortality data. Malnutrition rate data are from:

> *Center for International Earth Science Information Network - CIESIN - Columbia University. 2005. Poverty Mapping Project: Global Subnational Prevalence of Child Malnutrition. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4K64G12. Accessed 15 10 2014.*

Infant mortality data are from:

> *Center for International Earth Science Information Network - CIESIN - Columbia University. 2005. Poverty Mapping Project: Global Subnational Infant Mortality Rates. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4PZ56R2. Accessed 15 10 2014.*

High infant mortality is designated as 50 or more deaths within the first year of life per 1,000 births (or 500 deaths/10,000 live births consistent with the CIESIN gridded data set). This designation is similar to thresholds used to define poverty in other studies that have used the CIESN 2000 infant mortality gridded data set (de Sherbinin 2008).

Child malnutrition counts are the product of malnutrition rates and population counts. Malnutrition rates are based on the percentage of children with a weight-for-age z-score more than two standard deviations below the median of the NCHS/CDC/WHO International Reference Population. This designation is similar to other studies that have used the CIESN 2000 child malnutrition data set (de Shrebinin 2011; Turner et al. 2012).

Poverty masks and the urban extent were resampled using the nearest technique and snapped to the higher-resolution coastal population dataset. Based on the infant mortality rate metadata, countries with incomplete data have geo-referenced data for some but not all subnational administrative units. Calculations rely upon partial data when it is available. Countries without any geo-referenced data are excluded. Based on the malnutrition metadata, countries without a documented source for hunger data are also excluded.

The resulting estimates of the share (%) of total, urban and rural coastal populations with high infant mortality and child malnutrition by country in 2000 were then applied to the estimates of these low elevation coastal zone (LECZ) populations by country in 2000. The LECZ is the contiguous area along the coast that is less than 10 meters above sea level, and estimates of the LECZ total, urban and rural populations in 2000 by country are from:

Center for International Earth Science Information Network (CIESIN)/Columbia University. 2013. Urban-Rural Population and Land Area Estimates Version 2. Palisades, NY: NASA

Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/lecz-urban-rural-population-land-area-estimates-v2.

The population and land area estimates for coastal populations in this data set are subdivided by elevation zone as derived from Shuttle Radar Topographic Mission (SRTM) elevation data at ~90m (3 arc seconds) resolution.