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THE COASTLINE PARADOX

*Ryan B. Stoa**

ABSTRACT

How long is the coastline of the United States? While it may sound counterintuitive, there is no objectively true answer to this question. In fact, it is impossible to precisely measure the length of any coastline.

A coastline features an endless array of bays and promontories at all scales, from hundreds of miles to fractions of an inch. Thus, the length of a coastline depends on the unit of measurement being used. The smaller the unit of measurement, the more of these bays and promontories are detected, and thus, the longer the coastline becomes. Follow this logic down to the atomic level, and the length of a coastline—any coastline—approaches infinity.

This phenomenon is known as the "coastline paradox," and it is more than just a mathematical curiosity. Because coastlines play such a prominent role in legal frameworks, the coastline paradox presents troubling legal implications at all scales. From international maritime jurisdictions to local real estate markets, the complexities created by this phenomenon are disconcertingly understudied. In fact, the coastline paradox has never been considered as a significant source of legal problems.

This Article is the first to address the legal implications of the coastline paradox. It begins with an explanation of the coastline paradox and other, similar characteristics of coastlines that defy accurate measurement. Then the legal implications for international, federal, and local legal frameworks are introduced and examined. It is apparent that awareness of the coastline paradox is low, and challenges are scarcely being addressed. While a mathematical solution to the coastline paradox may be impossible, this Article concludes with a set of recommendations for coastal stakeholders.

* Visiting Associate Professor of Law, Florida International University College of Law and Associate Professor of Law, Concordia University School of Law. The Author is grateful to Chase Petty for providing excellent research assistance and to Dr. Rothstein, Professor Robin Craig, and Professor McKay Cunningham for their helpful feedback.

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I. INTRODUCTION

In 2006, a report by the Congressional Research Service ("CRS") estimated the total length of the United States coastline to be 12,383 miles.[1] By contrast, the National Oceanic and Atmospheric Administration ("NOAA") has estimated the total length of the U.S. coastline to be 88,633 miles.[2] These figures suggest that NOAA believes the U.S. coastline is over seven times longer than the CRS estimate.

1. JANICE CHERYL BEAVER, CONG. RESEARCH SERV., U.S. INTERNATIONAL BORDERS: BRIEF FACTS 3 (2006), https://fas.org/sgp/crs/misc/RS21729.pdf.

2. NAT'L OCEANIC & ATMOSPHERIC ADMIN., THE COASTLINE OF THE UNITED STATES (1975), https://shoreline.noaa.gov/_pdf/Coastline_of_the_US_1975.pdf; *see also A Guide to*

A comparison of the CRS and NOAA estimates is even more striking on the state level. According to the CRS, the state of Virginia has a coastline 112 miles long.[3] NOAA, on the other hand, believes Virginia's coastline is 3,315 miles long (or nearly thirty times longer than the CRS estimate).[4] Similarly, the New York coastline is 127 miles according to the CRS, or 2,625 miles according to NOAA.[5]

But the most striking comparison takes place along the coast of Maryland. The CRS estimates the Maryland coastline to be a relatively short 31 miles.[6] NOAA, on the other hand, provides an estimate over 100 times longer, at 3,190 miles.[7] The CRS estimate suggests the coast of Maryland is a few miles longer than a marathon. The NOAA estimate suggests the coast of Maryland is several hundred miles longer than the width of the contiguous United States.

At the opposite end of the spectrum, the state of Hawai'i provides a source of relative agreement between the two agencies. The CRS and NOAA put the Hawaiian coastline at 750 and 1,052 miles, respectively.[8] The agencies diverge, however, when considering Hawai'i's relative ranking among other U.S. states. While the CRS believes Hawai'i to have the fourth longest coastline in the United States, Hawai'i's place in NOAA's rankings is a more modest eighteenth.[9]

One last example is perhaps the most striking. NOAA estimates the length of the Alaskan coast to be a whopping 33,904 miles.[10] Recall above that the CRS estimates the U.S. coastline (which, of course, includes Alaska) is only 12,383 miles.[11] In other words, NOAA's Alaska coastline estimate is nearly three times longer than the CRS estimate for the entire country.

These estimates, and the dramatic differences between them, are perplexing. Which agency is to be believed—the CRS, the nonpartisan

National Shoreline Data and Terms, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://shoreline.noaa.gov/faqs.html?faq=2 (last updated May 9, 2016). NOAA's frequently cited total is even larger, at 95,471 miles, which includes the coastline of the Great Lakes. The CRS estimate does not include the Great Lakes, so for comparison purposes, the NOAA total in the text above does not include the Great Lakes.

3. BEAVER, *supra* note 1.

4. NAT'L OCEANIC & ATMOSPHERIC ADMIN., SHORELINE MILEAGE OF THE UNITED STATES (2018), https://coast.noaa.gov/data/docs/states/shorelines.pdf.

5. BEAVER, *supra* note 1; NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

6. BEAVER, *supra* note 1.

7. NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

8. BEAVER, *supra* note 1, at 4; NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

9. *See* BEAVER, *supra* note 1, at 3–4; NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

10. NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

11. *See supra* text accompanying note 1.

public policy research arm of the United States Congress, or NOAA, the scientific agency tasked with understanding and protecting the nation's oceanic and coastal resources?[12]

Even more perplexing than these wildly divergent estimates of coastline length is the likely conclusion that neither agency's estimates are unequivocally correct. And, on some level, neither agency's estimates are incorrect, either. The reason for these seemingly inconsistent observations is a phenomenon known as the "coastline paradox."

A coastline features an endless array of bays and promontories at all scales, from hundreds of miles to fractions of an inch. Thus, the length of a coastline depends on the unit of measurement being used. The smaller the unit of measurement, the more of these bays and promontories are detected, and thus, the longer the coastline becomes. Follow this logic down to the atomic level, and the length of a coastline—any coastline—approaches infinity.

The coastline paradox has confounded mathematicians and geographers, among other subject matter experts, for decades.[13] As a prime example of fractal geometry, the coastline paradox illustrates the fallacy in thinking that objects in nature can be easily measured or classified.

However, the legal implications of the coastline paradox have not been examined by legal scholars. Despite the fact that a well-defined coastline would seem important to people and property, NOAA has noted that a legal definition of the "U.S. shoreline" does not exist:

> There is no legal reference that designates one specific shoreline as the legal shoreline. Furthermore, there is no simple answer to this question as there are many legal, technical, and general uses of the terms related to shoreline (shoreline, coastline, baseline, mean high-water line, mean-low water line, etc.).[14]

Nonetheless, does the fact that a coastline cannot be conclusively measured matter in any legal sense? The coastline paradox is an interesting quandary for mathematicians, geographers, and even philosophers, but should public policy or legal experts care?

The answer is yes. Not only does the coastline paradox have legal implications, those implications create significant challenges for current

12. See also the mission of the CRS and NOAA. *History and Mission*, LIBR. CONGRESS, http://www.loc.gov/crsinfo/about/history.html (last updated Nov. 15, 2012); *Our Mission and Vision*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://www.noaa.gov/our-mission-and-vision (last visited Dec. 2, 2019).

13. *See, e.g.*, KENNETH FALCONER, FRACTAL GEOMETRY: MATHEMATICAL FOUNDATIONS AND APPLICATIONS, at xvii (2d ed. 2003).

14. NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 2.

and future stakeholders in the coastal zone. In part because coastlines play such an important role in legal frameworks at all scales—international, federal, and local—those frameworks are weakened by their failure to address the coastline paradox.

This Article begins with an explanation of the coastline paradox, including its history and theoretical and practical mechanics. Next, a set of related coastline characteristics (collectively referred to in this Article as coastline non-conformism) are explored to the extent that they reinforce and exacerbate the challenges presented by the coastline paradox.

The most significant legal implications of the coastline paradox for international, federal, and local legal frameworks are investigated in Parts IV, V, and VI, respectively. On the international level, the coastline paradox's disruptive interactions with the law of the sea is at the root of international tensions over maritime jurisdictions. Similar tensions exist between states and the U.S. federal government, while federal agencies are using outdated measurements of coastline length to make critical funding decisions. Finally, the coastline paradox creates uncertainty and confusion at the local level for a troubling number of actors and processes, including property owners, real estate markets, and government agencies.

As long as the world's coastlines are left to their own, natural devices, they will remain impossible to objectively measure. For that reason, a perfect solution to the coastline paradox is an elusive notion. From a legal perspective, however, coastal stakeholders can take steps to provide clarity and minimize tension. To that end, this Article concludes by proposing solutions to some of the legal challenges presented by the coastline paradox.

II. THE COASTLINE PARADOX EXPLAINED

In order to appreciate the disruptive potential of the coastline paradox, a basic understanding of its properties is required. A more sophisticated analysis of fractal geometry is outside the scope of this Article, but the basic analysis of the coastline paradox provided here is sufficient to explore the implications of the phenomenon in later Parts.

A. A Brief History of the Coastline Paradox

Any two attempts to measure the length of a coastline are likely to produce two different results, since there is no objective reason why one

unit or method of measurement should be used over another.[15] For that reason, it may be that the coastline paradox has been observed informally by coastal communities or cartographers for centuries. One can imagine cartographers puzzling over significantly different estimates of coastline length, revising their estimates in a fit of self-doubt, or questioning the methodological approach of a predecessor's estimate. Or, perhaps, disagreements arose regarding the inclusion or exclusion of a fjord or inlet in the calculation of a coastline.[16] Regardless, the coastline paradox's existence does not depend on its recognition by humans, and it is likely to have produced confusion long before its formal recognition by the scientific community.

That recognition (and acceptance) arrived in the mid-twentieth century thanks to an eccentric English Quaker named Lewis Fry Richardson, who, despite a long career working outside the academic establishment, produced a number of contributions and advancements in the fields of psychology, meteorology, and numerical analysis.[17]

Richardson stumbled upon the coastline paradox while researching the potential relationship between conflict and shared border length.[18] Richardson noted with some confusion that Spain and Portugal reported significantly different length estimates of their shared border.[19] While Portugal estimated the border to be 1214 kilometers long, Spain's estimate was only 987 kilometers.[20] He found that neither country was objectively incorrect, they were simply using different units of measurement, and this, as explained further below, would produce different results.[21] Richardson's observation is considered the first formal conceptualization of the coastline paradox.[22]

A decade later, a Franco-American polymath named Benoit Mandelbrot expanded on Richardson's observations by using the coastline paradox as the basis for the development of fractal geometry, a

15. *See* discussion *infra* Section II.B.

16. The National Geographic Society defines a fjord as "a long, deep, narrow body of water that reaches far inland." *Fjord*, NAT'L GEOGRAPHIC, https://www.nationalgeographic.org/encyclopedia/fjord/ (last visited Jan. 16, 2020).

17. *See* J.C.R. Hunt, *A General Introduction to the Life and Work of L.F. Richardson*, *in* 1 COLLECTED PAPERS OF LEWIS FRY RICHARDSON: METEOROLOGY AND NUMERICAL ANALYSIS 1–2 (P.G. Drazin et al. eds., 1993).

18. P.G. Drazin, *Fractals*, *in* 1 COLLECTED PAPERS OF LEWIS FRY RICHARDSON, METEOROLOGY AND NUMERICAL ANALYSIS 45 (P. G. Drazin et al. eds., 1993).

19. *Id.*

20. *Id.*

21. *Id.* at 45–46.

22. *Id.*

field for which Mandelbrot is credited with creating.[23] In a seminal paper in *Science*, entitled *How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension*, Mandelbrot affirmed Richardson's observation of the coastline paradox, while noting the self-similarity of coastlines.[24] A coast is essentially a geographic feature with a series of bays and promontories, Mandelbrot observed.[25] Zoom in on a fragment of that coastline, however, and another, smaller series of bays and promontories will be observed.[26] Thus, Mandelbrot found, "[g]eographical curves are so involved in their detail that their lengths are often infinite or more accurately, undefinable."[27]

Mandelbrot wrote in his paper that "a number of conceptual problems . . . are also raised by the idea that a geographical curve is random."[28] Indeed, Mandelbrot went on to apply his fractal observation of coastlines (and the implications arising from it) to more accurately depict other natural objects such as mountains, rivers, and lungs, as well as more human phenomena such as stock prices and interest rates.[29] In 2004, as financial markets were sowing the seeds of a global economic crisis few would see coming, Mandelbrot warned that "[t]he financiers and investors of the world are, at the moment, like mariners who heed no weather warnings."[30]

The coastline length estimates used by NOAA in the Introduction above were collected shortly after Mandelbrot published his article on the inherent impossibility of measuring a coastline in 1967. According to one NOAA cartographer, legend has it that the measurements were collected by hand-rolling a mechanical measurement wheel around the largest scale nautical charts available.[31] But even today, with the availability and sophistication of geographic information systems ("GIS") and remote

23. *See* Ralph Gomory, *Benoît Mandelbrot (1924–2010) Mathematician and Father of Fractal Geometry, Who Described the Roughness of Nature*, NATURE (Nov. 17, 2010), https://www.nature.com/articles/468378a; *see also* BENOIT B. MANDELBROT, THE FRACTALIST: MEMOIR OF A SCIENTIFIC MAVERICK 286–87 (2012).

24. Benoit Mandelbrot, *How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension*, 156 SCI. 636 (May 5, 1967).

25. *Id.*

26. *Id.*

27. *Id.*

28. *Id.* at 638.

29. Gomory, *supra* note 23; *see also* BENOIT MANDELBROT, THE FRACTAL GEOMETRY OF NATURE (1983).

30. Gomory, *supra* note 23 (quoting BENOIT MANDELBROT & RICHARD L. HUDSON, THE (MIS)BEHAVIOR OF MARKETS: A FRACTAL VIEW OF FINANCIAL TURBULENCE (2004)).

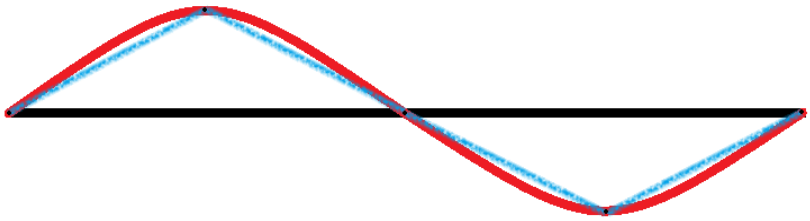
31. Cindy Fowler, *How Much Length Do You Really Need? Ahhh, Shoreline Length That Is!*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Mar. 26, 2012), https://web.archive.org/web/20131217062754/http://www.csc.noaa.gov/digitalcoast/geozone/how-much-length-do-you-really-need-ahhh-shoreline-length-that-is.

sensing ("RS") technologies, the coastline paradox persists—mapping experts must still choose the scale of the data set (or unit of measurement), and this choice will inform the length estimate obtained.[32]

B. Coastline Sinuosity

The coastline paradox is best understood as an observation that it is impossible to measure the length of a coastline in any "true" or "objective" or "unassailable" sense. But why is that the case? Because, as this brief explanatory section details, curves are longer than straight lines, the length of fractal curves approaches infinity, and coastlines are, essentially, statistically random fractal curves.

Beginning with the concept of length, it can be said that, at least geometrically speaking, the shortest distance between two points is a straight line. A basic curve takes longer to move from one point to another. Nonetheless, the length of a basic curve can be approximated by adding together the length of straight lines connecting various points on the curve. Because straight lines represent a shorter distance between two points than a curve, using straight lines to estimate the length of a basic curve will result in an estimate lower than the curve's true length. But, the shorter the lines being used, the closer the estimate will be to the curve's true length. The below illustration demonstrates this basic premise:



The shorter blue lines in this image come significantly closer to estimating the length of the red curve than the long black line.[33]

From this starting point alone, it can be fairly easy to see that measuring a coastline is a tricky endeavor. The length of a coastline will necessarily increase if the unit of measurement decreases, since the smaller unit of measurement picks up more curvature than the larger

32. *See* Joe Akintola, *GIS Data and the Coastline Paradox*, GISLOUNGE.COM (Oct. 30, 2014), https://www.gislounge.com/gis-data-coastline-paradox/.

33. Image created by the Author.

unit of measurement. A key to understanding the coastline paradox is therefore a concept called "sinuosity." Sinuosity is the ratio of a curve's length and the length of a straight line between the end points of that curve. Or, as one geophysicist put it, sinuosity is the "wiggliness" of a curve.[34] The more sinuous or wiggly a curve is between end points, the longer its length.

Because a very wiggly curve can be much longer than a straight line, the unit of measurement being used to measure the curve therefore becomes critical to determining the true length of a curve. A small unit of measurement will be able to detect much of the curve's path, whereas a large unit of measurement will not. The two findings could be significantly different as a result. The coast of Maryland, for example, which is very sinuous, yielded the astoundingly different estimates from the CRS and NOAA described above. The below illustration demonstrates this premise as well:

The coast of the United Kingdom is highly sinuous, resulting in divergent estimates of coastline length depending on the unit of measurement. In this image, measurement units of 200 km, 100 km, and 50 km (from left to right) result in length estimates of 2350 km, 2775 km, and 3425 km, respectively.[35]

34. *See* Drazin, *supra* note 18.

35. Avsa & Acadac, WIKIMEDIA COMMONS (May 5, 2005), https://commons.wikimedia.org/wiki/File:Britain-fractal-coastline-100km.png#/media/File:Britain-fractal-coastline-combined.jpg.

By, contrast, a curve that has low sinuosity will not be as sensitive to the unit of measurement. The length estimates of a curve that is almost a straight line might be similar even if a large unit of measurement is used. Hawai'i, for example, has relatively straight coastlines, rendering the CRS and NOAA estimates of the state's coastline length somewhat similar.

To illustrate this point differently, according to NOAA, Louisiana and Maine have longer coastlines than California.[36] This counter-intuitive finding is possible because the coasts of Louisiana and Maine are relatively sinuous (having many bays and promontories), whereas the coast of California is relatively straight, and NOAA's measurement methodology is sensitive to sinuosity (i.e. the unit of measurement is relatively small). Because the CRS approach is not as sensitive to sinuosity, it fails to detect the many bays and promontories of the Louisiana and Maine coastlines and, therefore, ranks California's coastline ahead of both states.[37] Again, the smaller the unit of measurement, the closer to the true length of a curve the length estimate will be.

C. Coastline Fractals

The complications do not end there, however. The length of a basic curve, such as the ones shown in the images above, could be precisely measured using calculus mathematics.[38] Coastlines, unfortunately, are not basic curves. They are statistically random fractal curves. Fractal curves cannot be measured because their complexity changes with measurement scale.[39] Mandelbrot, the father of fractal mathematics, defined a fractal as "a shape made of parts similar to the whole in some way."[40] The accuracy of measurement for the length of a basic curve increases as the unit of measurement decreases, but, in the case of a fractal curve, the smaller unit of measurement simply detects more complexity in the curve, and, therefore, the length continues to increase.[41] The illustrations below demonstrate this concept:

36. *See* NAT'L OCEANIC & ATMOSPHERIC ADMIN., *supra* note 4.

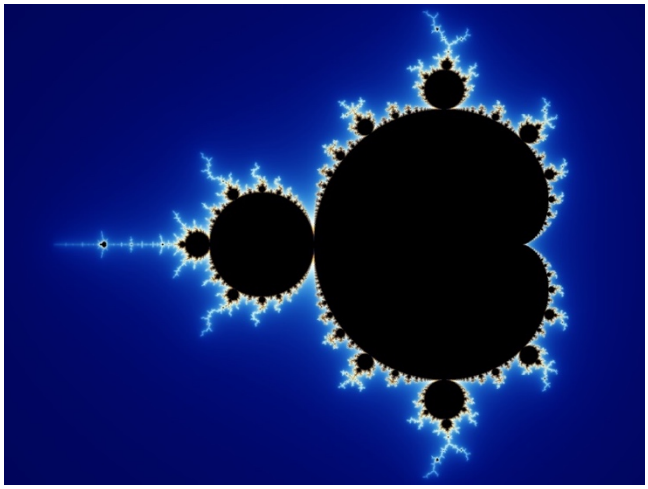
37. *See* BEAVER, *supra* note 1, at 3–4.

38. P.A.P. Moran, *Measuring the Length of a Curve*, 53 BIOMETRIKA 359, 359 (1966); Sean Kotz, *How to Calculate the Length of a Curved Line*, SCIENCING (May 22, 2018), https://sciencing.com/calculate-length-curved-line-8584551.html.

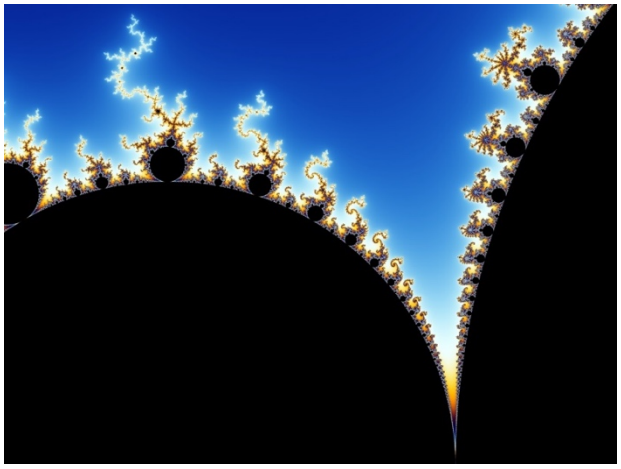
39. JENS FEDER, FRACTALS 11 (1st ed. 1988).

40. *Id.*

41. *Id.*



Initial image of the Mandelbrot Set, one of the best-known (and most beautiful) examples of fractal self-similarity.[42]



Step one of a zoom sequence of the Mandelbrot Set. Notice that as magnification increases, more detail is revealed, exposing smaller versions of the original shape. This pattern continues to infinity.[43]

42. *See* Wolfgang Beyer, *Initial Image of the Mandelbrot Set*, WIKIMEDIA COMMONS, https://commons.wikimedia.org/wiki/File:Mandel_zoom_00_mandelbrot_set.jpg (last updated Oct. 13, 2013).

43. *See* Wolfgang Beyer, *Step 1 of a Zoom Sequence of the Mandelbrot Set*, WIKIMEDIA COMMONS, https://commons.wikimedia.org/wiki/File:Mandel_zoom_00_mandelbrot_set.jpg#/media/File:Mandel_zoom_01_head_and_shoulder.jpg (last updated Sept. 11, 2005).

Because a fractal curve increases in complexity with measurement scale, attempts to measure its length will tend toward infinity. The smaller the unit of measurement, the more complexity is detected; the more complexity is detected, the longer the length estimate will be. This basic pattern (first articulated by Richardson and now referred to as the "Richardson Effect") has no logical end point.[44] The length of a fractal curve will continue to increase in this way, even down to the atomic or sub-atomic level.[45]

In this way, fractal curves present measurement challenges that straight objects, such as a pen, do not. A pen can be measured with a degree of uncertainty (which is to say, the length can be determined to be more than a certain amount and less than a certain amount) and, the more precise the measurement unit, the closer the length estimate will be to the true length of the pen.[46] The length of a fractal, by contrast, does not come into focus with a more precise measuring tool. Instead, the length estimate increases with measurement precision, and no maximum estimate can ever be obtained.[47]

Furthermore, even if idealized fractals could be measured, coastlines would still present measurement problems because they are not idealized.[48] The Mandelbrot set shown above, for example, is roughly self-similar in that smaller versions of itself can be found at smaller scales. But coastlines are statistically random fractal curves, with more random variations at smaller scales. To put it differently, coastlines are "curves that look different when magnified but still invoke the same

44. *See* Lewis F. Richardson, *The Problem of Contiguity: An Appendix to Statistics of Deadly Quarrels*, 6 GEN. SYS. Y.B. 139, 170 (1961).

45. The truth of this statement relies on the assumption that space can be subdivided into infinitely smaller pieces. This assumption is debated in philosophical and physicist circles, among others. *See, e.g.*, ANDREW PYLE, ATOMISM AND ITS CRITICS, at xii (1997); T. Padmanabhan, *Planck Length as the Lower Bound to All Physical Length Scales*, 17 GEN. RELATIVITY & GRAVITATION 215, 215 (1985).

46. *See generally* PERTTI MATTILA, GEOMETRY OF SETS AND MEASURES IN EUCLIDEAN SPACES: FRACTALS AND RECTIFIABILITY (1999).

47. *See, e.g.*, Richard F. Voss, *Characterization and Measurement of Random Fractals*, 13 PHYSICA SCRIPTA 27, 28 (1986); Heping Xie, Jin-an Wang & E. Stein, *Direct Fractal Measurement and Multifractal Properties of Fracture Surfaces*, 242 PHYSICS LETTERS 41, 44 (1998).

48. This is true not only of coastlines but other fractals found in nature as well. *See, e.g.*, Michael F. Goodchild, *Fractals and the Accuracy of Geographical Measures*, 12 MATHEMATICAL GEOLOGY 85, 87 (1980); Bruce T. Milne, *Measuring the Fractal Geometry of Landscapes*, 27 APPLIED MATHEMATICS & COMPUTATION 67, 67–69 (1988); George Sugihara & Robert M. May, *Applications of Fractals in Ecology*, 5 TRENDS ECOLOGY & EVOLUTION 79, 80 (1990).

characteristic impression."[49] This makes coastlines even more difficult to measure than idealized fractals.

Coastlines are impossible to measure for one final, additional reason. Not only are coastlines statistically random fractal curves, they are also continuously changing due to natural and human forces. Mandelbrot wrote that "[c]louds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line."[50] Nature has an inherent roughness to it which makes the measurement of natural objects elusive.

Coastlines, especially, are constantly changing in shape and composition. With every ebb and flow of the tide, sand is withdrawn from, or deposited on, the shore. An extreme weather event can wash away large swaths of land into the ocean or make an equally large deposit.[51] Human development may intentionally or unintentionally alter the nature of a coastline.[52] And climate change is causing sea levels to rise at unprecedented rates.[53] Any of these dynamics is capable of rendering a coastline measurement obsolete in short order.

In summary, coastline length is impossible to measure, and the very notion of a true length of a coastline proves elusive. The above-described complexities involved in attempting to identify the length of a coastline collectively form the coastline paradox. But the complexities do not end there. As noted above, coastlines are natural objects that, in addition to being statistically random fractal curves, do not remain static. The following Part explores more implications of coastline non-conformism, and the challenges that non-conformism can present when evaluating the nature of a coastline.

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49. HEINZ-OTTO PEITGEN, HARTMUT JÜRGENS & DIETMAR SAUPE, CHAOS AND FRACTALS: NEW FRONTIERS OF SCIENCE 424 (2004).

50. Jacob Goldstein, *'Clouds Are Not Spheres, Mountains Are Not Cones,'* NAT'L PUB. RADIO (Oct. 18, 2010), https://www.npr.org/sections/money/2010/10/18/130643155/-clouds-are-not-spheres-mountains-are-not-cones.

51. *See* WALLACE KAUFMAN & ORRIN H. PILKEY, THE BEACHES ARE MOVING: THE DROWNING OF AMERICA'S SHORELINE 51–53 (1983); Chris Houser, Cheryl Hapke & Stuart Hamilton, *Controls on Coastal Dune Morphology, Shoreline Erosion and Barrier Island Response to Extreme Storms*, 100 GEOMORPHOLOGY 223, 224 (2008); Stephen P. Leatherman, Keqi Zhang & Bruce C. Douglas, *Sea Level Rise Shown to Drive Coastal Erosion*, 81 EOS 55, 55 (2000); *Shoreline Effects of Storms*, PENNSTATE: COASTAL PROCESSES, HAZARDS & SOCIETY, https://www.e-education.psu.edu/earth107/node/1519 (last visited Dec. 3, 2019).

52. KAUFMAN & PILKEY, *supra* note 51, at 179; E. Sanjaume & J.E. Pardo-Pascual, *Erosion by Human Impact on the Valencian Coastline*, 49 J. COASTAL RES. (SPECIAL ISSUE) 76, 77 (2005).

53. *See* Keqi Zhang, Bruce C. Douglas & Stephen P. Leatherman, *Global Warming and Coastal Erosion*, 64 CLIMACTIC CHANGE 41, 41–42 (2004); Leatherman, Zhang & Douglas, *supra* note 51.

III. COASTLINE NON-CONFORMISM

The coastline paradox is not the only reason coastlines are hard to measure. Many other factors complicate coastline measurements, including the river problem, the constantly shifting nature of shorelines, ambiguous coasts whose landmass is intertwined with the marine environment (such as mangrove shorelines), and, finally, the uncertainty presented by climate change and sea level rise. These are collectively referred to in this Article as coastline non-conformism.

A. The River Problem

The river problem is a corollary of the coastline paradox. The essence of that problem is that there are no objective criteria for determining where a river ends and the ocean begins. Especially when a large river system forms a delta at its mouth (by depositing sediment gathered upstream), it can be challenging to delimitate between the river and the ocean because deltas often form a network of channels that form or shape-shift very quickly.[54] Miles of land can emerge or submerge depending on the time of year (or, in the case of tidal lands, the time of day).[55] Because the landmass of a delta is not static, it becomes difficult to establish a coastline by connecting points on the shore.

In theory, salinity measurements could be used to distinguish between freshwater (which would presumably be classified as internal water and therefore part of the coast) and saltwater (which would presumably be considered beyond the coastline). However, salinity levels are also variable, and many river systems form estuaries along the coast where salinity levels are not unambiguously fresh or salty.[56]

Even if the lands surrounding the mouth of a river were stable, the line between river and ocean can remain blurred. In the case of the Mississippi River, for example, NASA satellite imagery tracking the flow of freshwater and sediment from the river's mouth in 2004 made a surprising discovery. The imagery showed the Mississippi River

54. *See* William W. Hay, *Detrital Sediment Fluxes Continents and Oceans*, 145 CHEMICAL GEOLOGY 287, 288 (1998); *see also* John D. Milliman & Robert H. Meade, *World-Wide Delivery of River Sediment to the Oceans*, 91 J. GEOLOGY 1, 2, 19 (1983); James P.M. Syvitski et al., *Impact of Humans on the Flux of Terrestrial Sediment to the Global Coastal Ocean*, 308 SCI. 376, 377 (2005).

55. *See* Michael Fenster & Robert Dolan, *Assessing the Impact of Tidal Inlets on Adjacent Barrier Island Shorelines*, 12 J. COASTAL RES. 294, 307 (1996).

56. *See What Is an Estuary?*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://oceanservice.noaa.gov/education/kits/estuaries/estuaries01_whatis.html (last visited Dec. 3, 2019).

continuing on into the Gulf of Mexico for hundreds of miles, before eventually joining up with the Gulf Stream, rounding the coast of Florida, and heading north. The Mississippi River's flow could be detected as far north as the coast of Georgia.[57]

Certainly no one is arguing that the Mississippi River's resilient forays into the Atlantic Ocean should be grounds for rethinking political boundaries. However, the impacts felt by the river's flow have long been a source of tension between U.S. states, and between the United States and other countries in the Caribbean.[58] Should the United States—or states contributing to water pollution carried by the river—be liable for the impacts caused by that pollution hundreds if not thousands of miles away?[59] Some have argued affirmatively, with mixed results.[60] Either way, the river problem presents ongoing measurement challenges and frustrates efforts to establish a consistent coastline.

B. Ambulatory Coastlines

To make matters more complex, coastlines are constantly shifting. With every wave that crashes on shore, sediments are deposited, adding to the coast (a process known as accretion).[61] As the water recedes, sediment is washed away, subtracting from the coast (a process known as erosion).[62] This pattern is magnified with every ebb and flow of the

57. *Mississippi River Escapes the Gulf*, NASA: EARTH OBSERVATORY, https://earthobservatory.nasa.gov/images/5868/mississippi-river-escapes-the-gulf (last visited Dec. 3, 2019).

58. *See* Jack Cullen, *Mississippi River Generates $405,000,000,000 Annually*, QUAD-CITY TIMES (Sept. 16, 2015), https://qctimes.com/news/local/govt-and-politics/mississippi-river-generates-annually/article_b1e73932-db0f-544d-86a5-3923c54fc5aa.html; *see also*, *Where Is the Invading Sargasso Coming From?* YUCATAN TIMES (June 26, 2019), https://www.theyucatantimes.com/2019/06/where-is-the-invading-sargasso-coming-from/.

59. For a contrast in approaches between the Rhine River and Mississippi River, see Stephanie K. Chase, *There Must Be Something in the Water: An Exploration of the Rhine and Mississippi Rivers' Governing Differences and an Argument for Change*, 29 WIS. INT'L L.J. 609, 635–36 (2011).

60. *See* Theresa Heil, *Agricultural Nonpoint Source Runoff – The Effects Both on and off the Farm*: *An Analysis of Federal and State Regulation of Agricultural Nonpoint Source Pollutants*, 5 WIS. ENVTL. L.J. 43, 52–53 (1998); Jan G. Laitos & Heidi Ruckriegle, *The Clean Water Act and the Challenge of Agricultural Pollution*, 37 VT. L. REV. 1033, 1069–70 (2013); J.W. Looney, Rylands v. Fletcher *Revisited: A Comparison of English, Australian and American Approaches to Common Law Liability for Dangerous Agricultural Activities*, 1 DRAKE J. AGRIC. L. 149, 169–72 (1996).

61. *See, e.g.*, J.S. Schoonees, A.K. Theron & D. Bevis, *Shoreline Accretion and Sand Transport at Groynes Inside the Port of Richards Bay*, 53 COASTAL ENGINEERING 1045, 1045 (2006).

62. *See, e.g.*, S. Penland & R. Boyd, *Shoreline Changes on the Louisiana Barrier Coast*, 81 OCEANS 209, 209 (1981); Manon Besset et al., *2500 Years of Changing Shoreline*

tide. And since coastal waters are always in motion, the coast is never static. The processes of accretion and erosion are typically, however, gradual and imperceptible. For this reason, in most jurisdictions littoral property owners have a right to accretions, while at the same time their properties are at risk of erosion.[63]

Major events can make dramatic changes to a coastline as well. When a coastline is modified suddenly or perceptibly, such as by a hurricane, this process is known as avulsion (whether the change enlarges or diminishes the coast).[64] In many cases, littoral property owners may have a right to restore the coastline to its pre-avulsion state. However, coastal re-nourishment projects are often costly and labor-intensive.[65]

Ambulatory coastlines can also be problematic for federal-state relations, as a shifting coastline also means a potential shift in federal-state jurisdiction over marine waters. In *United States v. Louisiana*, for example, the Supreme Court held that ambulatory coastlines may shift the federal-state marine boundary if the state's coastline erodes (thereby ensuring the state's jurisdictional area remains the same), but, when the state's coastline accretes, the federal-state marine boundary remains the same (thereby shrinking the state's jurisdictional area).[66] Although many other coastal states were not disadvantaged by a similar application of the rule (as discussed further in Part V below), the case demonstrates the chaotic potential of ambulatory coastlines.[67]

Today the shifting (or ambulatory) nature of coastlines is nearly ubiquitous. A 2019 study of coastlines in the mid-Atlantic United States found that only 13.7% of the coast is considered stable.[68] The rest is either in a process of accretion or erosion. The implications for coastal stakeholders are significant—in an era when coastal property is in high demand from private property owners and developers, public interests,

Accretion Rates at the Mouths of the Mekong River Delta, ASTROPHYSICS DATA SYS. (Apr. 2016), http://adsabs.harvard.edu/abs/2016EGUGA..1813555B.

63. *See* CHRISTIE RIESER & HILDRETH KALO, OCEAN AND COASTAL LAW 165–66 (4th ed. 2013).

64. *See, e.g.*, Janet Neuman, *Accretion, Reliction, and Avulsion – Oregon Common Law*, *in* ADAPTING TO CLIMATE CHANGE ON THE OREGON COAST: A CITIZEN'S GUIDE 56 (2015); J. Silvestre, A.J. Chadwick & M.P. Lamb, *Deltaic Avulsions Over the Past Half-Century Captured by Satellite Imagery*, ASTROPHYSICS DATA SYS. (Dec. 2018), https://ui.adsabs.harvard.edu/abs/2018AGUFMEP31D2378S/abstract.

65. *See* RIESER & KALO, *supra* note 63, at 169–72.

66. 394 U.S. 11, 35 (1969).

67. *See* RIESER & KALO, *supra* note 63, at 88.

68. *See* Mark Crowell & Stephen P. Leatherman, *Reassessment of Large-Scale Reversals in Shoreline Trends Along the U.S. Mid-Atlantic Coast*, 2019 J. COASTAL RES. 2, 3.

and ecosystems, the precise shape, location, and nature of that property is almost always changing.[69]

C. Ambiguous Coastlines

How can a coastline be measured when it is not clear where land ends and water begins? Many coastlines are wetlands, which, by definition, are lands saturated with water.[70] There are over forty million acres of coastal wetlands in the conterminous United States, found along the Pacific Coast from California to Washington, along the Atlantic Coast from Maine to Florida, and along the Gulf of Mexico from Florida to Texas.[71] Alaska alone contains over twenty million acres of coastal wetlands.[72]

In these contexts, it is more difficult to delineate between land and sea using the typical "mean high water line" or "mean low water line" measurements that apply easily to stable and discrete coastlines, especially since many coastal wetlands can extend for miles inland.[73]

The Everglades in southern Florida, for example, comprise 1.5 million acres of wetlands, forming an ecosystem found nowhere else on Earth.[74] On its southern boundary, the Everglades water system flows into Florida Bay across hundreds of miles of mangroves.[75] Mangrove habitats form in brackish or saline water, committing neither to land nor sea.[76] Does that make them part of a territorial or marine environment?

69. *See also* Xin Liu et al., *A State of the Art Review on High Water Mark (HWM) Determination*, OCEAN & COASTAL MGMT. (Dec. 2014), https://www.researchgate.net/publication/266973157_A_state_of_the_art_review_on_High_Water_Mark_HWM_determination.

70. *What Is a Wetland?*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://oceanservice.noaa.gov/facts/wetland.html (last visited Dec. 3, 2019).

71. *Coastal Wetlands*, ENVTL. PROT. AGENCY, https://www.epa.gov/wetlands/coastal-wetlands#activities (last visited Aug. 29, 2019).

72. JOHNATHAN V. HALL, U.S. FISH & WILDLIFE SERV., ALASKA COASTAL WETLANDS SURVEY 24–25 (1988), https://www.fws.gov/wetlands/Documents/Alaska-Coastal-Wetlands-Survey.pdf.

73. *See Coastal Wetlands*, *supra* note 71.

74. *See America's Everglades – The Largest Subtropical Wilderness in the United States*, NAT'L PARK SERV., https://www.nps.gov/ever/planyourvisit/index.htm (last updated Sept. 11, 2018); Ian Frazier, *The Snakes that Ate Florida*, SMITHSONIAN MAG. (July 2019), https://www.smithsonianmag.com/science-nature/snakes-ate-florida-180972534/.

75. *See* James W. Fourqurean & Michael B. Robblee, *Florida Bay: A History of Recent Ecological Changes*, 22 ESTUARIES 345, 353 (1999).

76. *Mangal (Mangrove)*, UCLA: MILDRED E. MATHIAS BOTANICAL GARDEN, http://www.botgard.ucla.edu/html/botanytextbooks/worldvegetation/marinewetlands/mangal/index.html (last visited Nov. 1, 2019).

More broadly, how can the Florida coastline be measured under these conditions?

Courts in Florida, as well as the United States Supreme Court, have adopted a "meander line" approach to determining the contours of the coastline in circumstances when the mean high water mark would be unhelpful.[77] The meander line consists of a series of straight lines connecting points on the shore. A meander line is therefore a very rough approximation of the coastline for the same reasons that straight lines are weak estimates of the length of a sinuous curve.

Even the public-private boundary of coastal wetlands is unclear. Historically, coastal wetlands were viewed by public officials as noxious wastelands impeding development, and many were practically given away to private property owners.[78] Today, those divestments are being challenged, and states are using various means to wrest them back into public control.[79]

Needless to say, ambiguous coasts are problematic for purposes of delineating legal boundaries, be they public-private or federal-state.[80] They are challenging to define, challenging to measure, and frequently in a state of change.

D. Artificial Coastlines

In some cases, coastlines are fixed and not subject to the coastline paradox. This is possible when the coastline is artificially created, maintained, or reinforced by human activities because, conceptually, the coastline becomes a human construct and no longer displays fractal characteristics. In other cases, coastlines are modified inadvertently by human activities.

But, while artificial coastlines may escape some of the dilemmas created by the coastline paradox, they present other related challenges. It is not always clear if artificial coastlines become the new legal coastal boundary, for example. In cases where the artificial coastline does fix a new legal boundary, there are typically winners and losers, and the losers do not take the loss lightly.

77. Florida Bd. of Tr. v. Wakulla Silver Springs Co., 362 So. 2d 706, 712 (Fla. Dist. Ct. App. 1978); *see also* Utah v. United States, 403 U.S. 9, 12–13 (1971).

78. RIESER & KALO, *supra* note 63, at 152.

79. *See, e.g.*, Monica K. Kalo & Joseph J. Kalo, *The Battle to Preserve North Carolina's Estuarine Marshes: The 1985 Legislation, Private Claims to Estuarine Marshes, Denial of Permits to Fill, and the Public Trust*, 64 N.C. L. REV. 565, 567–68 (1986).

80. *See* SARA WARNER, DOWN TO THE WATERLINE: BOUNDARIES, NATURE, AND THE LAW IN FLORIDA 80–91 (2005).

Beach nourishment projects provide a modern example of this dynamic. Since coastal property (especially beachside property) is valuable to private landowners and the public, stakeholders often initiate beach nourishment projects to restore beaches that have lost coastal lands to erosion or avulsion.

But, when those projects are funded by the public and create an "erosion control line" that provides a fixed coastline boundary, do coastal property owners lose their littoral rights? Property owners argued in the affirmative to the United States Supreme Court in *Stop the Beach Renourishment, Inc. v. Florida Department of Environmental Protection*.[81] The Supreme Court disagreed.[82]

Sometimes a government or private entity intentionally modifies a coastline for reasons other than coastline modification. In the aftermath of the Deepwater Horizon oil spill in the Gulf of Mexico, the largest oil spill in human history, mitigation teams rushed to create makeshift alterations to the coastal environment in order to protect people, property, and ecosystems from exposure (or further exposure) to petroleum.[83]

In particular, forty-six miles of sand berms were built seaward of barrier islands and coastal wetlands in an effort to block the oil from reaching more sensitive ecosystems.[84] Some inlets were blocked or restricted for similar reasons, and freshwater flows were diverted in order to flush oil back out to sea.[85] It is unclear if these coastline modifications achieved their goals, while it is likely that the modifications to the coastline will have long-lasting impacts.[86]

Finally, in many cases coastlines are inadvertently modified by human activities. Construction of a jetty, for example, can disrupt the natural flow of sand and sediments and stimulate erosion or accretion patterns of nearby coasts.[87] Seawalls and erosion control structures, similarly, can interfere with natural processes so as to negatively impact neighboring properties. These cases often illustrate that it takes

81. 560 U.S. 702, 709 (2010).

82. *Id.* at 732–33.

83. M. Louisa Martinez et al., *Artificial Modifications of the Coast in Response to the Deepwater Horizon Oil Spill: Quick Solutions or Long-Term Liabilities?*, 10 FRONTIERS ECOLOGY & ENV'T 44, 45 (2011).

84. *Id.*

85. *Id.* at 45–48.

86. *Id.* at 48.

87. Paul D. Komar, et al., *Oregon Coast Shoreline Changes Due to Jetties*, 102 TRANSPORT. RES. BOARD 13 (1977).

relatively minimal human interference with these processes to create significant coastline modifications.[88]

E. Sea Level Rise and Disappearing Coastlines

Even if coastlines were static, climate change and sea level rise are disrupting previously held assumptions about the integrity, viability, and future of the world's coastlines. Though a full treatment of coastal dynamics in an era of climate change is very much outside the scope of this Article, the basic parameters of the challenge, particularly regarding the uncertainty of coastlines and the boundaries they purport to create, bears mentioning.

Sea level rise is one of many consequences of global climate change. It occurs primarily for two reasons: melting ice and glaciers add water to the world's oceans, and, as the oceans absorb more heat from the atmosphere, seawater expands.[89] These processes reinforce each other as well—a loss in the total area covered by ice sheets reduces the amount of sunlight reflected back into space and increases the amount of sunlight directly absorbed by the oceans, while warmer oceans and higher seas help accelerate ice melt.[90]

Taken together these dynamics have led to a rise in global sea levels by about eight inches since 1900, a rate higher than any century in at least 2800 years.[91] Future projections of sea level rise are notoriously difficult to estimate, with most credible estimates ranging between two and six feet of sea level rise by 2100.[92] The U.S. National Climate Assessment concluded in 2017 that a global sea level rise of eight feet was not impossible.[93] Importantly, however, sea level rise impacts vary across regions. Some studies suggest the United States coastline will likely be hit 20% harder than the global average.[94]

88. *See, e.g.*, United States v. Milner, 583 F.3d 1174, 1187 (9th Cir. 2009); Lummis v. Lilly, 429 N.E.2d 1146, 1148 (Mass. 1982); RIESER & KALO, *supra* note 63, at 174.

89. *Vital Signs: Sea Level*, NASA'S JET PROPULSION LAB. (June 2019), https://climate.nasa.gov/vital-signs/sea-level/.

90. NAT'L RESEARCH COUNCIL ET AL., ADVANCING THE SCIENCE OF CLIMATE CHANGE 239 (National Academies Press ed. 2010) (eBook).

91. DONALD J. WEUBBLES ET AL., U.S. GLOBAL CHANGE RESEARCH PROGRAM CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT, VOLUME I (2017), https://science2017.globalchange.gov/chapter/12/.

92. NAT'L RESEARCH COUNCIL ET AL., *supra* note 90, at 245; *see also* Jonathan L. Bamber et al., *Ice Sheet Contributions to Future Sea-Level Rise from Structured Expert Judgement*, PROC. NAT'L ACAD. SCI. (June 4, 2019), https://www.pnas.org/content/116/23/11195.

93. WEUBBLES, *supra* note 91, at 351.

94. NAT'L RESEARCH COUNCIL ET AL., *supra* note 90, at 246.

There is a major difference between sea levels rising two feet (as in conservative projections) versus eight feet (as in worst case scenarios), but regardless of the relative extent of sea level rise, the consensus is that sea levels will rise dramatically and with devastating consequences.

In low-elevation coastal zones (defined as coastal zones under ten meters above sea level), the at-risk coastal population will increase from 625 million people in 2000 to at least one billion people by 2060.[95] Most of the world's megacities are located in the coastal zone, and population density is greater in coastal versus non-coastal areas.[96] The United States is not immune to these trends, as nearly 40% of the national population lived in coastal counties in 2010.[97]

Property values of coastal properties will decline.[98] Many will be forced to migrate away from the coasts.[99] Lands will be lost as human development along the coastline prevents ecosystems from providing natural defenses to sea level rise.[100] And, of course, the coastlines themselves will change along with rising sea levels. Some coastlines that were previously natural may become fixed as cities armor themselves with seawalls. Other coastlines will recede as lands are lost. The following images highlight the properties in Miami Beach and Southern Louisiana that will be lost if sea levels rise six feet, and the new coastlines that will be left behind:

95. Barbara Neumann et al., *Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding – A Global Assessment,* PLOS ONE 2 (2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4367969/#sec013.

96. *Id.*

97. *What Percentage of the American Population Lives Near the Coast?*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (June 25, 2018), https://oceanservice.noaa.gov/facts/population.html.

98. *Rising Seas Erode $15.8 Billion in Home Value from Maine to Mississippi*, FIRST STREET FOUND. (Feb. 27, 2019), https://assets.floodiq.com/2019/02/9ddfda5c3f7295fd97d60332bb14c042-firststreet-floodiq-mid-atlantc-release.pdf.

99. Tim McDonnell, *Climate Change Creates a New Migration Crisis for Bangladesh*, NAT'L GEOGRAPHIC (Jan. 24, 2019), https://www.nationalgeographic.com/environment/2019/01/climate-change-drives-migration-crisis-in-bangladesh-from-dhaka-sundabans/.

100. MICHAEL J. SAVONIS ET AL., U.S. CLIMATE CHANGE SCI. PROGRAM, IMPACTS OF CLIMATE CHANGE AND VARIABILITY ON TRANSPORTATION SYSTEMS AND INFRASTRUCTURE: GULF COAST STUDY, PHASE I § 1.6 (2008), https://downloads.globalchange.gov/sap/sap4-7/sap4-7-final-all.pdf.

Miami Beach and Eastern Miami. Lands below sea level are shown in light blue.[101]

New Orleans and surrounding lowlands.[102]

It is unlikely that sea level rise will cease to present challenges to the world's coastal populations and ecosystems anytime soon. The full effect of increased greenhouse gas emissions levels in the atmosphere is exponential and delayed by years or decades.[103] Spatially, the negative

101. *Sea Level Rise Viewer*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., https://coast.noaa.gov/digitalcoast/tools/slr.html/ (last updated Sept. 25, 2019).

102. *Id.*

103. Ove Hoegh-Guldberg et al., *Impacts of 1.5°C of Global Warming on Natural and Human Systems*, *in* GLOBAL WARMING OF 1.5°C, at 282–83 (2018), https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf.

consequences of emissions released from one actor or group of actors is shared by the entire international community and felt disproportionately by poor and disadvantaged communities, minimizing incentives for individual actors to internalize their externalities.[104] And economically, climate change is a cross-sectoral issue, the regulation of which may curtail the profitability of certain industries (such as fossil fuel production, animal agriculture, and transportation), while ensuring the sustainability of others (such as renewable energy production and tourism).[105]

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The takeaway from the above discussion of both the coastline paradox and other characteristics of coastline non-conformism is that coastlines present one of the most vexing and, to a certain extent, impossible, measurement and definitional challenges. While it can be said that many natural objects can prove elusive when attempting to categorize them into easy anthropocentric constructs, coastlines may be one of the most elusive phenomena to grasp.

However, this Article has not yet directly answered a question that is at the heart of this study: does the coastline paradox, and coastline non-conformism more generally, matter in any meaningful legal sense?

The answer is yes, the coastline paradox is legally problematic on multiple levels. As the following Parts will detail, the coastline paradox and coastline non-conformism present coastal stakeholders with legal challenges at the international, national, and subnational levels.

IV. INTERNATIONAL LAW COMPLICATIONS

By frustrating efforts to determine the precise location and extent of coastlines—and often, therefore, political boundaries—the coastline paradox has disconcerting implications for international law and the framework for delineating maritime jurisdictions. In part because coastlines are hard to objectively measure, there is an increasing

104. *Id.* at 245.

105. S*ee* Ryan B. Stoa, *Climate Change Mitigation and Adaptation: The Role of International Ocean and Freshwater Agreements*, *in* SUSTAINABILITY OF INTEGRATED WATER RESOURCES MANAGEMENT: WATER GOVERNANCE, CLIMATE AND ECOHYDROLOGY 445, 446 (Shimelis Gebriye Setegen & Maria Concepcion Donoso eds., 2015), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2417064. The divergence of these challenges has been called a "perfect moral storm" that pushes us towards moral corruption or inaction. Stephen M. Gardiner, *A Perfect Moral Storm: Climate Change, Intergenerational Ethics and the Problem of Moral Corruption*, 15 ENV'T VALUES 397, 398 (2006), http://www.environmentandsociety.org/mml/gardiner-stephen-m-perfect-moral-storm-climate-change-intergenerational-ethics-and-problem-moral.

willingness on behalf of coastal states to exploit coastline ambiguities in order to claim as much marine territory as possible. Unfortunately, the international legal community's inability to stem this tide has fostered a global crisis in the South China Sea, among other coastal waters. There is perhaps no better (or more alarming) example of the coastline paradox and coastline non-conformism contributing to legal instability.

A. A Brief History of Maritime Jurisdictions

For hundreds of years, scholars have written about jurisdictional disputes over the oceans and its vast resources. Even Hugo Grotius, a seventeenth century Dutch scholar often credited for being the father of international law itself, published one of his first works on the law of the sea in 1609.[106] In *Mare Liberum*, Grotius argued that the oceans are owned by all nations and must be open for free passage and trade.[107]

Grotius did suggest, however, that coastal states could exert jurisdiction over the immediately adjacent waters they could bring under their control, a suggestion Cornelis von Bynkershoek later developed into the "cannon-shot rule."[108] According to the rule, coastal states can claim that amount of territorial sea that can be defended with a cannon, which, in practical terms, was later interpreted to be a distance of three miles from shore.[109]

Unfortunately, neither *Mare Liberum* nor the cannon-shot rule put an end to maritime jurisdictional conflicts. Nations continued warring over the oceans while claiming exclusive rights to its resources. In the twentieth century, maritime jurisdictions were dramatically extended, as U.S. President Harry Truman proclaimed that the entirety of the continental shelf off the coasts of the United States would be regarded by the federal government to be under the jurisdiction of the country.[110]

106. David Armitage, *Introduction* to HUGO GROTIUS, THE FREE SEA 3 (David Armitage ed., Indianapolis: Liberty Fund 2004) (1609), https://scholar.harvard.edu/files/armitage/files/free_sea_ebook.pdf; *see also* Richard Tuck, *Introduction* to HUGO GROTIUS, THE RIGHTS OF WAR AND PEACE 3, 7 (Richard Tuck ed., Indianapolis: Liberty Fund 2005) (1625), https://oll.libertyfund.org/titles/grotius-the-rights-of-war-and-peace-2005-ed-3-vols. *But see* John T. Parry, *What Is the Grotian Tradition in International Law?*, 35 U. PA. J. INT'L L. 300, 320 (2014).

107. GROTIUS, supra note 106, at 3, 6, 18, 21.

108. *See* Cornelius von Bynkershoek, *De Dominio Maris Dissertatio*, 18 AM. J. INT'L L. 845, 850 (1924).

109. Wyndham L. Walker, *Territorial Waters: The Canon Shot Rule*, 22 BRIT. Y.B. INT'L L. 210, 210 (1945); H.S.K. Kent, *The Historical Origins of the Three-Mile Limit*, 48 AM. J. INT'L L. 537, 549–50 (1954).

110. Proclamation No. 2667, 64 Fed. Reg. 48,701 (Sept. 28, 1945).

Other countries with extensive continental shelves off their coastlines were all too happy to follow suit.[111]

In 1958, the United Nations convened the Geneva Conference on the Law of the Sea in order to address growing concerns about the legal uncertainty of maritime claims. Although the conference did not come to an agreement regarding the extent of national claims outward from the coast, it did make significant advances with regard to defining coastlines and the coastal zone. In particular, it established a framework for determining baselines from which maritime jurisdictions could be measured.[112]

Noting that in most cases the baseline is the coast itself, the Conference endorsed the occasional use of straight baselines in cases where the coastline is too sinuous or pocked with islands to be of practical use as a baseline.[113] In these circumstances, a straight line can be drawn between points on the coast, thereby converting some coastal waters into "internal waters."[114]

Recognizing that countries might take advantage of this exception to draw straight lines liberally—as that would extend their jurisdiction by enclosing inland waters—the Conference further established a twenty-four-mile closing line rule.[115] Under this rule, a bay can be considered an inland water only if its connecting headlands are less than twenty-four miles apart, and only if a hypothetical semi-circle drawn between those two points would create an area less than the area of the bay.[116]

The Conference would largely be remembered as a precursor to more meaningful law of the sea conventions to come, but in hindsight, it is notable that the 1958 Conference presciently observed the dilemmas created by sinuous coastlines and the cynical ways in which countries might exploit them.

Two decades later, the international community formed what may be the most sweeping and comprehensive international environmental agreement in human history, the United Nations Convention on the Law of the Sea ("UNCLOS"). UNCLOS was the result of a nearly ten-year

111. MICHAEL P. SCHARF, CUSTOMARY INTERNATIONAL LAW IN TIMES OF FUNDAMENTAL CHANGE 116–17 (2013).

112. *See* Tullio Treves, *1958 Geneva Conventions on the Law of the Sea*, AUDIOVISUAL LIBR. INT'L L., http://legal.un.org/avl/ha/gclos/gclos.html (last visited Dec. 10, 2019).

113. Sir Gerald Fitzmaurice et al., *Some Results of the Geneva Conference on the Law of the Sea*, INT'L & COMP. L.Q. 73, 76–77 (1959). By doing so, the conference incorporated principles articulated in the International Court of Justice's Fisheries Case. *See* Fisheries Case (United Kingdom v. Norway), Judgment, 1951 I.C.J. 116, 133, 140–41 (Dec. 18).

114. Fitzmaurice et al., *supra* note 113, at 73, 76.

115. *Id.* at 101.

116. *Id.* at 79, 84; Aaron L. Shalowitz, *Boundary Problems Raised by the Submerged Lands Act*, 54 COLUM. L. REV. 1021, 1028–35 (1954).

negotiation process that aimed to achieve consensus from member states on a wide variety of issues. The Convention contains 320 articles regulating jurisdiction, seabed mining, fisheries, dispute resolution, pollution, military activity, and navigation, among others.[117]

One of the most significant achievements of the Convention is the way in which it defines jurisdictional boundaries. All nation-states are entitled to certain privileges that extend outward from their nautical baseline.[118] For example, states can set laws and regulate all resource use within twelve miles of the baseline (referred to as the "territorial sea") or establish exploitation rights over natural resources within 200 miles of the baseline (referred to as the "exclusive economic zone").[119] The baseline was somewhat generally defined as the low-water line along the coast.[120] Still, UNCLOS established for the first time a recognized jurisdictional framework governing coastal waters.

B. Coastlines as Baselines: The Flaw in the UNCLOS Jurisdictional Scheme

The above description of the development of maritime jurisdictions has been extensively discussed in scholarly literature. And to be sure, many have criticized the jurisdictional scheme for its various downsides, such as the resource exploitation incentives it creates for coastal states or the tragedy of the commons dilemma presented by the high seas.[121]

What is often overlooked, however, is another major flaw in the scheme: that in order to assert outward jurisdictional limits, a baseline must be established from which to measure. And this baseline, of course, is the coastline. Unfortunately, UNCLOS poorly addressed the challenges inherent when using coastlines as baselines.

UNCLOS departs from similar language used in the Geneva Conference with respect to straight baselines. Article 7 of UNCLOS allows countries to use straight baselines in three instances: where a coastline is "deeply indented and cut into," where there is a "fringe of islands along the coast," and where, due to natural processes such as delta flows, the coastline is "highly unstable."[122]

117. *See* Ryan Stoa, *Coastal Zones: The Nexus Between Law, Policy, and the Coastal Environment*, *in* THE ENCYCLOPEDIA OF ENVIRONMENTAL LAW (forthcoming 2020).

118. United Nations Convention on the Law of the Sea art. 2, Dec. 10, 1982, 1833 U.N.T.S. 397.

119. *Id.* arts. 3, 5, 56, 57.

120. *Id.* art. 5.

121. *See*, *e.g.*, Charles Perrings, *The Economics of the Marine Environment: A Review*, ENVTL. ECON. & POL'Y STUD. 277, 296 (2016).

122. United Nations Convention on the Law of the Sea, *supra* note 118, art. 7.

Article 7's permissiveness is tempered, in turn, by four controls: a straight baseline cannot depart from the "general direction of the coast," the seas within the baselines must be governed by the country's regime for internal waters, the straight baseline cannot use as points of reference the coast's low-tide elevations (except if those points have been internationally recognized or contain human infrastructure), and a straight baseline cannot interfere with another country's maritime jurisdictions.[123]

The drafters of article 7 had good intentions. By allowing countries to use straight baselines in good faith, international maritime boundaries would avoid creating a "complex pattern of territorial seas."[124] A U.N. study interpreting the rules stressed that it is not within the spirit of article 7 for countries to use straight baselines in order to unduly increase the territorial sea.[125]

Unfortunately, article 7 leaves ample room for interpretation, failing to clarify how sinuous a coastline needs to be in order for straight baselines to be justified, or how closely integrated to the mainland coast a fringe of islands needs to be in order to loop them into a straight baseline.

As a result, most coastal countries have used article 7 to establish straight baselines along their coasts. According to a 2018 study of the International Law Association ("ILA"), ninety out of a possible 150 coastal countries have used straight baselines to establish their international coastline baseline.[126] Furthermore, there does not appear to be a customary methodology with respect to this practice. The United States uses a three-prong test to determine the appropriateness of a straight baseline, for example,[127] while other countries have drawn straight baselines along coasts that appear fairly straight to begin with.[128] While the United States has objected to this practice, it is

123. *Id.*

124. *See* Int'l Law Ass'n, Baselines Under the International Law of the Sea: Final Report ¶ 15 (2018).

125. *Id.*

126. *Id.* § C ¶ 16, 18.

127. The U.S. test for establishing straight baselines is as follows:

> 1. In a locality where the coastline is deeply indented and cut into, there exist at least three deep indentations; 2. The deep indentations are in close proximity to each other; and 3. The depth of penetration of each deep indentation from the proposed straight baseline enclosing the indentation at its entrance to the sea is, as a rule, greater than half the length of that baseline segment.

Id. ¶ 20.

128. Those countries identified include Albania, Colombia, Costa Rica, Egypt, Guinea, Iran, Madagascar, Norway, Oman, Pakistan, Senegal, and Spain. VICTOR PRESCOTT & CLIVE SCHOFIELD, THE MARITIME POLITICAL BOUNDARIES OF THE WORLD 150 (2d ed. 2004);

perhaps not surprising that countries are cynically exploiting the ambiguous language of article 7 to enlarge their territorial seas.

A similar pattern emerged with respect to baselines drawn to incorporate islands or unstable coasts. The United States established a relatively stringent test to determine the validity of the practice as it relates to island fringes, but many states disregard the test and draw baselines around islands with less perceived connection to the coastal mainland. Vietnam, for example, uses straight baselines to draw an island eighty miles off the coast into its inland waters.[129] The United States objects to these practices, of course, including baselines established by China, Cuba, Italy, Japan, and Mexico, among others.[130] But, since the United States is not a party to UNCLOS, its objections lack persuasive force.

Finally, it is clear that states are pushing the envelope of straight baseline length. Whereas the Geneva Conference suggested a twenty-four mile limit to a straight baseline, state practice appears to reject that norm.[131] At least 263 straight baselines have been created world-wide that exceed forty miles in length.[132] Thirteen countries have drawn baselines that exceed 100 miles in length.[133] One wonders if long, straight baselines are becoming so common that their use might ripen into a rule of customary international law.

As one observer noted, the attempt to limit the application of straight baselines to highly sinuous coasts has failed.[134] In fact, there have been a number of cases brought before courts and tribunals that address conflict between countries that was sparked or exacerbated by the drawing of straight baselines.[135] In its 1951 *Fisheries Case* between Norway and the United Kingdom, the International Court of Justice ("ICJ") implicitly endorsed a straight baseline forty miles in length, to

J. ASHLEY ROACH & ROBERT W. SMITH, EXCESSIVE MARITIME CLAIMS 83–95 (Robin Churchill & Vaughan Lowe eds., 3d ed. 2012).

129. U.S. DEP'T OF STATE, NO. 99, LIMITS IN THE SEAS, STRAIGHT BASELINES: VIETNAM 8 (1983).

130. Int'l Law Ass'n, *supra* note 124, ¶ 21; *see also, e.g.*, U.S. DEP'T OF STATE, NO. 140, LIMITS IN THE SEAS, MAURITIUS: ARCHIPELAGIC AND OTHER MARITIME CLAIMS AND BOUNDARIES (2014); *id.* at 6–10.

131. *See* Int'l Law Ass'n, *supra* note 124, ¶ 25.

132. *Id.*

133. *Id.*

134. *See* 1 D.P. O'CONNELL, THE INTERNATIONAL LAW OF THE SEA 214–15 (I.A. Shearer ed., 1982).

135. *See, e.g.*, Maritime Delimitation and Territorial Questions (Qatar v. Bahrain), Judgement, 1994 I.C.J. 112 (July 1); Territorial Sovereignty and Scope of the Dispute (Eritrea v. Yemen), 22 R.I.A.A. 317–18 (Perm. Ct. Arb. 1998).

date the longest straight baseline endorsed by the ICJ.[136] The case would suggest that a forty-mile-long straight baseline is in compliance with article 7.

In the ongoing geopolitical feud between the United States and China, straight baselines have become a point of contention. The United States alleges that China's liberal interpretation of article 7 betrays the spirit of UNCLOS and has allowed China to claim more than two thousand square miles of territorial seas that would otherwise be regarded as international waters if the baselines were more appropriately drawn.[137]

It should be noted, however, that even if state practice is exploiting the permissive language of article 7, it is not clear if any interpretation would be capable of eliminating the ambiguities that are presented by the world's coastlines.[138] Indeed, the 2018 ILA report declined to propose a limit on the length of straight baselines, noting only that the longer a straight baseline is, the less likely it will be in compliance with article 7.[139]

As explained above, coastlines elude delineation for many reasons. Using them as a reference point for highly-valuable maritime jurisdictions is a recipe for tension, if not conflict.

C. The Arms Race to Create Artificial Coastlines

In recent years, the UNCLOS paradigm and mechanisms for conflict resolution have been tested to their limits. Not only are countries using the Convention's ambiguous definitions for coastal baselines to claim large swaths of marine territory, they are, to an alarming degree, engaged in an arms race to create new coastlines altogether.

The incentive for countries to create new baselines is created in article 121 of UNCLOS. UNCLOS makes a distinction between an island, a rock, and a low-tide elevation (LTE).[140] Those distinctions, and the way in which a landmass is classified, also have large jurisdictional and economic implications.

136. *See Fisheries* (U.K. v. Nor.), Judgment, 1951 I.C.J. Rep. 116 (Dec. 18).

137. *See* Andrew J. Thomson, Keeping the Routine, Routine: The Operational Risks of Challenging Chinese Excessive Maritime Claims 8–9 (Feb. 9, 2004) (unpublished thesis) (on file with author).

138. Even the criteria proposed by the United States for determining the validity of straight baselines can be subjected to various interpretations, for example.

139. Int'l Law Ass'n, *supra* note 124, ¶ 109.

140. United Nations Convention on the Law of the Sea, *supra* note 118, arts. 13, 121.

An island, according to article 121, is a "naturally formed area of land, surrounded by water, which is above water at high tide."[141] A rock, by contrast, is a landmass that "cannot sustain human habitation or economic life" on its own.[142] In addition, article 13 defines an LTE as a landmass that is emerged at low tide but submerged at high tide.[143] These distinctions are ripe for interpretation, exploitation, and manipulation.

Why do these distinctions (and their ambiguities) matter? Because the extent to which a country with sovereignty over one of these formations can claim jurisdiction over the seas surrounding that formation is determined by its classification as an island, rock, or LTE. An island, for instance, entitles the country controlling it to also claim a two hundred-mile exclusive economic zone surrounding the island. A rock is only entitled to a twelve-mile territorial sea. An LTE is entitled to nothing.[144]

Clearly, countries are incentivized to not only lay claim to remote islands, reefs, atolls, rocks, or any other formation that might give rise to a maritime claim, they are also incentivized to do what is necessary to ensure that those formations are defined as islands, not rocks or LTEs. And that is exactly what many countries are doing.

In order to stake territorial claims (and the two hundred-mile exclusive economic zones that may go with them), countries in the South China Sea are "reclaiming" islands, rocks, and LTEs such as shallow coral reef areas by dredging the seafloor in order to build artificial islands and artificial coastlines.[145] Shipping channels are being cut; infrastructure is being built over the reefs, rocks, and LTEs; coastlines are being fixed with seawalls and levees; and housing quarters are being installed to demonstrate human habitation and economic life.[146] The U.S. Pentagon even expressed concern that China would begin to deploy nuclear energy stations in the region.[147]

141. *Id.* art. 121.
142. *Id.*
143. *Id.* art. 13.
144. *See* Steven Geoffrey Keating, *Rock or Island? It Was an UNCLOS Call: The Legal Consequence of Geospatial Intelligence to the 2016 South China Sea Arbitration and the Law of the Sea*, 9 J. NAT'L SEC. L. & POL'Y 509, 513 (2018).
145. *Occupation and Island Building*, ASIA MARITIME TRANSPARENCY INITIATIVE, https://amti.csis.org/features/ (follow "China" hyperlink) (last visited Aug. 30, 2019).
146. *See generally* ASIA MARITIME TRANSPARENCY INITIATIVE, FEATURES, https://amti.csis.org/features/ (last visited Aug. 30, 2019).
147. Christopher Bodeen, *Neighbors Square off with Beijing in South China Sea*, NAVY TIMES, https://www.navytimes.com/news/your-navy/2018/08/27/neighbors-square-off-with-beijing-in-south-china-sea/ (last visited Sept. 23, 2018).

A 2002 agreement between Association for Southeast Asian Nations ("ASEAN") called for self-restraint in the area, but recently all countries have participated in an island development arms race to justify maritime and territorial claims.[148] As a result, the South China Sea has become a conflict of global concern. Relations between China and its neighbors have deteriorated, in part because China has also claimed an ambiguously-explained "nine-dash line" that seemingly cuts into the maritime jurisdictions and coastal resources of Vietnam, Malaysia, and the Philippines and does not appear to be based on a coastline baseline.[149]

These legal tensions came to a head in 2016, when a UNCLOS Arbitration Tribunal rebuked many of China's maritime claims over land formations in the South China Sea.[150] The Tribunal concluded that the classification of a land formation is to be made based on its "earlier, natural condition, prior to the onset of significant human modification."[151] The artificial coastlines purporting to make islands out of rocks or LTEs could not give rise to an island claim and the exclusive economic zone that goes with it.[152]

While the Tribunal's decision is a hopeful sign that countries will cease the arms race to create artificial coastlines, there is reason to be circumspect. First, the Tribunal's decision came after analyzing extensive evidence, such as historical records, nautical charts, satellite imagery, direct observations, and geospatial intelligence.[153] The inquiry was thus fact- and resource-intensive, a reality that may make application of the Tribunal's rule challenging across the world. Second, China rejected the Tribunal's authority over the case in general, and its ruling in particular.[154] Third, it does not appear that island development

148. *See* Ass'n of Southeast Asian Nations, *Declaration on the Conduct of Parties in the South China Sea* (Nov. 4, 2002), https://asean.org/?static_post=declaration-on-the-conduct-of-parties-in-the-south-china-sea-2.

149. Hannah Beech, *Just Where Exactly Did China Get the South China Sea Nine-Dash Line from?*, TIME (July 19, 2016), https://time.com/4412191/nine-dash-line-9-south-china-sea/. *But see* Zhiguo Gao & Bing Bing Jia, *The Nine-Dash Line in the South China Sea: History, Status, and Implications*, 107 AM. J. INT'L L. 98, 99 (2013), https://www.jstor.org/stable/10.5305/amerjintelaw.107.1.0098?seq=1#page_scan_tab_contents.

150. *See* Nilufer Oral,*"Rocks" or "Islands"? Sailing Towards Legal Clarity in the Turbulent South China Sea*, 110 AJIL UNBOUND 280, 281 (2016).

151. South China Sea Arbitration (China v. Phil.), Case No 2013-19, ¶ 305 (Perm. Ct. Arb. 2016).

152. *Id.* ¶ 305–06, 308.

153. Steven Geoffrey Keating, *Rock or Island? It Was an UNCLOS Call: The Legal Consequence of Geospatial Intelligence to the 2016 South China Sea Arbitration and the Law of the Sea*, 9 J. NAT'L SECURITY L. & POL'Y 509, 511, 537 (2018).

154. Tom Phillips, *Beijing Rejects Tribunal's Ruling in South China Sea Case*, GUARDIAN (July 12, 2016), https://www.theguardian.com/world/2016/jul/12/philippines-wins-south-china-sea-case-against-china.

and the construction of artificial coastlines has ceased since the decision.[155]

Ironically, the construction of artificial coastlines may serve to avoid the coastline paradox, as artificial coastlines are often straight and fixed installations. However, coastline non-conformism, and the UNCLOS regime's inability to address it, is at the heart of the South China Sea dispute. A better approach to the problems presented by coastlines is needed in order to resolve geopolitical tensions and environmental destruction. Until then, the integrity of coastlines and UNCLOS will continue to be undermined.

V. FEDERAL LAW COMPLICATIONS

The coastline paradox and coastline non-conformism have certainly presented headaches for the United States in the international arena, partly because the coastline paradox makes the development of a uniform coastline baseline methodology unlikely (if not impossible) and partly because coastline non-conformism has given rise to widespread island building. But the coastline paradox has been problematic in the domestic arena as well. Coastline non-conformism has long sparked conflicts between states and the federal government regarding jurisdictional authority over submerged lands along the coast; the coastline paradox undermines the Coastal Zone Management Act's funding formula; and federal monitoring and mapping of the coastal zone struggles to keep up with coastline change.

A. A Brief History of Coastline Federalism

States and the federal government share a storied history of tension when it comes to governance over coastlines and submerged lands along the coast.[156] In the early history of the country, however, it was generally

155. Megan Specia & Mikko Takkunen, *South China Sea Photos Suggest a Military Building Spree by Beijing*, N.Y. TIMES (Feb. 8, 2018), https://www.nytimes.com/2018/02/08/world/asia/south-china-seas-photos.html.

156. One of the earliest examples of coastline complexities sparking conflict for the United States had several federalism dimensions. At the turn of the twentieth century, the United States, Canada/the United Kingdom, and British Columbia found themselves at odds with each other over the border between British Columbia and Alaska. The conflict illustrated the potential for disagreement between a colonial government (the United Kingdom), national government (Canada), and sub-national government (British Columbia), as well as between two national governments (Canada/the United Kingdom and the United States). The language at issue was contained in an 1825 treaty between Russia (which then controlled Alaska) and the United Kingdom (which then controlled Canada). According to the treaty, part of the border was to "follow the summit of the mountains

accepted that states controlled the marginal seas, or what we now conceive as the territorial sea. In *Martin v. Waddell*, for example, the United States Supreme Court endorsed the state of New Jersey's articulation of the public trust doctrine, which determined that the state held submerged lands in trust for all the people of the state.[157]

Fifty years later, the Supreme Court in *Illinois Central Railroad Co. v. Illinois* held that the public trust doctrine cannot be abdicated by state governments, and that states must manage submerged lands so as to protect the ability of the people to fish, navigate, and carry on commerce over them.[158] And manage submerged lands the states did. Many states (whether through the legislature or state courts) asserted jurisdiction over the territorial sea three miles from shore or further, and federal courts and federal agencies largely acquiesced.[159] Even when natural resource regulation in the territorial seas became controversial, Congress passed a joint resolution quitclaiming any rights of the federal government in tidelands and navigable waters.[160]

Unfortunately for the states, President Truman and the Supreme Court did not share those views. In *United States v. California* and subsequent cases, the Supreme Court established the federal paramountcy doctrine.[161] The doctrine stipulates that the federal government must have "paramount rights" over seaward submerged lands such as the territorial sea, on the grounds that those waters are critical to national defense and international relations.[162]

The decision and its jurisprudential progeny prompted Congress to enact the Submerged Lands Act of 1953 ("SLA").[163] The SLA gave states maritime jurisdiction over the seas within a three-mile distance from the coastline, including title and ownership over the submerged lands, as well as the right to manage and regulate resource use.[164] The "coast line"

situated parallel to the coast." Anglo-Russian Convention of 1825, Gr. Brit.-Russ., Feb. 16, 1825, 75 C.T.S. 95. The treaty went on to clarify that, in certain circumstances, the border "shall be formed by a line parallel to the winding of the coast." *Id.* This being some of the least precise border delineation language seen by the author, the parties submitted to arbitration, which established a compromise border between the United States, the United Kingdom, and British Columbia government claims. *See* Christopher Sands, *Canada's Cold Front: Lessons of the Alaska Boundary Dispute for Arctic Boundaries Today*, 65 INT'L J. 209, 209–10 (2010).

157. 41 U.S. 367, 367 (1842).
158. 146 U.S. 387, 452–55, 460 (1892).
159. RIESER & KALO, *supra* note 63, at 74.
160. H.R.J. Res. 225, 79th Cong. (1946).
161. 332 U.S. 19, 35–36 (1947).
162. United States v. Louisiana, 339 U.S. 699, 704–05 (1950).
163. *See* Submerged Lands Act of 1953, 43 U.S.C. §§ 1301 to 1356b (2012).
164. *Id.* §§ 1311(a), 1312.

is defined by the SLA as "the line of ordinary low water along that portion of the coast which is in direct contact with the open sea and the line marking the seaward limit of inland waters."[165] The SLA does not define these terms further.

In the years since the enactment of the SLA, a number of cases have demonstrated the challenges presented by the coastline paradox. Since the SLA did not define the term "inland waters," states began using straight baselines to incorporate large swaths of open ocean into their inland waters, extending their three-mile seaward boundary as a result.

In a subsequent *United States v. California*, the Supreme Court rejected California's liberal use of the straight baseline approach.[166] Instead, the Court adopted the 1958 Geneva Convention's twenty-four mile closing line rule, which, when applied to the California coast, invalidated most of the state's straight baselines.[167] A number of states have since seen their straight baselines invalidated by the Supreme Court, including Maine's claim that Nantucket Sound is within its internal waters and Alaska's claim that parts of the Beaufort Sea are within its internal waters.[168]

On the subject of coastline non-conformism, both Congress and the Supreme Court have favored fixed coastlines. The Supreme Court has been permissive of states extending state baselines by creating artificial coastlines.[169] In addition, Congress amended the SLA in 1986 so that a coastline (and therefore the state-federal offshore boundary) would be considered fixed if the Supreme Court so held in a decree.[170] In other words, even if a coastline is ambulatory in reality, the legal coastline may not be. The amendment would appear favorable to states if sea level rise pushes the low-water mark further inland, since that would increase the total area of territorial sea controlled by the state.[171]

B. The Coastal Zone Management Act Funding Formula

In 1972, Congress passed the Coastal Zone Management Act in order to address the country's growing coastal populations and corresponding

165. *Id.* § 1301(c).
166. 381 U.S. 139, 167–68 (1965).
167. *Id.* at 164.
168. *See* United States v. Maine, 475 U.S. 89, 90 (1986); United States v. Alaska, 521 U.S. 1, 9, 11 (1997). *But see* United States v. Maine, 469 U.S. 504, 526 (1985) (classifying Long Island Sound as an internal water of New York and Connecticut).
169. *See* RIESER & KALO, *supra* note 63, at 88.
170. 43 U.S.C. § 1301(b).
171. Whether or not this is a favorable development when land loss is taken into account, however, is another matter.

decline in the coastal zone's environmental health and integrity.[172] The CZMA's approach to coastal zone management is dependent on federal-state cooperation, as it relies on state coastal zone management plans to drive land use planning and zoning in the coastal zone, powers traditionally reserved to the states.

The CZMA provides two incentives for states to develop coastal zone management plans. The first is the requirement that federal activities affecting a state's coastal zone or coastal waters must be consistent with that state's coastal zone management plan or program.[173] The ability of a state to declare a federal activity inconsistent with its state plan is a powerful tool for states to help guide federal activities in their coastal region.[174]

The second incentive is financial: Congress appropriates tens of millions of dollars every year for NOAA to distribute to coastal states that develop and maintain a coastal zone management plan. In FY2019, Congress allocated $75.5 million for NOAA to distribute to the states.[175] The funding is primarily used to finance a state's coastal management programs and activities. In many states federal funding through the CZMA comprises a significant percentage of the state's coastal zone management budget.

In 1982, NOAA promulgated regulations to guide states on the formula the agency would use to make its CZMA funding determinations for each state. The weighted formula appears simple: 60% is determined by the state's proportionate share of shoreline miles, while 40% is determined by the state's proportionate share of coastal population.[176] Of course, determining shoreline miles is anything but simple.

The 1982 regulations require NOAA to determine shoreline miles "based on the most recently available data from or accepted by the National Ocean Survey."[177] But, according to the Government Accountability Office, NOAA still uses the coastline length estimates it

172. Coastal Zone Management Act of 1972, 16 U.S.C. §§ 1451 to 52 (2018).

173. *Id.* § 1456(c).

174. *See* Winter v. NRDC, 555 U.S. 7, 33 (2008).

175. LAURA PETES, U.S. DEP'T OF COMMERCE, FY 2019 FUNDING GUIDANCE AND ALLOCATIONS COASTAL ZONE MANAGEMENT ACT SECTIONS 306/306A AND 309 (2019), https://coast.noaa.gov/czm/media/fy19-funding-guidance.pdf.

176. Allocation Formula, 15 C.F.R. § 923.110(c) (2019); Allocation of Section 306 Program Administration Grants, 47 Fed. Reg. 95, 21021 (May 17, 1982).

177. 15 C.F.R. § 923.110(c)(2)(i). The National Ocean Survey office was renamed to the National Ocean Service in 1983. *See NOS Publications*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. CENTRAL LIBRARY, https://noaa.libguides.com/nospubs (last visited Aug. 16, 2019).

developed in 1975 (cited in the Introduction above).[178] NOAA admits that these 1975 figures themselves were developed by hand between 1939 and 1940 using large nautical charts.[179]

In other words, 60% of CZMA funding for state programs is based on coastline length estimates that were developed using rudimentary tools predating World War II. Even if NOAA used sophisticated GIS techniques, a unit of measurement would need to be chosen, and that choice would invariably favor some states over others. Furthermore, the coastline paradox ensures there could never be an indisputable method for calculating shoreline miles.

In addition to using a funding formula heavily weighted toward shoreline mileage, NOAA sets a funding floor and funding ceiling for state grants.[180] This means that states with short coastlines and small populations will still receive a minimum funding amount, while states with long coastlines and large populations will not receive an outsized proportion of the overall funding pie.

Both the weighted formula and the funding floor/ceiling limits favor some states over others. Because the length measurements used by NOAA are more sinuosity-sensitive than the CRS estimates, states with highly sinuous coastlines are at an advantage relative to states with relatively straight coastlines.

In fiscal year 2019, for example, Maine received almost as much funding ($2.766 million) as California ($2.894 million),[181] despite having a population that is twenty-eight times smaller and, according to the CRS estimates, a coastline that is three times shorter.[182] Even with the NOAA coastline estimates used in the weighted formula, California should have received more but was capped by the funding ceiling.[183]

It is within NOAA's discretion to award federal funding to states based on a weighted formula that relies heavily on coastline mileage estimates, just as it is within NOAA's discretion to continue using the length estimates created in 1940. However, the coastline paradox

178. *See* U.S. GOV'T ACCOUNTABILITY OFF., GAO-08-1045, COASTAL ZONE MANAGEMENT: MEASURING PROGRAM'S EFFECTIVENESS CONTINUES TO BE A CHALLENGE 24 (2008); *supra* text accompanying note 2.

179. THE COASTLINE OF THE UNITED STATES, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (1975), https://shoreline.noaa.gov/_pdf/Coastline_of_the_US_1975.pdf; *A Guide to National Shoreline Data and Terms*, *supra* note 2.

180. Coastal Zone Management Act of 1972, 16 U.S.C.A. § 1455(b) (2018).

181. PETES, *supra* note 175.

182. BEAVER, *supra* 1, at 3; *2010 Resident Population Data*, U.S. CENSUS BUREAU (Dec. 25, 2010), https://web.archive.org/web/20101225031104/http://2010.census.gov/2010census/data/apportionment-pop-text.php.

183. Which, in fiscal year 2019, was set at $2.894 million. *See* PETES, supra note 175.

ensures the former decision will always be flawed, while the latter decision will become increasingly outdated.

C. Flood Zone Mapping

A central coastal zone management challenge is disaster risk mitigation and adaptation to extreme events. While extreme events and natural disasters are nothing new for coastal zones, they are occurring globally at increased rates, particularly extreme precipitation and coastal flooding events.[184] A critical component of coastal zone management, therefore, is a robust flood insurance safety net for coastal property owners. Unfortunately for coastal stakeholders in the United States, however, the federal flood insurance framework that provides flood insurance to coastal areas makes rate determinations based on mapping of the coastline and coastal zone that is in dire need of additional resources.[185]

The typical response to coastal hazards in developed countries is to subsidize insurance rates while offering generous disaster relief aid to affected regions.[186] Unfortunately, lawmakers and regulators face a moral hazard problem in doing so, as they may inadvertently be further incentivizing migration toward the coasts by reducing the risk burden for coastal populations (subsidized by inland population taxpayers).[187]

The U.S. National Flood Insurance Program ("NFIP") is an excellent example of the moral and regulatory challenge governments face by entering the risk regulation arena.[188] The NFIP operates by providing eligible communities with flood insurance, with rates tied to maps illustrating the degree of risk to which a particular community is exposed.[189] In areas deemed "Special Flood Hazard Areas," new construction must adhere to certain flood management requirements, and flood insurance is required when purchasing a home.[190] Older buildings grandfathered into the program enjoy subsidized insurance rates and less stringent regulations, while new buildings pay below-

184. *Coastal Hazards: The Importance of "Going Green and Building Strong*,*"* INS. INST. FOR BUS. & HOME SAFETY, https://disastersafety.org/wp-content/uploads/Coastal-Hazards-IBHS.pdf (last visited Sept. 23, 2018).

185. DAN HUBER, CTR. FOR CLIMATE & ENERGY SOLS, FIXING A BROKEN NATIONAL FLOOD INSURANCE PROGRAM: RISKS AND POTENTIAL REFORMS 1 (June 2012), https://www.c2es.org/document/fixing-a-broken-national-flood-insurance-program-risks-and-potential-reforms/.

186. *Id.* at 4.

187. *Id.* at 7.

188. Ryan Stoa, *Droughts, Floods, and Wildfires: Paleo Perspectives on Disaster Law in the Anthropocene*, 27 GEO. INT'L ENVTL. L. REV. 393, 440 (2015).

189. HUBER, *supra* note 185, at 2–3.

190. *Id.* at 1, 3, 5.

market actuarial rates that more accurately reflect risk and must otherwise comply with flood mitigation requirements.[191]

Unfortunately, the program is deeply flawed. Many communities willingly choose unimpeded development along the coastline over subsidized insurance conditioned on building code modifications or stringent land-use regulations.[192] Within participating communities, many individuals remain uninsured. More than half of U.S. counties have insurance penetration rates lower than 1%, including many counties who experience repeated flooding and are required to participate,[193] possibly due to a lack of enforcement capacity.[194] Those who purchase insurance typically do so for less than five years.[195] Buildings grandfathered into the program receive heavily subsidized rates, but even full actuarial rates do not cover the full risk of flood damage.[196]

Rates set by the program, meanwhile, are based on complex maps that struggle to incorporate evolving human and environmental changes that affect risk.[197] Some of these changes, of course, include coastline non-conformism, such as the movement of ambulatory coastlines, the construction of artificial coastlines, and the disappearance of coastlines altogether. Creating and updating maps in this way requires a nimble, well-funded agency and sophisticated techniques, but funding for mapping has been low and inconsistent.[198]

In many cases, FEMA must undertake updates to decades-old flood maps in piecemeal fashion, which often results in dramatic, overnight increases in affected homeowners.[199] The lack of funding has prompted

191. *Id.* at 4.

192. *Id.* at 7.

193. *See* Erwann Michel-Kerjan et al., *Policy Tenure Under the U.S. National Flood Insurance Program (NFIP)*, 32 RISK ANALYSIS 644, 649 (2012).

194. A. Dan Tarlock, *United States Flood Control Policy: The Incomplete Transition from the Illusion of Total Protection to Risk Management*, 23 DUKE ENVTL. L. & POL'Y F. 151, 168 (2012) ("[B]anks [have been] lax in enforcing the mandatory insurance requirement for mortgages.").

195. *See* Michel-Kerjan, *supra* note 193, at 652–53.

196. HUBER, *supra* note 185, at 4.

197. *See Flood Insurance Rate Map*, FEMA, https://www.fema.gov/faq-details/Flood-Insurance-Rate-Map (last updated Dec. 2, 2015).

198. *See* Scott Gabriel Knowles & Howard C. Kunreuther, *Troubled Waters: The National Flood Insurance Program in Historical Perspective*, 26 J. POL'Y HIST. 327, 332 (2014); *see also* Amanda Bryant, *Opinion: When It Comes to Flood Risk, More Data Equals Better Decisions*, NAPLES DAILY NEWS (Aug. 20, 2019, 8:05 AM), https://www.naplesnews.com/story/opinion/contributors/2019/08/20/when-comes-flood-risk-more-data-equals-better-decisions-opinion/2024168001/.

199. Jason Miles, *Updates to FEMA Insurance Map Add Thousands of Homes to Floodplains*, KHOU 11 (Aug. 7, 2019, 4:06 PM), https://www.khou.com/article/news/local/

some states, such as Texas, to start paying for flood map updates themselves.[200] While that could be a healthy contribution to flood protection federalism, it may portend a decline in the ability of the federal government to streamline and consolidate mapping of the coastal zone.

In the aggregate, these limitations have created a program that struggles to accomplish its objectives. To date, the NFIP has been forced to borrow $27 billion from the U.S. Treasury to cover the discrepancy between premiums and actual risk.[201] The Biggert-Waters Flood Insurance Reform Act of 2012 represented recognition that the NFIP and flood policy generally is structurally unsound and sought to improve mapping and mitigation enforcement capacities while moving premiums closer to actual risk.[202] Importantly, it also provided vouchers for low-income households whose rate increases would be severely felt.[203] The reforms did not last long—in March 2014, the Menendez-Grimm Homeowner Insurance Affordability Act rolled back many of Biggert-Waters' strongest provisions.[204] Mapping of the coastline and the coastal zone continues to present a challenge to agencies tasked with disaster risk mitigation efforts.

VI. LOCAL LAW COMPLICATIONS

While differences in coastline measurements are more pronounced at larger scales (at least from a relative human perspective), the coastline paradox still presents legal tensions at the local level. Real estate values of waterfront properties almost always incorporate coastline length estimates (referred to as "frontage"), and, in turn, these estimates become a basis for assessing property taxes.[205] Certain benefits of land ownership—such as the right to wharf out from, subdivide, or develop on the property—depend on meeting minimum frontage requirements.[206]

updates-to-fema-insurance-map-add-thousands-of-homes-to-floodplains/285-52b36d51-067e-411a-ad1b-8be9dc1991c7.

200. *See* David A. Lieb, *States Brace for Long-Term Flood Fight as Damages Mount*, AP NEWS (Aug. 12, 2019), https://www.apnews.com/15f799240ef84204b5e2f2f42aaa8043.

201. Knowles & Kunreuther, *supra* note 198, at 328.

202. Biggert-Waters Insurance Reform Act of 2012, 42 U.S.C. § 4004 (2018); Knowles & Kunreuther, *supra* note 198, at 328–29.

203. Knowles & Kunreuther, *supra* note 198, at 347.

204. *Id.* at 329.

205. *See, e.g.*, Molly Hoeg, *Buying by the (Frontage) Foot*, LAKE SUPERIOR MAG. (May 29, 2013), https://www.lakesuperior.com/lifestyle/homes/352home-buying-by-the-frontage-foot/.

206. *See How to Estimate Front Feet (Water Frontage) If House Sits on Its Own Peninsula*, APPRAISERSFORUM (Nov. 6, 2017), https://appraisersforum.com/forums/threads/how-to-estimate-front-feet-water-frontage-if-house-sits-on-its-own-peninsula.218517/#.

And local governments often use frontage to guide coastal development planning.[207] Each of these dynamics is undermined by the coastline paradox.

A. A Brief History of Littoral Rights

Traditionally, coastal property owners enjoyed certain littoral rights related to the coastline. These included the right to have the water remain in place, the right of access, the right to wharf out, and the right of free use.[208] Today all of these traditional rights are subject to reasonable regulation, as coastlines have become heavily regulated areas of local, state, and federal concern.

What has changed little, if at all, is the legal definition of the public-private boundary of the coastline. For centuries this boundary was determined by the "ordinary" high-tide line, and today, the federal common law rule still employs the "mean" high-tide line.[209] Some states have modified this understanding to some extent (e.g., Florida's use of the meander line along ambiguous coasts), but generally speaking the mean high-tide line remains the boundary between public submerged lands and private dry lands.

In addition to these rights, littoral property owners typically enjoy the right to (and risk of) ambulatory changes in the coastline. That is to say, littoral property owners are entitled to gain land through accretions, but they may also lose land through erosion or avulsion. In that sense, owning coastal property carries with it a significant risk/reward gamble.[210] And in an era of global sea level rise, it seems likely that most properties will see their boundaries recede.

Not without controversy, government agencies are doing what they can to protect coastlines from erosion, avulsion, and sea level rise. Fixed coastlines and beach nourishment projects can provide relief to property owners. But, as mentioned above, doing so may also be viewed as an interference with littoral rights. The Supreme Court in *Stop the Beach Renourishment, Inc. v. Florida Department of Environmental Protection* appears to have endorsed state interventions on public trust grounds, but the ambulatory nature of coastlines in an era of global change promises

207. *See id.*
208. RIESER & KALO, *supra* note 63, at 163.
209. *Id.* at 164.
210. Frank E. Maloney & Richard C. Ausness, *The Use and Legal Significance of the Mean High Water Line in Coastal Boundary Mapping*, 53 N.C. L. REV. 186, 225–26 (1974).

to bring continued complications for coastal property owners and their littoral rights.[211]

B. Real Estate Values and Frontage Taxes

One of the more direct and relatable examples of the coastline paradox undermining markets and legal regimes is in the real estate context. Simply put, waterfront properties with more waterfront (or frontage) are more valuable than properties with less waterfront. And, in general, waterfront properties often occupy the high end of the real estate market. For those reasons, properties with lake or ocean frontage almost always specify the amount of frontage (i.e., length of coastline) the property enjoys.[212] The Great Lakes real estate market, for example, valuates properties based on the total "frontage foot" of a waterfront property.[213]

But how is real estate frontage calculated? Surprisingly, perhaps, there is no consensus, custom, best practice, or commonly imposed regulation. Local real estate markets may have a localized custom in place, or a municipality might propose a methodology based on its tax assessments. But there is no accepted methodology for measuring frontage feet. Even professional real estate appraisers struggle to agree on the appropriate method to measure water frontage when valuating properties or conveying information to potential buyers.[214]

The implications for real estate markets are significant. A property with a highly sinuous waterfront may have an inflated market value because the frontage estimate takes into account most of the sinuosity, even if the usable area of the lot is the same as a property with a relatively straight waterfront. Or, alternatively, a property with a highly sinuous waterfront may have a deflated market value because the frontage estimate was made using a rough linear measurement from one point on the waterfront to another, rendering a lower frontage estimate that fails to appreciate the waterfront's sinuosity.

Savvy real estate investors would be wise, then, to take the sinuosity of waterfront properties into account when comparing frontage estimates. And, since the coastline paradox ensures that not a single

211. 560 U.S. 702, 707, 730 (2010); *see also* Phillips Petroleum Co. v. Mississippi, 484 U.S. 469, 472–73 (1988).

212. Hoeg, *supra* note 205.

213. *Id.*

214. *See, e.g.*, *How to Estimate Front Feet*, *supra* note 206; *see also* LAND VALUATION 2–8, http://publications.iowa.gov/6278/2/Land_Valuation_Section_2.pdf (last visited Aug. 30, 2019) (suggesting that "nearly all lots" can be measured roughly using triangles and rectangles).

frontage estimate on the planet is truly accurate, investors should also take reasonable steps to determine how those estimates were calculated (e.g., with a one-foot ruler versus a linear measurement from point to point) so that comparisons between properties are apples-to-apples. At the very least, frontage estimates should be taken with a grain of salt.

Because property taxes are calculated by assessing the market value of a property, the coastline paradox plays a role in the taxation of waterfront properties as well. Although it will be a factor among many, the frontage enjoyed by a property will contribute to the value assessed and tax imposed. Tax assessors in New Hampshire, for example, are advised to take water frontage into account when valuating a property.[215] The same is true for the Ontario government's tax assessment agency.[216]

Again, however, there is no consensus approach for measuring the length of a coastline for property tax assessment purposes. Unfortunately for homeowners, this presents considerable uncertainty surrounding the taxes imposed on the property. There is anecdotal evidence that tax assessors may use one methodology one year (such as a straight line measurement) and another methodology the next year (such as a sinuous detailed measurement) with little to no notice or explanation provided.[217] In cases where the methodology shift led to a significantly longer coastline (which would be expected for highly sinuous coastlines), the property owner may be hit with an unexpectedly high tax burden.

There is even some historical evidence that governments levied direct frontage taxes on waterfront property owners. These frontage taxes may have played a role in the architectural and land use development patterns of cities and rural areas that can still be observed today. In the Netherlands, for example, frontage taxes were imposed on properties with canal frontage, leading to construction of the narrower, longer homes that characterize Amsterdam's facades.[218]

It is believed that the French Colonial government, which levied frontage taxes on properties along the St. Lawrence River, may have done the same in Louisiana. The map below—depicting Louisiana plantation

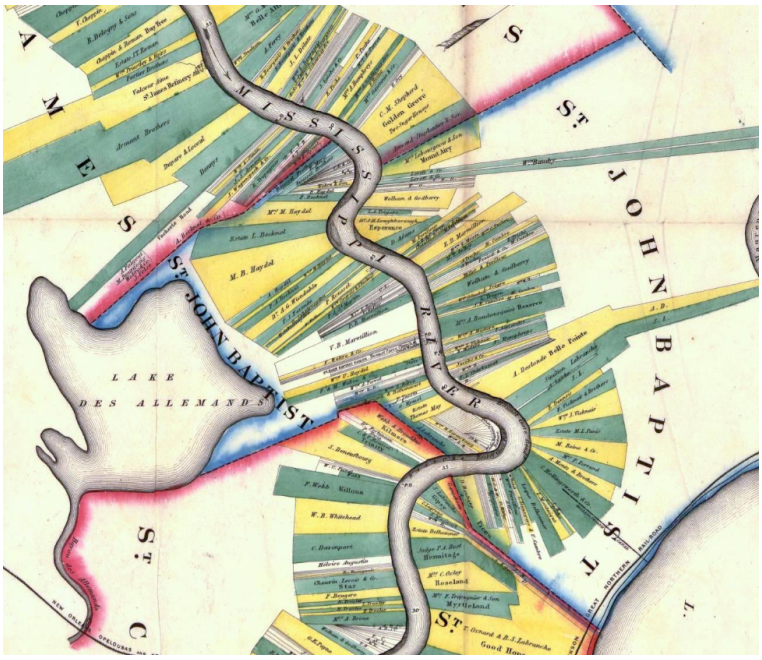
215. ASSESSING STANDARDS BOARD, UNDERSTANDING NH PROPERTY TAXES: THE OFFICIAL NEW HAMPSHIRE ASSESSING REFERENCE MANUAL 5–4 (2014), https://www.wolfeboronh.us/sites/wolfeboronh/files/uploads/asb-manual.pdf.

216. *Waterfront*, MUN. PROP. ASSESSMENT CORP., https://www.mpac.ca/PropertyTypes/ResidentialProperties/Waterfront (last visited Aug. 30, 2019).

217. Winnipesaukee Forum, *How Do You Measure Water Front*, WINNIPESAUKEE (Jan. 3, 2012, 11:06 PM), https://www.winnipesaukee.com/forums/showthread.php?t=13451.

218. Kurt Kohlstedt, *Vernacular Economics: How Building Codes & Taxes Shape Regional Architecture*, 99% INVISIBLE (Jan. 22, 2018), https://99percentinvisible.org/article/vernacular-economics-building-codes-taxes-shape-regional-architecture/.

plots along the Mississippi River in 1858—demonstrates the influence a frontage tax can have on land use development:



Cotton and sugar plantations abut the Mississippi River from Baton Rouge to Louisiana.[219] *It is speculated that this development pattern emerged in response to riverine frontage taxes levied by the French colonial government.*[220]

While direct frontage taxes are uncommon today, the incorporation of frontage into the assessed value of a property for taxation purposes is not. And yet, despite its widespread practice, assessors and real estate markets have not developed a consensus approach to the coastline paradox.

219. Image provided with permission by the United States Digital Map Library, see http://usgwarchives.net/maps/. A. Persac, *Norman's Chart of the Lower Mississippi River*, LIBR. CONGRESS (modified by J. H. Colton & Co., New York), http://usgwarchives.net/maps/louisiana/statemap/1858brno.jpg (last visited Dec. 11, 2019).

220. Frank Jacobs, *The Shotgun Tracts of the Lower Mississippi*, BIG THINK (Aug. 31, 2010), https://bigthink.com/strange-maps/478-the-shotgun-tracts-of-the-lower-mississippi.

C. Benefits Enjoyed by Longer Coastlines

In some cases, coastal properties with longer coastlines may enjoy certain benefits that properties with shorter coastlines do not. Because of these benefits, one might think that coastline length estimates are clear and sophisticated. Unfortunately, that is rarely the case.

One of the littoral rights mentioned above is the right to "wharf out." The right to wharf out refers to the ability of littoral property owners to build a wharf, dock, or pier from their property on the mean high water line to submerged lands owned by the state.[221] Complications have arisen in cases where littoral property owners seek to build a dock on curved shorelines, especially when the coastlines of properties in the area are not extensive, since doing so might negatively impact the right of access of other littoral property owners.[222]

In general, case law suggests that an inquiry of this nature is fact-dependent, and a bright-line rule for measuring the minimum length of coastline needed to wharf out would be inappropriate.[223] Moreover, the extent to which the right to wharf out is regulated or limited in nature is dependent on the state.[224] But it appears some states regulate more than others, and in those cases, the length of a coastline may influence the issuance of a dock permit.[225]

In Florida, for example, statutory permitting requirements for building docks over submerged lands are waived under certain conditions, one of which includes an exemption for a single dock for every sixty-five linear feet of waterfront.[226] Properties with less than sixty-five linear feet of waterfront must seek a permit from the state (in addition to any local authorities).[227] While the statute in question does not clarify the methodology to be used in measuring coastline length for this

221. *See, e.g.*, Jack L. Schoellerman, *Property—Wharfing Out—Riparian Owner Permitted to Use Filled-in Swamp as a Wharf to Reach Navigable Water*, 7 SAN DIEGO L. REV. 684, 686 (1970).

222. Dorroh v. McCarthy, 462 S.E.2d 709, 709 (1995).

223. *See* Pine Knoll Shores Ass'n v. Cardon, 484 S.E.2d 446, 449 (N.C. Ct. App. 1997); Water St. Assocs. Ltd. P'ship v. Innopak Plastics Corp., 646 A.2d 790, 796 (Conn. 1994); RIESER & KALO, *supra* note 63, at 180–81.

224. *See* RIESER & KALO, *supra* note 63, at 185.

225. *But see* 5F, LLC v. Dresing, 142 So. 3d 936, 943, 947 (Fla. Dist. Ct. App. 2014); David Levin, *Do Riparian Rights Include the Right to Build a Dock?*, FLA. WATERFRONT (Apr. 15, 2016), http://www.flwaterfront.com/2016/04/15/do-riparian-rights-include-the-right-to-build-a-dock/.

226. FLA. STAT. § 403.813(b)(1)(5) (2002).

227. FLA. OFFICE OF THE ATT'Y GEN., AGO 90-307, Advisory Opinion Letter on Construction of Dock by Riparian Owners (May 10, 1990), http://myfloridalegal.com/ago.nsf/opinions/85364917c3e58b7f85256245004b6218.

purpose, the permitting agency imposes a linear measurement (from one point on the coastline to the other).[228] This could be problematic for coastal property owners with both a narrow and sinuous coastline, such as a deep bay or thin peninsula, as they may not qualify for the preferential permit exemption.

The length of a coastline may also be a determinant in a property owner's right to subdivide the property. Since state and local governments generally seek to limit further development of the coastline,[229] a subdivision permit application for coastal property might be required to include frontage data.

In New Hampshire, for example, subdivision applications are required to provide frontage data.[230] Curiously, the methodology required to produce that data is a bit of a hybrid approach, defining frontage as "the average of the distances of the actual natural shoreline footage and a straight line drawn between property lines."[231] Presumably "actual" means an estimate that takes a high degree of sinuosity into account, though that is not further defined.

Averaging the actual estimate with the linear estimate may be an attempt to compromise between sinuous and straight property owners. Also notable is the fact that the same agency uses a different definition of frontage (just the "actual" footage this time) when determining if an accessory structure can be built in the waterfront buffer.[232]

Finally, as might be expected, properties with longer coastlines are advantaged with respect to the common law right to a view of the water. Though attempts to regulate the littoral property owner's right to a view have been upheld when reasonable (such as to maintain protected coastal vegetation), some states recognize and protect the right to a view more rigorously.[233]

In order to hedge against this, state and local governments may regulate the ways in which a property owner can maintain direct views of water by tying this right to the length of a coastline. One municipality, for example, allows owners to maintain a thirty-five foot-wide viewing

228. FLA. DEPT. ENVTL. PROT., WHAT'S UP DOCKS: NAVIGATING THE DOCK PERMITTING PROCESS (2017), https://floridadep.gov/sites/default/files/WUD_NavigatingDockPermitting Process.pdf; *see also* Jimerson Birr, *Accessing Navigable Water: Allocation of Riparian Rights Among Landowners*, JIMERSON BIRR (June 15, 2018), https://www.jimerson firm.com/blog/2018/06/accessing-navigable-water-allocation-riparian-rights/.

229. *See infra* Section IV.D.

230. N.H. CODE ADMIN. R. ANN. N.H. Dep't. Envtl. Servs. § 1003.07(*l*) (1996).

231. *Id.* § 1002.4.

232. *Frequently Asked Questions*, N.H. DEP'T. ENVTL. SERVS., https://www.des.nh.gov/organization/divisions/water/wetlands/cspa/categories/faq.htm#faq15 (last visited Aug. 30, 2019).

233. *See, e.g.*, Hayes v. Bowman, 91 So. 2d 795, 801 (Fla. 1957).

corridor for every one hundred feet of coastline, or 35% of the frontage on lots with less than one hundred feet of coastline.[234] Crucially, however, the viewing corridor allowances can be combined (i.e., run contiguously) for properties with two hundred feet of frontage or more, an experiential multiplier effect advantageous for longer coastline properties.[235] No methodology for determining frontage is provided.

D. Coastline Development Planning

Local governments in the United States are experimenting with an increasing array of regulatory tools to manage coastlines and the coastal zone. These include planning tools (e.g., comprehensive coastal zone planning), regulatory tools (e.g., zoning, building codes, and permitting/licensing), spending tools (e.g., capital improvement projects, eminent domain proceedings, conservation easements), and taxation tools (e.g., tax incentives and transferable development credits).[236]

Several of these tools use frontage estimates to guide sustainable development of the built environment or encourage development according to planning and zoning priorities.

Several states and local governments have imposed minimum frontage requirements on coastal properties, for example. In Maine, coastal property lots must have a minimum of one hundred and fifty feet of shore frontage for residential lots, and two hundred feet of shore frontage for commercial lots.[237] The state also provides tax relief for open space lots that provide a public benefit, but coastal lots with improvements must exclude at least one hundred feet of shore frontage from the tax benefit.[238]

Coastal frontage requirements are used more variably in local planning and zoning requirements. In Bayfield, Wisconsin, the local zoning ordinance adjusts the minimum frontage required according to the zoned use. Single-family residences must have a minimum of one hundred and fifty feet of frontage,[239] while multiple unit developments

234. BAYFIELD, WI., ZONING CODE § 13-1-23(a)(1)(a) (2019).

235. *Id.*

236. JESSICA GRANNIS, ADAPTATION TOOL KIT: SEA-LEVEL RISE AND COASTAL LAND USE 2–4 (2011), http://www.georgetownclimate.org/files/report/Adaptation_Tool_Kit_SLR.pdf.

237. *Maine's Waterfront Real Estate FAQ*, WATERFRONT PROPS. ME., https://www.waterfrontpropertiesofmaine.com/maine-waterfront-real-estate-faq/ (last visited Aug. 30, 2019).

238. *Maine Revenue Services Property Tax Division Property Tax Bulletin No. 21*, ME. REVENUE SERVS. (Feb. 21, 2019), https://www.maine.gov/revenue/forms/property/pubs/bull21.pdf.

239. Hoeg, *supra* note 205.

must have two hundred feet, and mobile home parks must have six hundred feet.[240]

Sioux Lookout, Ontario, a rural community prominently located on a large lake, incorporates frontage requirements into each of its permitted zoning uses.[241] Frontage is defined as the "front lot line," but, in the case of lakefront properties, the front lot line is also the shoreline.[242] Thus, coastline length is a critical factor in the entire planning and zoning scheme of the community.

The policy objective of a minimum frontage requirement for individual lots is to ensure that the coastline does not become over-developed, as that would detrimentally impact the aesthetic appeal of the coastline while reducing the amount of open space capable of providing ecosystem services to the coast (such as erosion and flood control).[243] Some scholars have promoted the idea of a frontage tax in urban areas as a means of promoting density and slowing the rate of urban sprawl.[244] Minimum frontage requirements work inversely by preventing density and promoting undeveloped—or at least less developed—coastlines.

By now, it should be clear that while frontage requirements can serve as a useful coastline development tool for local authorities, the approach will necessarily suffer from the inherent complexities of the coastline paradox. Many frontage requirements do not clarify how the frontage estimate is to be calculated. Or, in the case of Sioux Lookout, the calculation is linear, connecting points between property lines.[245] While there is simplicity to that approach, some coastal property owners with highly sinuous coastlines may suffer if their properties don't qualify for certain uses within the zone.

None of the frontage requirements cited above acknowledged the limitations presented by the coastline paradox, and few provided a clear methodology for measuring coastlines. While there is no easy or incontrovertible solution to the coastline paradox in these instances, a

240. BAYFIELD, WIS., ZONING CODE § 13-1-23(a)(1) (2019), https://www.bayfieldcounty.org/DocumentCenter/View/8968/ZONING-SECTION-13-Article-B-Sec-13-1-20-thru-13-1-39-doc-Revised-5-28-2019-General-Provisions.

241. *See* MACNAUGHTON HERMSEN BRITTON CLARKSON PLANNING LTD., SIOUX LOOKOUT ZONING BY-LAW (Nov. 21, 2018), https://www.siouxlookout.ca/en/invest-grow/resources/Sioux-Lookout-Zoning-By-law-85-18-Nov.-21-2018-ws.pdf.

242. *Id.* at 3–20.

243. Edward D. Barbier et al., *The Value of Estuarine and Coastal Ecosystem Services*, ECOLOGICAL SOC'Y AM. (May 1, 2011), https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/10-1510.1.

244. Peter F. Colwell & Geoffrey K. Turnbull, THE PROPERTY TAX, LAND USE AND LAND USE REGULATION 310 (Dick Netzer ed., 2003).

245. MACNAUGHTON HERMSEN BRITTON CLARKSON PLANNING LTD., *supra* note 241, at 3–20.

recognition of the challenge along with an articulated position on the issue would alleviate many legal ambiguities and inequities.

VII. SOLUTIONS AND CONCLUSIONS

Too little attention has been paid to the coastline paradox. Neither policymakers nor scholars have sufficiently explored the ramifications of this counter-intuitive phenomenon. Where the coastline paradox has been discussed, it is often relegated to a brief discussion of its curious properties.

That is unfortunate, because the coastline paradox is deserving of more scholarly attention. This is particularly true in the legal literature, as the coastline paradox presents coastal stakeholders with a dizzying array of complications. Many of these complications have significant legal implications that are underappreciated, despite the apparent tensions being created by the coastline paradox under the surface.

To that end, this Article has focused on exposing the coastline paradox as a source of potential legal conflict. Throughout the Article, the implications of the coastline paradox—for international, federal, and local law—have been identified and explored. To be sure, the implications discussed in this Article are not an exhaustive list of problems the coastline paradox might pose for coastal stakeholders. More research is needed to bring these problems to light.

More research is needed to find potential solutions to these problems as well. Although not the primary aim of this Article, five solutions to the legal challenges presented by the coastline paradox are proposed here. The first two are generally applicable, while the next three address problems created at the international, federal, and local levels.

First, there is a need for more awareness of the coastline paradox. If more coastal stakeholders (particularly policymakers) were aware of the inherently elusive nature of coastline length (and other non-conforming properties), it is doubtful that coastline length would be so prominently relied upon in legal and policy circles.

Coastlines are a poor proxy for determining jurisdictional boundaries, for example, and relying on coastline length for funding or tax purposes is questionable at best considering the impossible task of measuring accurately. It is possible, perhaps even likely, that these mechanisms would be replaced with more reliable methods if more awareness of, and appreciation for, the coastline paradox existed.

Second, if measurements of coastlines in general, and coastline length in particular, are going to be used as the basis for decisions with legal and economic consequences, the parties making those measurements must at least acknowledge the methodology used to make

them. In many of these instances described in this Article in which coastline length has been given legal or economic significance, it is disturbingly unclear how coastline length should be measured.

A linear measurement (from one point on the coastline to another) is the simplest method (though also the least precise), and might be appropriate for coasts with low sinuosity or in situations where resources are scarce. Where coasts are more sinuous and resources are available to conduct more sophisticated measurements, a unit of measurement can be specified. Either way, stakeholders must understand how coastlines are to be measured in order to understand their rights and liabilities and compare coastlines consistently.

Third, the use of long straight baselines as an indicator of maritime rights should be reined in. While the United States has expressed concerns over this issue, other countries should also do their part to limit the use of straight baselines and the potential for their widespread use to develop into a rule of customary international law. At the moment, long straight baselines are being used cynically to envelop large swaths of open ocean into countries' internal waters, extending their maritime rights seaward.

Though the ILA's 2018 report on straight baselines declined to propose a precise outer limit, it did note that the ICJ implicitly found a forty-mile straight baseline to be in compliance with UNCLOS. As that is the longest straight baseline to be validated by the ICJ, it seems an appropriate limit in the international context.

Fourth, the federal government should invest in coastline mapping and measurement technologies that would enable agencies to provide a more accurate picture of coastlines and coastline change. Current coastline length estimates used by NOAA, for example, were taken in 1940 and published in 1970. Updating those estimates (while clarifying the unit of measurement used to produce them) would be a welcome first step to addressing the coastline paradox and its complexities.

In addition, NOAA should consider revisiting its CZMA funding formula. Developed in 1982, the formula is simplistic in that 60% is weighted toward shoreline miles. A more holistic formula might be more responsive to coastal challenges and the funds needed to address them.

Fifth, and finally, any local legal frameworks (such as local zoning ordinances or tax assessments) that use coastline length to determine real estate values or the benefits and obligations of coastal property owners must identify the appropriate measurement methodology to be used by stakeholders.

When water frontage is a key variable in real estate values, for example, an unclear methodological framework (or the absence of a local custom) creates needless complexity and confusion for market

participants. A simple articulation of the unit of measurement local government officials or appraisers must use (or are expected to use) would provide clarity and consistency when making measurements and comparisons between properties.

The coastline paradox is a fascinating example of fractal geometry at work. As a naturally occurring phenomenon, it also presents a beautiful illustration of the ways in which natural objects refuse to conform to the rigid expectations of human society.

But the coastline paradox is more than just a curious oddity. Because coastlines play such an important role in legal frameworks around the world, the coastline paradox is also a source of tension. It is important, then, for coastal stakeholders to acknowledge and address the legal, political, and economic implications of the coastline paradox. After all, as long as the shores of the world's coastlines are left to their own, natural devices, they will never be perfectly straight and their lengths will never be objectively measurable.