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When all was said and done, we learned that the impact of a rising sea on the shores of America is as wide-ranging and complex as are the shores themselves. And we discovered that the views of people living near the shore are also wide-ranging, spanning from doubters to believers and from let's-wait-and-see types to let's-do-something-about-it types.

The whole exercise of writing this book was an extraordinary adventure in nature on a very large scale. We watched from afar the interactions of the oceans versus the lands. We watched the huge mass of the oceans expanding, reflecting both a warming atmosphere and the melting of Earth's massive ice sheets. We learned that scientific opinion varies quite a bit also. Very few scientists doubt the validity of global climate change, but there is a wide range of viewpoints on the direction and magnitude of the earth's changes. For example, in the all-important estimate of sea level rise by the year 2100, estimates from credible scientists range from 1 foot to a rather wild 10 feet. And we became convinced that great changes are coming to America because of sea level rise, including the loss of two major cities, Miami and New Orleans.

We relied heavily on the research and the intuition of many scientists. Owen Mason, an expert on the ways of the Arctic coast, introduced us to Shishmaref and Kivalina, Alaska, and the serious problems they face in a rising sea. We gained particular understanding of the problems during two trips to these villages in the Arctic winter. Denali Commission Federal Co-chair Joel Neimeyer helped us understand the politics of the American Arctic. Stan Riggs led us on an Inner Banks, North Carolina, field trip, educating us on how roads raised to prevent flooding can exac-

erbate flooding. They do so by acting as dams during storm surges. University of Miami geologist Hal Wanless, with his constant pounding of the table about the dismal future of a flooding Miami and South Florida, was an inspiration for us because he continues to sound the alarm even though he's not widely appreciated. Al Hine and Tonya Clayton are from the state that will be most impacted by sea level rise, and they helped us understand Florida's situation. Geologist Alex Glass kept us abreast of the deteriorating condition of the world's ice sheets and Peter Haff helped keep us abreast of the exponentially expanding literature on sea level rise and provided us with references, ideas, and inspiration that opened new, adventurous avenues of thinking. Daughter/sister Diane Pilkey, a senior nurse consultant, helped us with the health chapter, the subject in which we were least competent. Geologist Bill Neal told us about the similarity of the fate of Newfoundland's small villages and the apparent future of small coastal villages in Alaska.

Whenever we pushed the wrong button on our computers, ever-helpful Andy Minnis and Katheryne Doughty, IT experts, saved us. Without going into all the details, there were many others who helped us. Among them were scientists Joe Kelley, Andrew Cooper, Duncan Heron, Andy Coburn, and Rob Young. Fred Dodson and Marcia Tuttle provided ideas and timely edits from the standpoint of ones who know relatively little about the topic.

Geological technician and able research assistant Norma Longo carried out many hours of media research on a number of topics and provided proofing, editing, and just about everything else leading to the production of the manuscript and getting it to the press. We are very grateful for her unwavering support and patience. We are also very grateful for the assistance of our editor, Gisela Fosado, and editorial associate, Alejandra Mejia, and the staff at Duke University Press for their guidance and assistance in completing this book.

We also want to express our gratitude to Claire Le Guern Lytle, who maintains and monitors the website Coastalcare.org, a gold mine of global coastal information from which we obtained photos and ideas for this book. The website is sponsored by our friends Olaf and Eva Guerrand-Hermes through the Santa Aguila Foundation, a nonprofit foundation dedicated to defending the beaches and shorelines of our delicate planet.

We are most grateful for the foundation's support of our recent books, including *The World's Beaches*, *Global Climate Change*, *The Last Beach*, *Lessons from the Sand*, *The Magic Dolphin*, and *Retreat from a Rising Sea*.

Financial support for the production of the book came from North Carolina state representative Pricey Harrison and from the Duke University Nicholas School of the Environment.

· PROLOGUE ·

When a tsunami strikes a developed shoreline, the damage can be severe and instantaneous. When the sea level rises, the damage will also be severe but will occur slowly, over a period of years and decades. There are some other obvious differences. Sea level rise is not caused by earthquakes or volcanoes and will not readily subside but will continue for decades and centuries, perhaps millennia. And unlike the relatively regionalized impact of tsunamis, sea level rise will impact all the world's ocean shorelines. To emphasize the threat to our coast, we've chosen to describe sea level rise as a slow-motion tsunami.

The rising sea may be the first truly worldwide catastrophe caused by global climate change. It will impact all seven continents and all the world's coastal cities from Los Angeles to New York, Rotterdam, Lagos, Mumbai, Shanghai, Tokyo, Honolulu, and many others. A few, like Miami and New Orleans, will disappear, as their geographical features guarantee that they ultimately cannot be defended against the rising waters.

Since all the world's port facilities are at the same elevation, the world's economy will be impacted as docks, warehouses, and freight yards the world over will need to be raised—a process that must be repeated for centuries to come as the waters continue to rise due to the melting of the world's land-based ice. Oceanside tourist facilities will require reconstruction, raising up, moving, and in most cases, ultimately, abandonment. Finally, many millions of people will become refugees fleeing from the rising sea, perhaps within this century. We refer to these throughout the book as *climate refugees* because the storms and the sea level rise that are forcing the exodus from low-lying coastal regions are affected by global climate change.

In this book, we do not concern ourselves with the mechanics and causes of global sea level rise. It's already under way. Instead, we start with the assumption that the scientific consensus concerning the magnitude of the sea level rise, with all of its pluses or minuses, is correct. We emphasize the impact of sea level rise in America only.

We accept that a 3-foot sea level rise by the year 2100 is a good possibility in the context of our current understanding of all the processes that are raising sea level. It is a certainty that the magnitude and direction of these processes (melting ice and expanding oceans) will change in coming decades. Most likely that change will lead to an increase in the rate of sea level rise. The current minimum expected sea level rise by 2100 is around 1 foot, and the maximum is 6 feet. Field observations indicate that increasing instability of the Greenland and Antarctic ice sheets has led to the prediction by some that it is possible but unlikely that sea level will rise by 10 feet by the century's end. The instability of the West Antarctic Ice Sheet was demonstrated in an extraordinary article published in the June 13, 2018, issue of *Nature*. The article, authored by 84 scientists from 44 institutions located in 14 countries, using data from 15 satellites plus field observations, concluded that the rate of melting of Antarctic ice has tripled since 2012. Of particular concern is the massive Thwaites Glacier, which appears to be destabilizing.

Late 2018 brought a flurry of conference results and studies, each strongly supporting the proposition that response to global climate change, including sea level rise, is critical and needs immediate action. Most important of these responses is the reduction of carbon dioxide emissions.

- On October 6, 2018, the United Nations Intergovernmental Panel on Climate Change (IPCC) released a stunning report, three years in the making. The panel suggested that global warming is on track, to a critical 1.5 degrees Celsius (2.7 degrees Fahrenheit) above preindustrial level temperatures. Within 30 years, global problems with drought, floods, fires, sea level rise, and massive migration will likely reach critical stages if this degree of temperature rise occurs.
- On November 20, 2018, the World Meteorological Congress reported that atmospheric concentrations of carbon dioxide reached a new high of 405.5 parts per million in 2017.

- On Black Friday in November 2018, the federal government released the fourth National Climate Assessment. The document was produced by 13 separate agencies and emphasizes "The United States is already suffering economic and public health damages from climate change-fueled wild fires, heat waves and floods and these damages will get worse if we don't take bold action to address it."
- On December 3, 2018, the National Oceanic and Atmospheric Agency issued the annual Arctic Report Card and noted the Arctic is warming at twice the rate of the rest of the globe.
- On December 5, 2018, the Global Carbon Project reported that global carbon dioxide emissions reached an all-time high in 2018. It is widely accepted that human-produced carbon dioxide underlies global climate change.
- On December 11, 2018, UN climate talks in Poland reinforced the Paris Climate Agreement. The U.S. representatives argued unapologetically that a "rapid retreat" from fossil fuel use was unrealistic because of potential damage to the economy, a position ignoring the catastrophic damage we face from climate change.

At about the same time, in an extraordinary development, the editorial boards of the *Florida Sun Sentinel*, the *Miami Herald*, and the *Palm Beach Post* have joined forces to raise awareness in South Florida about the huge threat that region faces from sea level rise—more than in any other state.

The Magnitude of the American Problem

For the sake of convenience, we focus on what could be expected from sea level rise up to 2100. *But it is very important to recognize that we are actually dealing with a 400-year (and more) problem*. Sea level rise is occurring because of warming and expanding ocean waters and the melting giant ice sheets add to the volume of ocean waters. The warming is caused mainly by the heat-trapping effect of greenhouse gasses, such as carbon dioxide (the main one) and methane. Humans are largely responsible for the increasing greenhouse gasses in the atmosphere through emissions from the burning of fossil fuels (coal, natural gas, and oil). The gasses trapped

TABLE P.1 The Length of American Shorelines

	Ocean shoreline miles	Tidal shoreline miles
American shorelines	12,400	88,600
The Lower 48	4,993	53,677
East Coast	2,069	28,673
Gulf Coast	1,631	17,141
Pacific Coast w/o Alaska	1,293	7,863
Alaska—Arctic and Pacific	6,640	33,904
Hawaii	750	1,052
Florida, both sides	1,350	8,426
Puerto Rico	311	700
Virgin Islands	117	175

SOURCE: National Oceanic and Atmospheric Administration (NOAA).

in the atmosphere today will cause melting of ice and rising of seas for centuries to come.

As is apparent in table P.1, the United States has plenty of shoreline that will be impacted by sea level rise. This country has 12,400 miles of shoreline facing the open ocean. Including bays, lagoons, and estuaries, the total number of miles of American shoreline affected by ocean tides comes to more than 88,600 miles.

Much of the 88,600 miles of American shoreline is developed to one degree or another—development that ranges from farms to small native Alaskan villages to major cities to miles and miles of beach cottage–lined shores to many miles of long rows of massive high-rise condominiums and hotels. The impacts along these miles of shoreline will be immense because of the expected long-term sea level rise.

Recently, Silicon Valley startups (e.g., Jupiter and Coastal Risk Consulting) have come on the scene, with plans to predict the risks that businesses and communities may face over coming decades from heavy rains, sea level rise, storm surges, and other climate change-related threats. A company called FM Global does the same for insurance companies. Some academic institutions, such as Western Carolina University, with its Program for the Study of Developed Shorelines, are entering the community

risk-analysis business. The success of the commercial entities remains to be seen, but their establishment reflects the growing public recognition of the threats from and the reality of global climate change.

Of course, the coastal risk hazards are not evenly distributed around our coasts. A 2017 research report by Climate Central listed the top 25 cities in the United States and their populations at risk of flooding within the Federal Emergency Management Agency's (FEMA) 100-year coastal floodplain. New York City has by far the largest population at risk (426,000). The extraordinary risk of Florida communities to flooding and sea level rise is indicated by the fact that out of the top 25 communities, only 5 are not in Florida (New York, Charleston, Virginia Beach, Norfolk, and Boston).

It is essential that Americans have a good grasp of what sea level rise has in store for us along our shorelines—politically, environmentally, and economically. We conclude that we are left with two choices. We can respond to sea level rise now in a peaceful, organized way, or we can respond later in crisis mode in reaction to flooding and storm disasters. If we plan now, we will save future generations from visiting shorelines with no beaches along a coast littered with rubble from destroyed seawalls, roads, and building foundations, looking like a battleground where the battle was lost.

. . .

This is the third book on sea level rise that Orrin Pilkey, the senior author, has written, with two of the three co-authored by Keith Pilkey. An earlier one (*The Rising Sea*, with coauthor Rob Young) was concerned with the mechanics of sea level rise, global warming skeptics, and the global impact. *Retreat from a Rising Sea*, by three Pilkeys (Orrin, Keith, and Linda), covers all aspects of sea level rise and the necessary retreat from the shore. The present book is concerned primarily with the impact of sea level rise on American shores.

· THE RISING SEA ·

Can't you see the climates changing?
Mother Earth is rearranging.

A rising sea laps at my feet
Prairies scorched by soaring heat

Shriveled crops cry out from thirst
Some say we ain't seen the worst

Critics claim it's nature's way
Man's impact has played no sway

Seas may swell and glaciers melt
Before the full effects are felt

Cities drown, shorelines retreat
Streams disappear in sweltering heat

Mother Earth cries in despair
Why don't people really care?

Skeptics claim it's all a myth
Wallowing in apathy and ignorant bliss

Denying facts, it's just a hoax
To calm the fears that truth evokes

But let's unite and take a stand
To face the facts and save the land

If not, what will the children say?
A generation or two away?

Will they cry out in despair?
Why didn't people really care?

—Ronald D. Perkins