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Drowned Lands

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Introduction

"Drowned Lands" captures the stark and sobering reality faced by low-lying areas across the globe as they confront the relentless advance of rising seas. Through the lens of climate science, geography, and human experience, this book seeks to illuminate the ongoing transformations wrought by global sea level rise—a phenomenon largely driven by thermal expansion of the oceans and the melting of polar ice. Since industrialization began, the rise in global average temperature has set in motion changes that, while gradual to start, have accelerated with forceful momentum, threatening to irreversibly reshape coastlines, displace populations, and challenge the very definition of habitable land.

Low-lying coastal regions, river deltas, and small islands are on the front lines, bearing the environmental brunt of submergence, intensified erosion, habitat loss, and the creeping inundation of saltwater into freshwater resources. For many, the first signs are slow and subtle: salt-killed fields, dying mangroves, or more frequent tidal flooding in streets and homes. In time, these forewarnings become existential—swallowing up farmland, infrastructure, and the cultural heartbeats of communities.

The economic costs of rising seas are nothing short of daunting. Damaged roads, eroding property values, contaminated water supplies, lost fisheries, and battered tourism economies all threaten the security of millions. The struggle is not merely financial, but deeply social. As livelihoods vanish, people are forced to choose between abandoning ancestral lands or enduring increasingly hazardous conditions. The prospect of mass migration—whether in pursuit of safer ground or economic opportunity—raises questions about fairness, preparedness, and the social contract that binds communities together.

Overlaying these tangible damages are profound cultural and psychological consequences. Entire ways of life, identities rooted in place, and historical treasures are at risk of being washed away—sometimes literally, as historic sites succumb to the waves, and sometimes figuratively, as collective memory and intangible heritage are disrupted by displacement. These losses diminish not only those directly affected, but all humanity, whose history and diversity are embedded in the world's rivers, coastlines, and islands.

Yet, amidst this daunting reality, there are emerging stories of adaptation and resilience. Governments, scientists, local leaders, and everyday citizens are confronting the threat head-on, experimenting with new forms of engineering, policy, and, crucially, working with the rhythms of the natural world rather than against them. From managed retreat to ecosystem-based adaptation, from innovative land-use

planning to global commitments on emissions, the response to sea level rise is as complex and varied as the threat itself.

This book sets out to chart both the devastation and determination found along the world's vulnerable coasts. Drawing from scientific research, on-the-ground reporting, and case studies from every continent, "Drowned Lands" aims to move beyond abstractions—to give voice to the places and people at the water's edge, to examine the real costs being paid today, and to consider what meaningful action looks like if we are to shape a more secure, equitable, and resilient future for all in the face of the rising seas.

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CHAPTER ONE: The Science of Rising Seas: Causes and Trends

To comprehend the profound transformations unfolding along our coastlines, we must first journey into the fundamental science driving sea level rise. It's not simply a matter of the ocean getting "fuller"; rather, it's a complex interplay of physics and geology, amplified by human activity. Think of it as a grand, slow-motion experiment unfolding across the planet, with the oceans as our primary beaker. This chapter will delve into the primary culprits behind this phenomenon, tracing the intricate pathways through which a warming planet translates into higher water marks.

At its core, global sea level rise is predominantly driven by two main factors: the thermal expansion of ocean water and the melting of land-based ice. While seemingly straightforward, each of these mechanisms harbors its own nuances and contributions to the overall trend. Understanding them is crucial for grasping the scale of the challenge we face.

Let's start with thermal expansion, a concept familiar to anyone who's ever seen a thermometer rise. Just as most materials expand when heated, so too does water. The oceans, vast reservoirs covering over 70% of our planet's surface, have been absorbing a tremendous amount of the excess heat trapped by greenhouse gases in the atmosphere. This absorbed heat causes the water molecules to move more vigorously, spreading further apart and occupying a slightly larger volume. While the expansion of a single water molecule is minuscule, multiply that across the entire global ocean, particularly its upper layers, and you have a significant contribution to rising sea levels.

Imagine trying to measure this expansion in a bathtub; it would be imperceptible. But on an oceanic scale, over decades and centuries, this seemingly minor change adds up. The deeper layers of the ocean warm more slowly, but even small temperature increases at depth contribute substantially to the overall volume increase. This process is not uniform across the globe; ocean currents, regional warming patterns, and even variations in salinity can influence how and where this thermal expansion manifests, leading to regional differences in sea level rise.

The second major driver, the melting of land-based ice, might seem more intuitive. When ice melts, it turns into water, and if that ice was previously resting on land, the resulting meltwater flows into the ocean, adding to its volume. The key here is "land-based ice." Sea ice, such as the ice floating in the Arctic Ocean, does not significantly contribute to sea level rise when it melts, much like ice cubes melting in a glass of

water don't cause the water to overflow. The volume it displaces as ice is roughly equal to the volume it occupies as liquid water.

However, the Earth's two largest ice sheets—Greenland and Antarctica—along with countless glaciers scattered across mountain ranges worldwide, are entirely land-based. These colossal frozen reservoirs hold enough water to dramatically alter our coastlines if they were to fully melt. The sheer scale of these ice sheets is difficult to comprehend. The Greenland ice sheet, for instance, covers an area roughly three times the size of Texas. The Antarctic ice sheet is even larger, encompassing nearly 14 million square kilometers.

The melting of glaciers and ice caps, while smaller in comparison to the great ice sheets, has been a consistent and significant contributor to sea level rise throughout the 20th and early 21st centuries. These glaciers, often found in high-altitude regions, are particularly sensitive to even slight increases in air temperature. As temperatures climb, the rate of melt exceeds the rate of snowfall, leading to a net loss of ice and a steady trickle of water into the oceans. The retreat of these glaciers is not just a scientific curiosity; it's a visible testament to a warming world, and a direct input to the ever-rising tide.

Then we come to the behemoths: the Greenland and Antarctic ice sheets. Their contribution to sea level rise has become increasingly significant in recent decades. The melting here isn't always a simple surface thaw. In Greenland, rising air temperatures cause surface melt, creating meltwater lakes that can drain through the ice to the bedrock below, lubricating the ice flow and accelerating its movement toward the sea. The edges of the ice sheet are also vulnerable to warming ocean waters, which can undercut the ice, leading to calving events where large chunks break off and fall into the ocean.

Antarctica presents a different, and perhaps even more concerning, dynamic. While much of the continent is still extremely cold, particularly the interior, the periphery, especially the West Antarctic Ice Sheet, is highly susceptible to warming ocean currents. Large sections of this ice sheet are grounded below sea level, meaning the ice rests on bedrock that is itself below the ocean surface. Warmer ocean water can intrude beneath these floating ice shelves, thinning them from below and making the ice sheet more unstable. When ice shelves collapse, they no longer act as a buttress, allowing the grounded ice behind them to flow more rapidly into the ocean. This is not just melting; it's a dynamic response where vast quantities of ice are discharged into the sea.

Beyond these two primary drivers, other, more localized or smaller-scale factors also play a role in shaping sea level changes. For instance, changes in land elevation, known as vertical land movement, can either exacerbate or mitigate the effects of global sea level rise. In some regions, land is naturally subsiding due to geological

processes, sediment compaction, or the extraction of groundwater or fossil fuels. This subsidence effectively amplifies the relative sea level rise experienced in those areas, as the land is sinking while the ocean is simultaneously rising. Conversely, areas that are still rebounding from the weight of ancient ice sheets (a process called glacial isostatic adjustment) may experience a slower rate of relative sea level rise, or even a local fall in sea level, as the land slowly lifts.

Ocean currents and atmospheric pressure also influence sea levels on shorter timescales. Strong winds can push water towards or away from coastlines, and variations in atmospheric pressure can cause temporary bulges or depressions in the sea surface. These phenomena, while not contributing to long-term global sea level rise, can influence local water levels and exacerbate events like storm surges, making coastal communities more vulnerable to flooding.

The precise measurement of global sea level rise has evolved significantly over time. Historically, tide gauges—essentially sophisticated rulers placed in the water—were the primary tools. These gauges provide valuable long-term records, some stretching back over a century, offering crucial insights into regional sea level trends. However, tide gauges measure relative sea level, meaning they reflect the combined effect of changes in ocean volume and local land movement. To get a true picture of global absolute sea level, we needed more advanced technology.

That technology arrived with satellite altimetry, beginning in the early 1990s. Satellites like TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3, and now Sentinel-6 Michael Freilich, precisely measure the height of the sea surface from space, covering nearly the entire globe every ten days. These satellite missions have revolutionized our understanding of sea level rise, providing a comprehensive and accurate record of global average sea level and its regional variations. They have confirmed that not only is sea level rising, but the rate of rise has accelerated in recent decades.

According to these measurements, global average sea level has risen by approximately 8-9 inches (21-24 centimeters) since 1880. While that might not sound like much, consider the enormous volume of water it represents, spread across the entire ocean basin. More importantly, the rate of rise has not been constant. For much of the 20th century, the rate was around 1.4 millimeters per year. However, since the early 1990s, with the advent of satellite altimetry, the rate has more than doubled, now averaging around 3.6 millimeters per year. This acceleration is a critical piece of the puzzle, indicating that the forces driving sea level rise are intensifying.

The contributions from thermal expansion and ice melt have shifted over time. In the early to mid-20th century, thermal expansion was the dominant factor. However, in recent decades, the melting of glaciers and, increasingly, the great ice sheets of Greenland and Antarctica have become larger and larger contributors, often surpassing thermal expansion in their annual contribution to sea level rise. This shift

underscores the growing concern about the stability of these massive ice reservoirs and their potential for rapid, large-scale melt.

Understanding the causes and trends of sea level rise is not merely an academic exercise; it forms the bedrock of our ability to predict future changes and develop effective adaptation strategies. Without this foundational knowledge, we would be navigating the future of our coastlines blindly, unable to distinguish between natural variability and the profound, accelerating impacts of a warming planet. The science is clear: the seas are rising, and the pace is quickening, setting the stage for the dramatic consequences explored in the chapters that follow.

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