The Threat of Sea Level Rise on the Northern Oregon Coast

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Abstract

Sea level rise poses particular risks to coastal communities. With an estimated rise of 18 to 59 cm by 2100 (Nageswara et al., 2008), coastlines around the world have become vulnerable to higher sea levels. While these impacts may not yet be felt on each coastline, proactive policy measures should still be taken to mitigate future damages. To serve this need, coastlines must be assessed and rated depending on vulnerability to sea level rise. Efforts like this have already begun. The Coastal Vulnerability Index is the result of one such effort that measures the vulnerability of coastlines to sea level rise. The index takes into account five variables; geomorphology, percent slope, significant wave height, mean tide range, and erosion/accretion rates. These variables are classified by vulnerability and result in the CVI. This study created this index for the northern Oregon coast. While the Oregon coast is not the most threatened coastline to sea level rise, assessment of it is still necessary. Land features like estuaries and wetlands, which are important to natural processes, are threatened by rising sea levels. Creating a CVI for the northern Oregon coast can be important for directing future policy measures and mitigation efforts that protect the coastline.

Introduction

Climate change poses a particular threat to the world's oceans and, by association, coastal communities. Rising temperatures have contributed to the melting of glaciers and ice caps, leading to an excessive amount of water entering the world's oceans (Fischer et al., 2009). Higher temperatures also have a direct impact on the oceans themselves. Oceans are the main storer of heat on the Earth's surface (Fischer et al., 2009). All of the stored energy contributes to thermal expansion, which expands the volume of the oceans (Fischer et al., 2009) These two impacts have compounded and resulted in a rising sea level. Projections indicate that sea level can rise between 18 to 59 cm by 2100 (Nageswara et al., 2008). This has different impacts around the globe.

The effects of sea level rise are not uniform. Sea level rise has already had catastrophic impacts on small islands in the Pacific. The island nation of Kiribati has been inundated with flooding as tides become higher (Ives, 2016). Full communities become uprooted as entire islands sink below the tides. This has raised massive concern for a potential humanitarian issue (Wyett, 2014). Wyett argues the need for proactive policy measures in Kiribati to mitigate the impact of sea level rise. The Kiribati government should be taking steps to guide the relocation of its citizens. Important infrastructure should be moved away from the most vulnerable areas.

In the United States, the threat of sea level rise is less severe. There is no fear of a potential humanitarian crisis spurred by sea level rise as the US is a bigger land mass that allows its population to move. There are still economic consequences to sea level rise. Properties along coastlines risk damage or complete destruction due to rising tides. By 2100, the impact is predicted to value $98 billion (Neumann et al., 2015). Though not as severe as Kiribati, the idea of creating proactive measures to mitigate sea level rise that was argued by Wyett is still applicable.

Within the US, impacts can vary by state. Southern states have already seen damage to coastal properties (Brangham, 2022). On the other hand, impacts in Oregon have been less noticeable. In fact, most residents on the Oregon coast see sea level rise as a “longer-term” issue that doesn’t require immediate action (Hoelting & Burkardt, 2017). Rather, coastal Oregonians are more concerned with higher temperatures, drought, and abnormal ocean patterns (Hoelting & Burkardt, 2017). But the lack of concern shouldn’t prevent mitigation efforts. Sea level rise is predicted to have an impact on the coastline; mainly with property damage or changes to land features (Flitcroft & Giannico, 2013). Wetlands and estuaries in particular are at an acute risk to sea level rise (Flitcroft & Giannico, 2013). Those two land features are not only integral to local ecosystems but the natural processes that exist along the Oregon coast. Wetlands themselves are key features in flood control (Mitsch & Gosselink, 2000). Losing wetlands can exacerbate the vulnerability of the coastline to future hazards. This provides good reasoning for the creation of proactive mitigation measures.

The coastline would then need to be assessed to find regions most vulnerable to sea level rise. One of these measures is the Coastal Vulnerability Index (CVI). The CVI has been deployed around the world to measure the vulnerability of coastlines to sea level rise (Nageswara et al., 2008; Pendleton et al., 2004). Employing this index on the Oregon coast can be an important step in influencing further mitigation efforts. For this paper, the study area was narrowed to the northern Oregon coast; Lincoln, Tillamook, and Clatsop counties. The smaller focus area refines the resulting index as there is no aggregation of values across the entire Oregon coastline. A central question was created to drive the project: how vulnerable is the northern Oregon coast to sea level rise?

Methodology

CVIs have been constructed in multiple locations around the world to measure the vulnerability of regional coastlines to sea level rise. The USGS has been active in creating these indexes across the United States (Pendleton et al., 2004). This paper follows the steps outlined by Nageswara et al. who constructed a coastal vulnerability index for the Andhra Pradesh section of the Indian coast. The Nageswara et al. paper was chosen over USGS publications for the fact of detail. USGS publications like Pendleton et al. described methodologies in broad language that made replication difficult. Nageswara et al. provided steps and details for the construction of their CVI. Because of this, Nageswara was the main methodology that was followed. Supplemental information from USGS publications was used sparingly, with Pendleton et al. being the main USGS publication considered.

The CVI is constructed using five variables that are each divided into five classes based on vulnerability. These variables are then combined into one data layer depicting vulnerable sections of coastline. The resulting CVI is ranked on a scale of four vulnerability classes; “Low”, “Moderate”, “High”, and “Very High.” The basic analytical framework followed that of Nageswara et al. It involves processing five data layers and classifying them dependent on vulnerability to result in a CVI layer. The variables, as well as the classification and ranking of each, is provided in Table 1.

Table 1: CVI variables and classification for the vulnerability classes

	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Slope percent	> 1	0.5 to 1	0.1 to 0.5	0.05 to 0.1	< 0.05
Mean tide range (m)	< 1	1 to 2	2 to 4	4 to 6	> 6
Significant wave height (m)	0.8 to 1.7	1.7 to 1.9	1.9 to 2.1	2.1 to 2.3	2.3 to 2.4
Erosion/accretion (m/yr)	> 2	1 to 2	-1 to 1	-1 to -2	< -2
Geomorphology	Rocky shorelines	Embayed beaches	High dunes	Estuaries	Beaches

Variables chosen align with those used by Nageswara et al. Additional information from Pendleton et al. was used to adjust classification ranges. Coastal slope percent was the first variable considered. Steep slopes were given a low vulnerability rating while shallow slopes were given a high vulnerability rating. The logic behind this stems from the fact shallow slopes will secede more during sea level rise due to being lower in elevation. Steep slopes rise in elevation over a shorter distance making sea level rise less impactful. Exact class ranges were taken from Nageswara et al. Mean tide ranges were also considered. From Pendleton et al., “tidal range is linked to both permanent and episodic inundation hazards.” A wide tide range can have an impact on flooding in coastal regions. Class ranges were determined by Nageswara et al. Significant wave height was considered as a proxy variable for wave energy that drives sediment change along the coastline (Pendleton et al., 2004). High wave heights were given high vulnerability ratings while low wave heights were given low vulnerability ratings. Classification ranges were determined based on standard deviations (Nageswara et al., 2008). Erosion and accretion were considered as measures for shoreline change. Noting shoreline change in this index provides information on current physical trends that can be exacerbated by sea level rise. The class ranges were determined by Pendleton et al. Geomorphology is the last variable to be considered. It incorporates qualitative data on land features that differ in relative erodibility. Class ranges were determined by Nageswara et al. Table 2 outlines the sources for the data used.

The Methodology is divided into five sections, each section describing the steps taken to process one of the five data layers. ModelBuilders are provided depicting the process taken for constructing each variable. Separating ModelBuilder into different sections instead of keeping it as one whole model improves readability and ease of operability.

Table 2: Data used for this spatial analysis

Name	Date	Resolution	PCS	GCS	Creator	Attributes	Quality	Creation method	Relevance
Significant wave height	2023	N/A	Web Mercator	WGS84	NOAA	The height of significant waves for each month and annually.	Covers the full study area. Sufficient amount of data points to be used in creating an interpolated surface model.	Altimeters located in the ocean use radar to measure the height of waves from the sea floor over a set interval	Significant waves are one of the variables included in the CVI. It acts as a proxy variable for wave energy and sediment movement.
Mean tide range	04/2024 to 05/2024	N/A	N/A	MLLW Tidal datum	NOAA	High and low tide heights, subtracted and averaged.	Lack of data points (only three) to be sufficiently accurate for the model. Was still used; the tide range was applied to each part of the coastline it was closest to.	NOAA stations located on the coast measure the water level at high tide and low tide	Mean tide range is one of the factors included in the coastal vulnerability index creation. Tide range can influence flood hazards.
DEM	12/29/2008	10 m	Oregon Lambert (meters)	NAVD88	OR Dep. of Forestry	Surface elevation for the state of Oregon.	Complete for study area, adequate resolution	LiDAR scanned the landscape to measure elevation	DEM can be used to calculate slope which is a key variable in creating the CVI.
Mean water level shoreline	2016	N/A	Web Mercator	NAD 83	NOAA	A line feature depicting the shoreline at mean water level.	Covers the full study area. Line feature.	Vectorized the shoreline at mean water level	The shoreline was used to delineate physical surface features along the coastline. The resulting CVI is cast to the shoreline to create a line layer depicting vulnerability of the shoreline to sea level rise.
National Wetland Inventory	05/17/2024	N/A	Web Mercator	NAD 83	USFWS	Depicts the different water features and wetland types across the state of Oregon. These range from estuaries to rivers to marine wetlands, etc.	Covers the full study area. Vector format	USFWS continuously monitors wetlands across the state and updates the shapefiles accordingly.	Used to note wetlands and estuaries which were used in the creation of the geomorphology layer, which was then used as a variable in constructing the CVI.
Shoreline for erosion and accretion	2013	N/A	Web Mercator	WGS84	USGS	Rate of erosion or accretion, length of each shoreline section, date and time measured.	Covers the study area. Vector format.	USGS looked at historic shoreline positions over 100 years and created a vector feature for each position. Erosion or accretion rates were then calculated using a rate-of-change regression statistic	Erosion and accretion is one of the variables used to construct the CVI. Current trends with erosion and accretion can become exacerbated due to sea level rise.

Slope classification

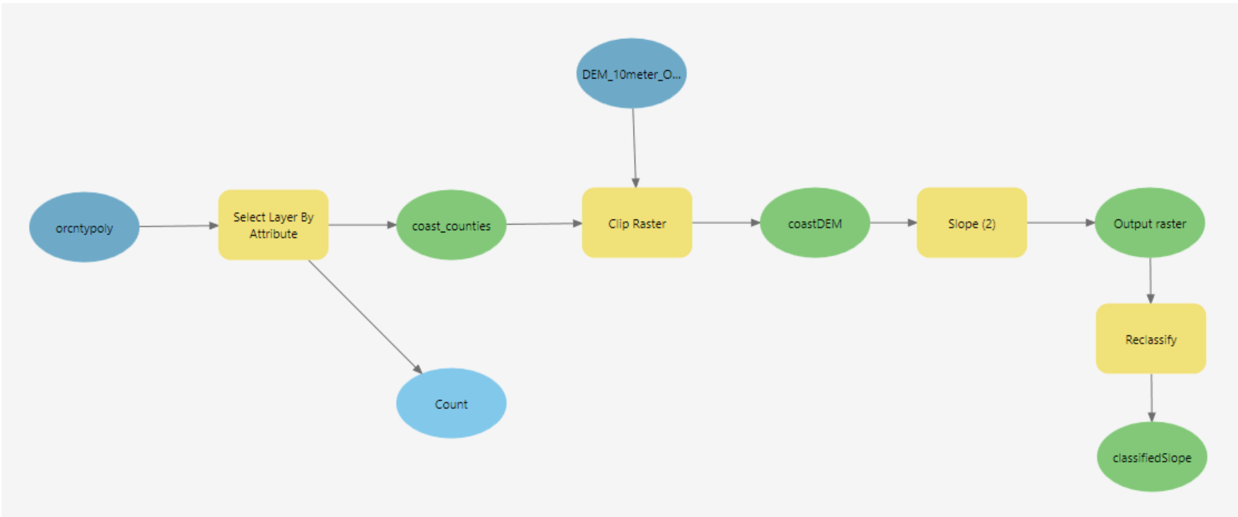

Figure 1: ModelBuilder for classifying slope

Figure 1 shows the ModelBuilder workflow for creating and classifying the slope raster. Initial steps involved taking the vector layer for counties in Oregon and selecting counties along the northern coastline; Lincoln county, Tillamook county, and Clatsop county. These counties were then used to clip a 10 m resolution DEM of Oregon created by the Oregon Department of Forestry to create a DEM that only occupies the coastal region. This was then fed into the Slope tool to create a slope raster of coastal Oregon. The slope raster was then classified according to the classification ranges depicted in Table 1 to result in the classified slope raster.

Mean tide range classification

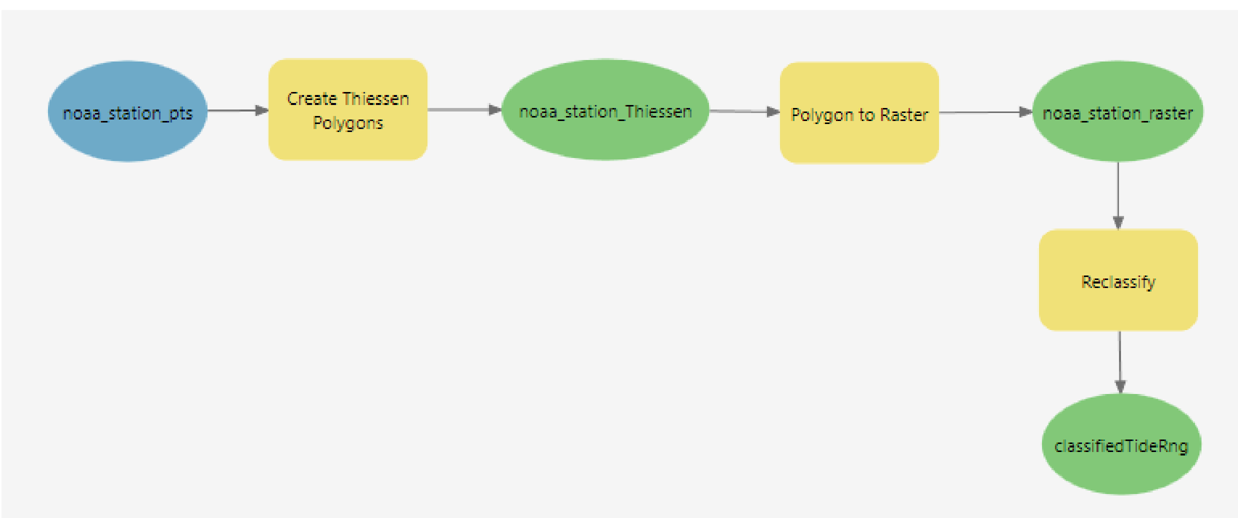

Figure 2: ModelBuilder for classifying tide range

Figure 2 shows the ModelBuilder workflow for classifying the mean tide range along the Oregon coast. Data was collected from coastal NOAA stations. Data quality became an issue with this layer. There are only three active NOAA stations along the northern Oregon coast that measure tide heights and changes. Despite quality issues, the data was still used. Nageswara et al. described assigning the coastline to the closest point where mean tide height was collected. For this project, this was achieved by creating Thiessen polygons around the point locations for NOAA stations. The result was then converted to a raster. Each tide range was then classified following the class ranges depicted in Table 1 to result in the classified mean tide heights layer.

Significant wave height classification

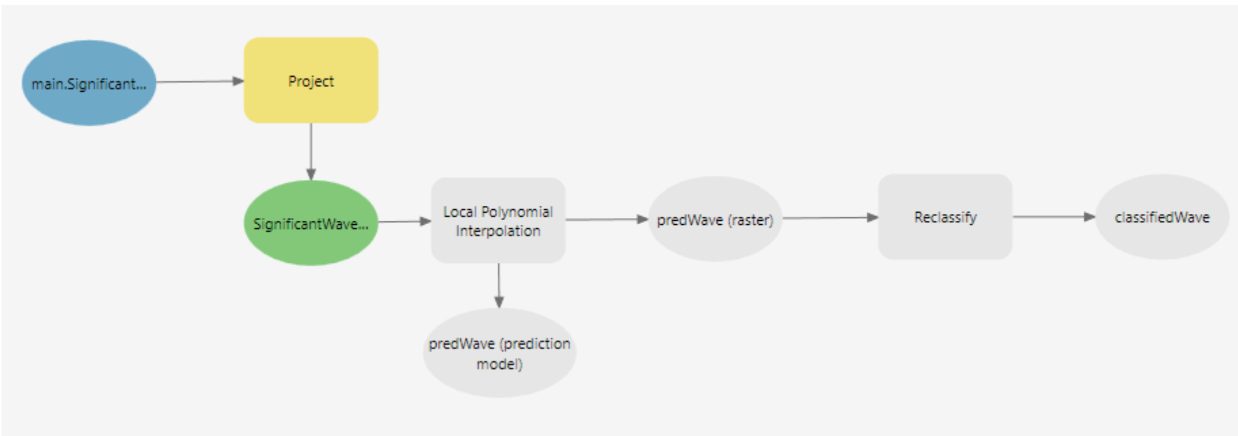

Figure 3: ModelBuilder for classifying significant wave heights

Figure 3 shows a ModelBuilder workflow for classifying significant wave height. Nageswara et al. achieved the creation of this layer by creating a surface model of predicted wave height values. The same process was taken in this project using a preset workflow provided through Geostatistical Wizard in ArcGIS Pro. Significant wave height data was sourced from NOAA and used in Geostatistical Wizard. Local polynomial interpolation was used for the creation of the surface model. The predicted surface model resulted in a Root-Mean-Square value of 0.02, which essentially means the predicted model is a good representation of the true model. The predicted surface model was then classified according to the class ranges depicted in Table 1 which resulted in the classified wave heights layer.

Erosion and accretion classification

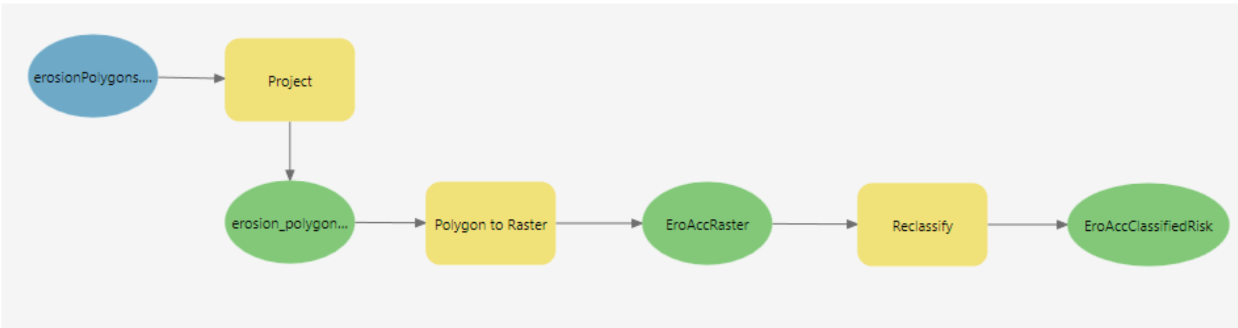

Figure 4: ModelBuilder for classifying erosion and accretion

Figure 4 shows the ModelBuilder workflow used for classifying erosion and accretion rates along the coastline. USGS provided data on long term (100 years) erosion and accretion rates in vector format. A polygon area represents meters of ground gained or lost per year. These polygons were then converted to raster and reclassified according to the class ranges outlined in Table 1 to result in the classified erosion and accretion layer.

Geomorphology classification

The creation of the geomorphology layer involved manipulating five data layers that represented the five physical land categories depicted in Table 1. Input layers for this varied from polygon to line features. The final goal for this portion was to have a polygon layer delineating physical land features along the coastline. Two layers were already in polygon format; the dunes layer and the estuaries layer. Beaches, embayed beaches, and rocky shorelines were all derived from one line feature. For ease and visibility, the model is split into two figures. The first figure depicts the manipulation and conversion of the line features to polygons. The second figure then shows steps taken to merge the different layers into one dataset.

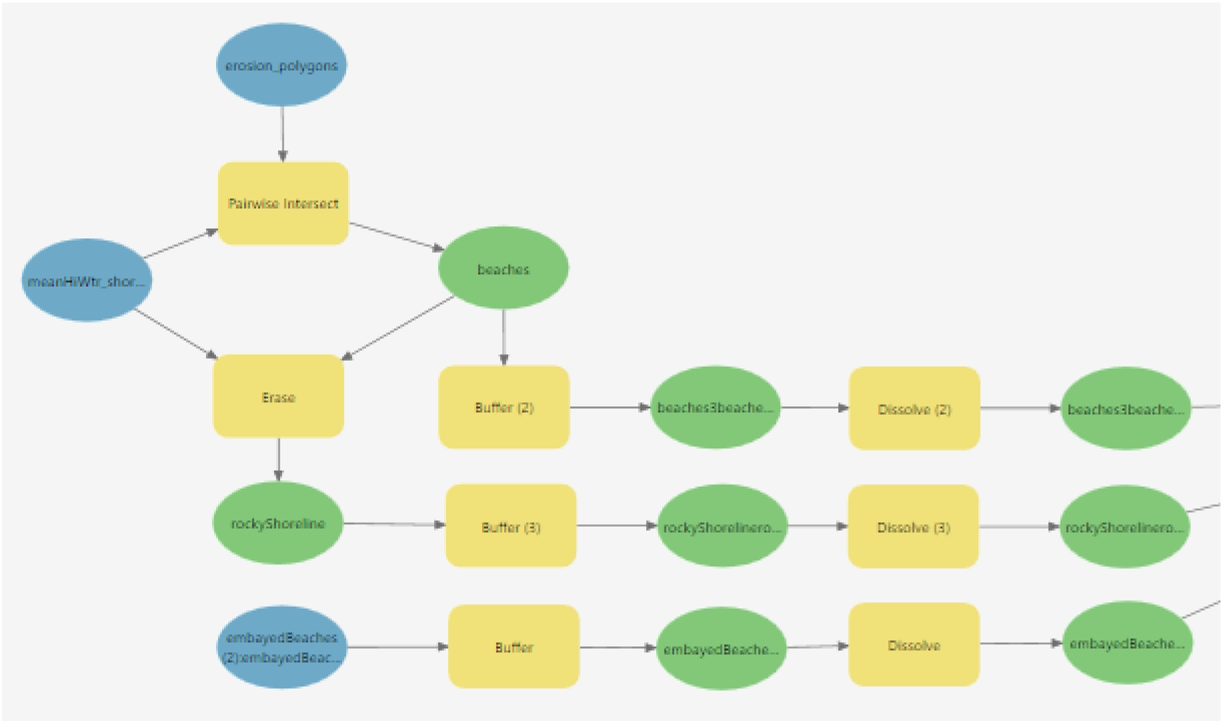

Figure 5: Initial ModelBuilder for geomorphology; manipulating line features

Figure 5 details the initial steps taken in ModelBuilder to manipulate and convert the line features to polygons. This first required delineation of the different land features along the coastline. The coastline layer was created by NOAA. It depicts the shoreline of Oregon at mean tide. This layer was segmented into the different physical features that were outlined in Table 1 to create a line feature for physical features along the coastline.

The first layer to be outlined was for beaches. Beaches were delineated with the addition of the erosion and accretion data layer which was used previously. This is because the erosion and accretion data layer was created by a comprehensive effort from USGS to gather data on every beach in Oregon, no matter the size. Intersects between the erosion and accretion layer and the coastline layer delineated sandy beaches. Because the erosion and accretion layer depicts all sandy beaches, the absence of polygons in that layer implies a rocky shoreline. This was then used to create the rocky shoreline layer. Embayed beaches are not a major feature in Oregon. Because of this, it was simple to delineate these features by hand. Each of these line features were buffered and dissolved to create a polygon feature.

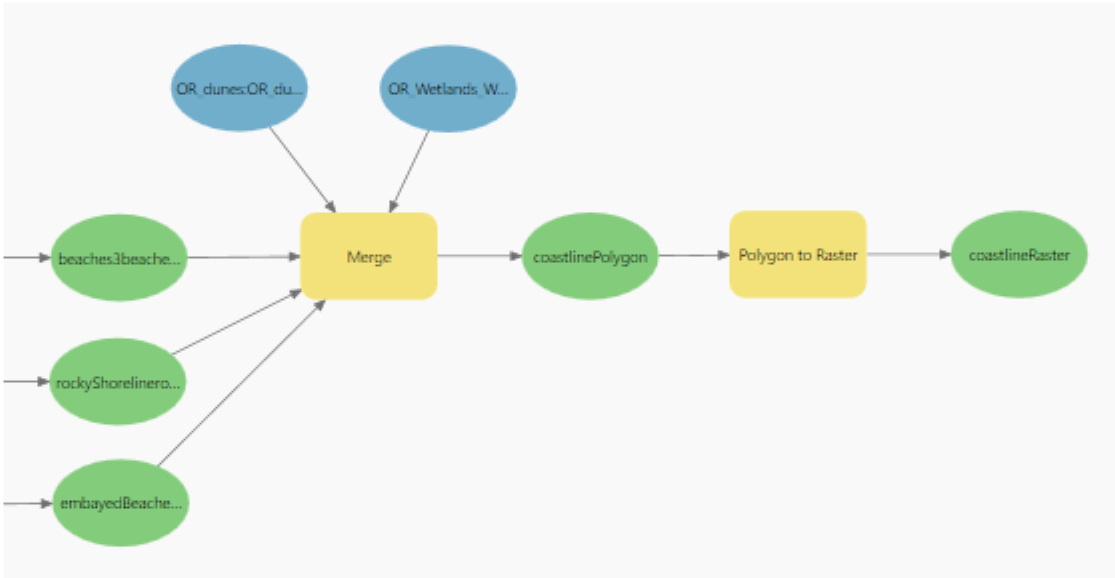

Figure 6: ModelBuilder for creating the geomorphology layer; merging the polygons

Figure 6 depicts the final steps taken to create the geomorphology layer. This involved taking the polygons that were created previously and merging them with the other two polygon layers. The output was then converted to raster to depict classified geomorphology features along the coastline.

Raster compilation and the index

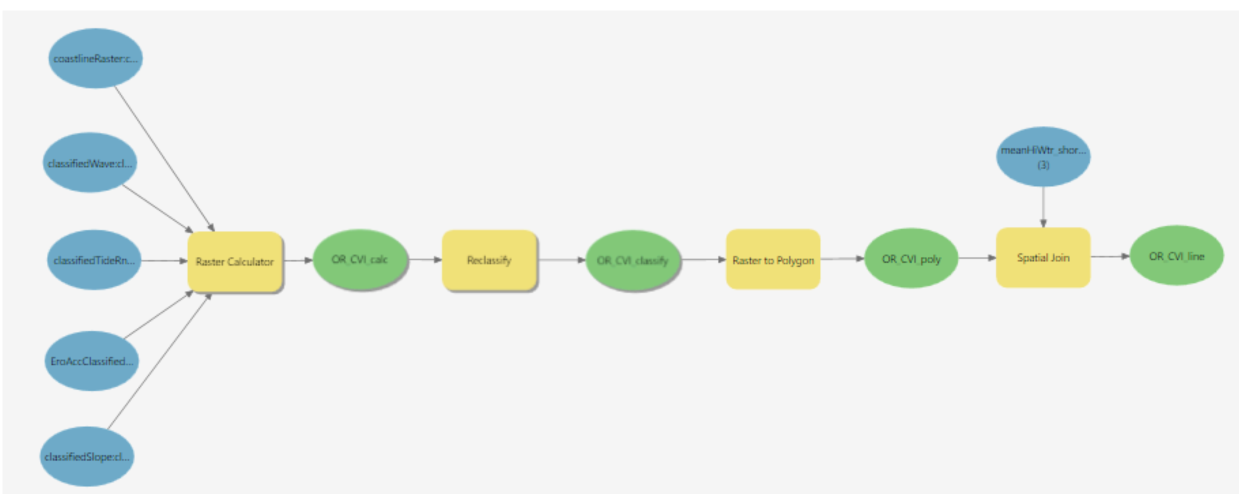

Figure 7: The final ModelBuilder outlining the combination of rasters and the final CVI layer

Figure 7 depicts the final ModelBuilder workflow that combined the raster datasets together and classified the shoreline depending on vulnerability. It starts with combining the rasters together with the Raster Calculator tool. The following expression was used to calculate the output raster:

$$CVI = \sqrt{((a * b * c * d * e) / 5)}$$

where a, b, c, d, and e represent the five input raster datasets. This formula was derived by Pendleton et al. The final raster was then processed and eventually converted to a line feature that represents the coastline. The line feature was segmented depending on a range of four categorical values; “Low”, “Moderate”, “High”, and “Very High.” This produced the final layer shown in Figure 8; a CVI of the northern Oregon coastline that is segmented depending on vulnerability.

Results

Figure 8 shows the Coastal Vulnerability Index across the coastline of northern Oregon. Vulnerability was ranked with four classes; Low, Moderate, High, and Very High. The most dominant vulnerability class is “Moderate,” with 39% of the total coastline being rated this way. Next is “Very High,” which comprises 28% of the coastline. “Low” is third at 21% of the coastline, and “High” is fourth at 10%. Looking at the extent of the other data layers gives an explanation to these results.

Figure 9 depicts the classification of geomorphology features. Beaches compose a majority of the coastline; 63% in total. Beaches were given a rating of 5 (see Table 1), meaning a majority of the coastline was classified as being at “Very High” risk to sea level rise. Rocky shoreline composed 34% of the coastline, making it the second most common physical feature along the coast. Rocky shoreline exists on the opposite side of the spectrum from beaches as it was given a rating of 1. These two features practically composed the entire coastline. The other three features (dunes, estuaries, and embayed beaches) only comprised about 3% of the shoreline combined.

Depictions of coastline erosion and accretion in Figure 10 provides more context to the CVI rankings. The most common rating by far was 3 for “Moderate”, meaning there were negligible effects of erosion or accretion over the course of a year. 79% of the coastline saw no impact from erosion or accretion. This “Moderate” rating of erosion and accretion could have been a major force in rating the majority of the northern Oregon coastline as being “Moderate” in terms of the CVI. 5 for “Very High” was the next highest rating at 10%, meaning more than 3 meters of erosion per year has occurred along 10% of the coastline. The last three ratings were “High” at 7%, “Low” at 2%, and “Very Low” at 1%.

The issues with data quality are apparent in Figure 11. As mentioned in the Methodology section, mean tide range is measured at coastal NOAA stations. Only three of these stations exist in the study area. Lack of mean tide range at a finer resolution leads to the broad vulnerability classification of “Very High” to practically the entire north coast. Since each data layer was given the same weighting of importance in the final CVI, the high ratings of the tide range layer can overestimate the actual vulnerability of the coastline. Essentially, the index can list the coastline as being more vulnerable than it actually is.

Depictions of slope are provided in Figure 12. Slope varies along the shoreline, but tends to be pretty shallow along the shoreline. Shallower slopes were given a higher rating. There are sections of steeper slopes, delineating portions of the coastline that are cliffs. Figure 13 depicts significant wave height along the Oregon coast. Impacts from significant wave height on the coastline is confined to the ratings 1 through 3. This is because significant wave activity is skewed to be more prominent further away from the shoreline. Because these ratings are confined to low values, the significant wave height layer can have the opposite effect of the mean tide range layer: vulnerability can actually be underestimated due to the abundance of low values. There is no conclusion to say whether this underestimation “balances out” the overestimation from the mean tide range layer. But the fact that the mean tide range layer uniformly applied one value to the whole coastline, while the significant wave height layer has a range of values, leads to reasoning that there is still overestimation.

Discussion

The resulting CVI is designed to assess the vulnerability of the northern Oregon coastline to sea level rise. Issues with data quality leave certain limitations regarding the output. A more comprehensive measure of mean tide range is necessary if the variable is to be continually used in the construction of the CVI. Nageswara et al. and Pendleton et al. both used the variable. It is an important measure of vulnerability that has a justified reasoning for belonging in the model. Issues with data quality sully the results. The problem is not confined to just this paper either. Nageswara et al. also ran into the same issue with lack of measurements on mean tide range within their model. Additional efforts to collect this data is required for a more accurate CVI.

There is also a lack of uniformity with the construction of the CVI. Researchers differ on what variables should be included when constructing the index. This was seen with the two CVI studies used in this paper; Nageswara et al. and Pendleton et al. Pendleton et al. included relative sea level change as a variable in the construction of their CVI. The inclusion is obvious; an index measuring vulnerability to sea level rise should include some measure of that rise. Nageswara et al. acknowledged a lack of the variable and explained it was due to an absence in data availability. Relative sea level change was not measured on a fine enough scale to include in the model (A similar issue occurred when constructing the CVI for this paper, as relative sea level change is only measured at two NOAA stations within the study area. Lack of data availability informed the variables exclusion from this paper as well). The fact the variable can be absent raises questions on its use and importance in the model or what vulnerability the CVI actually depicts.

The lack of uniformity and the questions around it leaves a lingering uncertainty with the CVI. Additional uncertainties exist that are inherent to the CVI. For one, the CVI lacks descriptions of extent and magnitude. The CVI is meant to indicate areas along a shoreline that are vulnerable to future sea level rise. This speaks nothing of the extent or magnitude of sea level rise. A higher sea level would extend water further inland, potentially increasing vulnerability in bays and along rivers. Recognition of this was absent from the CVI as it focused purely on the existing coastline rather than the area of impact. Finding extent and magnitude would require a more comprehensive study incorporating multiple projections of future sea level height. Along with lack of extent and magnitude is a lack of recognition for human impacts. Five variables were considered for the index and none of them represented the impact to humans. Incorporating some mention of social vulnerability can be integral for assessing the full vulnerability of a coastline. This would require additional research that is based on a local, community-size scale.

Further research is also required to model the full impact of climate change on the coastline. The CVI is mainly designed to measure impacts from sea level rise. Other coastline vulnerabilities exist, though. Storm surges are expected to increase in magnitude in future years (Flitcroft & Giannico, 2013). Incorporating these impacts into a new index can create a more comprehensive model of coastal climate change vulnerability.

Because of these limitations, this Coastal Vulnerability Index is not the best measure of coastline vulnerability to sea level rise. There are still some usages for it as it does indicate broad ranges of vulnerability. But a more in depth study is needed to assess acute vulnerability across the coast. More comprehensive studies would provide better information to influence mitigation efforts. For the protection of the Oregon coast, coastline assessments need to be more in depth and mitigation efforts need to be taken.

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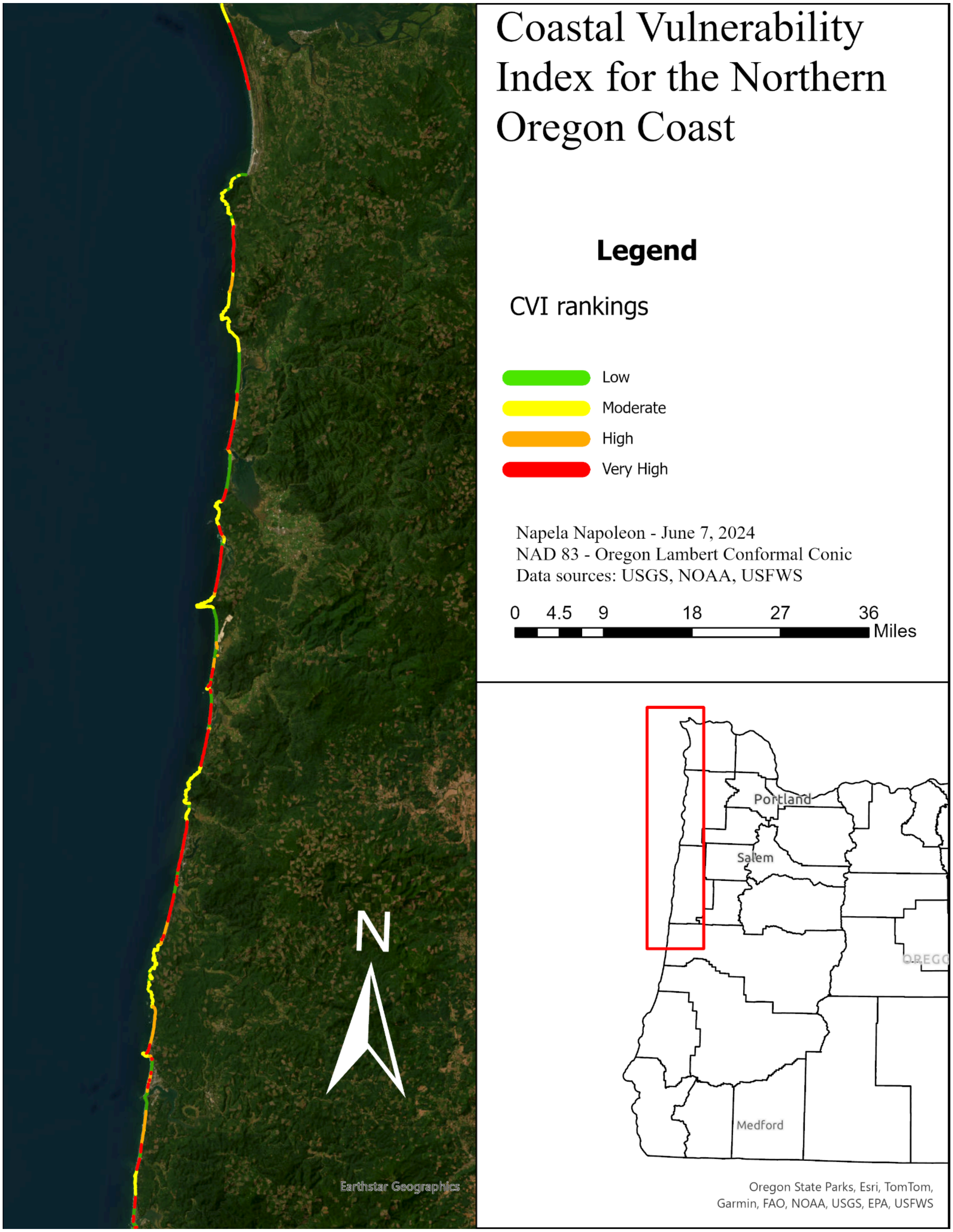

Figure 8: CVI along the northern Oregon coastline

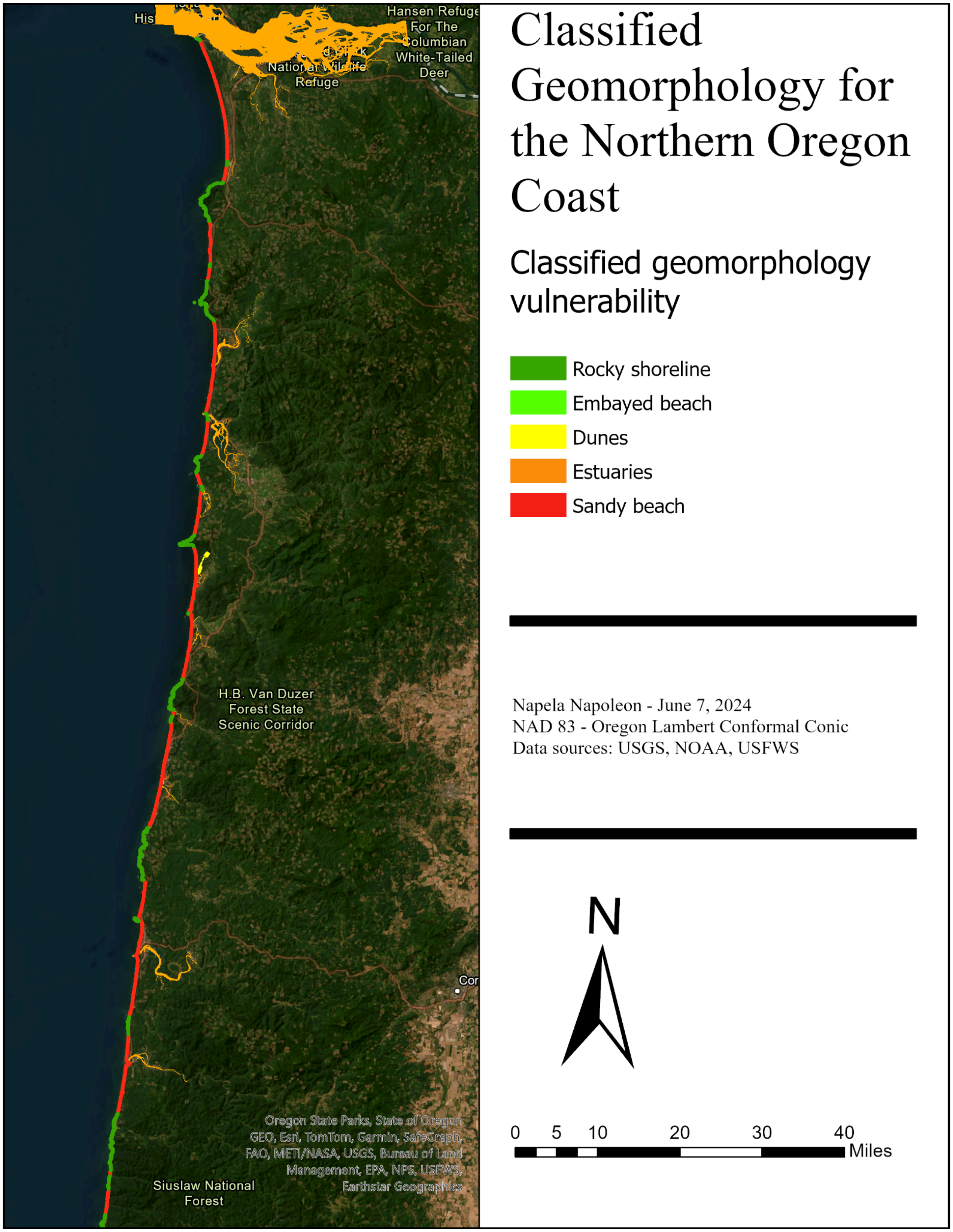

Figure 9: Classified geomorphology features along the northern Oregon coastline

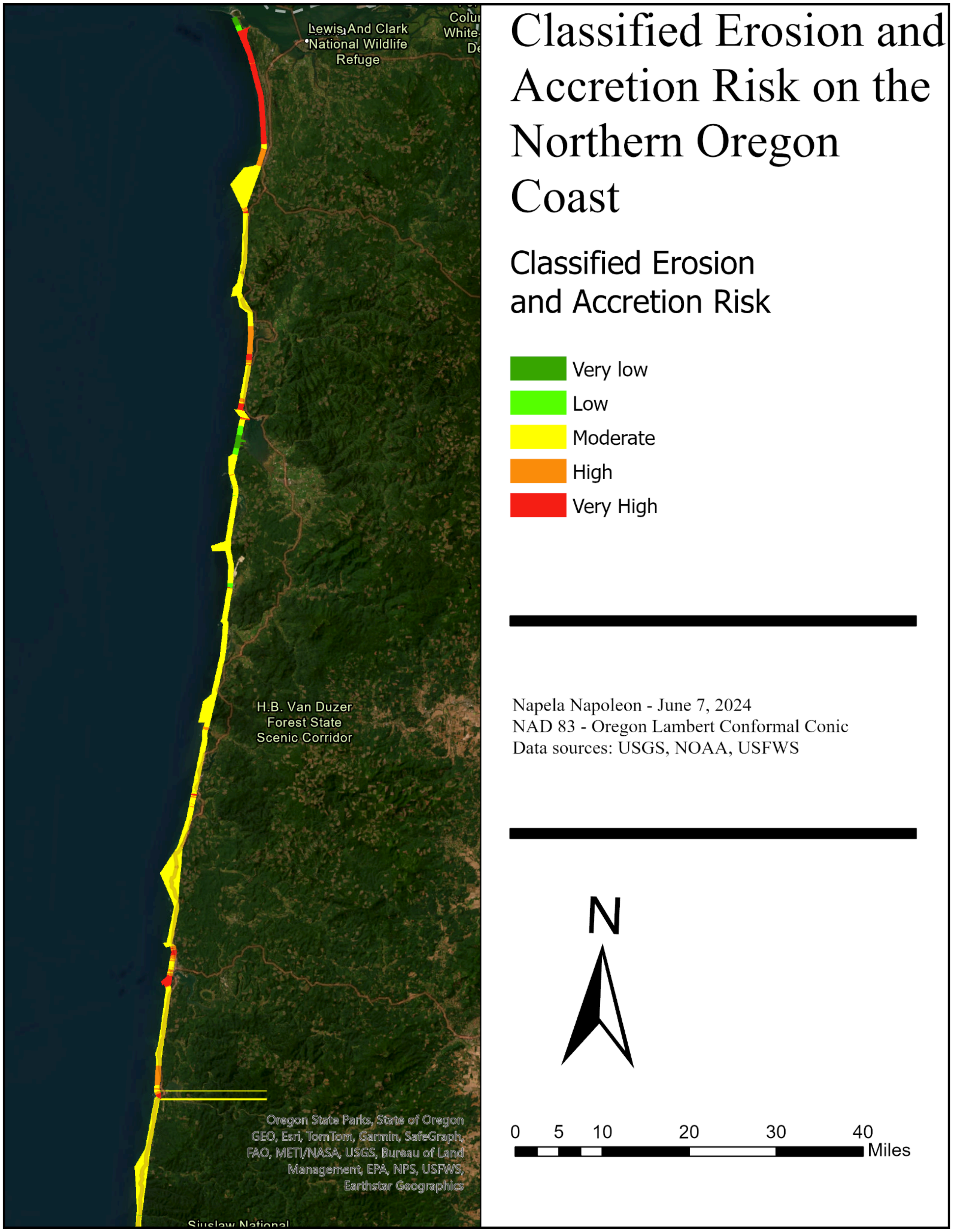

Figure 10: Classified erosion and accretion risk along the northern Oregon coastline

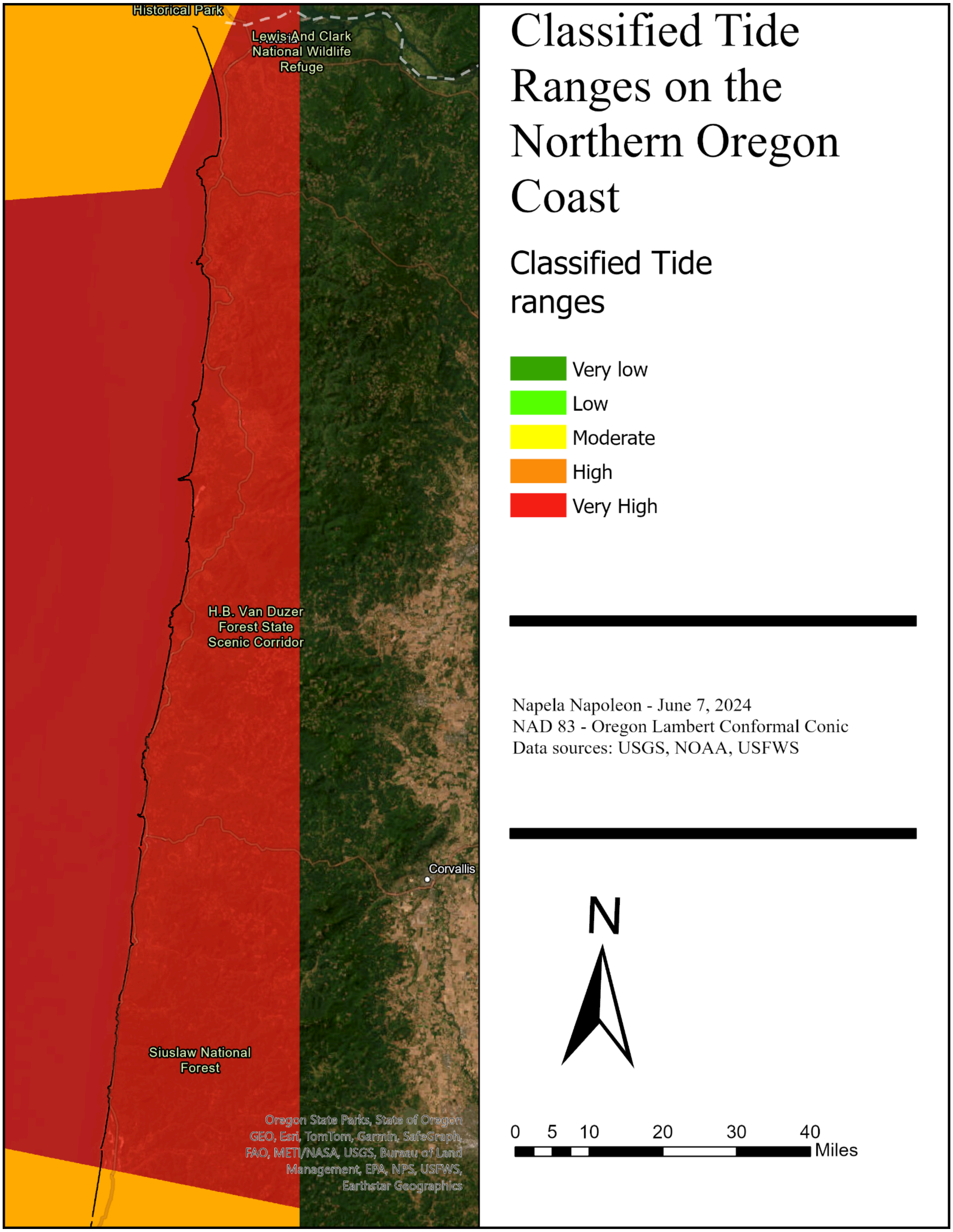

Figure 11: Classified tide ranges along the northern Oregon coast

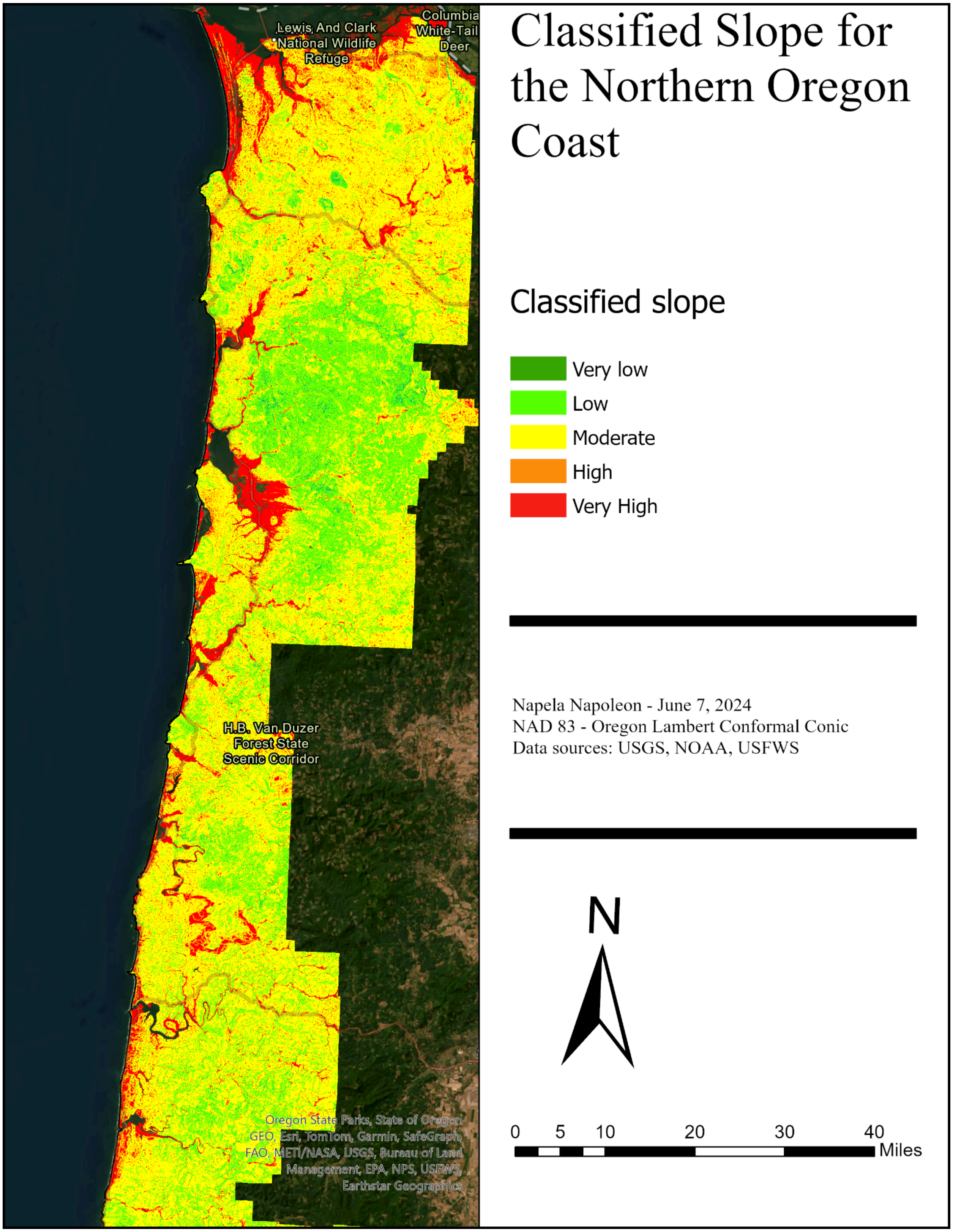

Figure 12: Classified percent slope in coastal northern Oregon

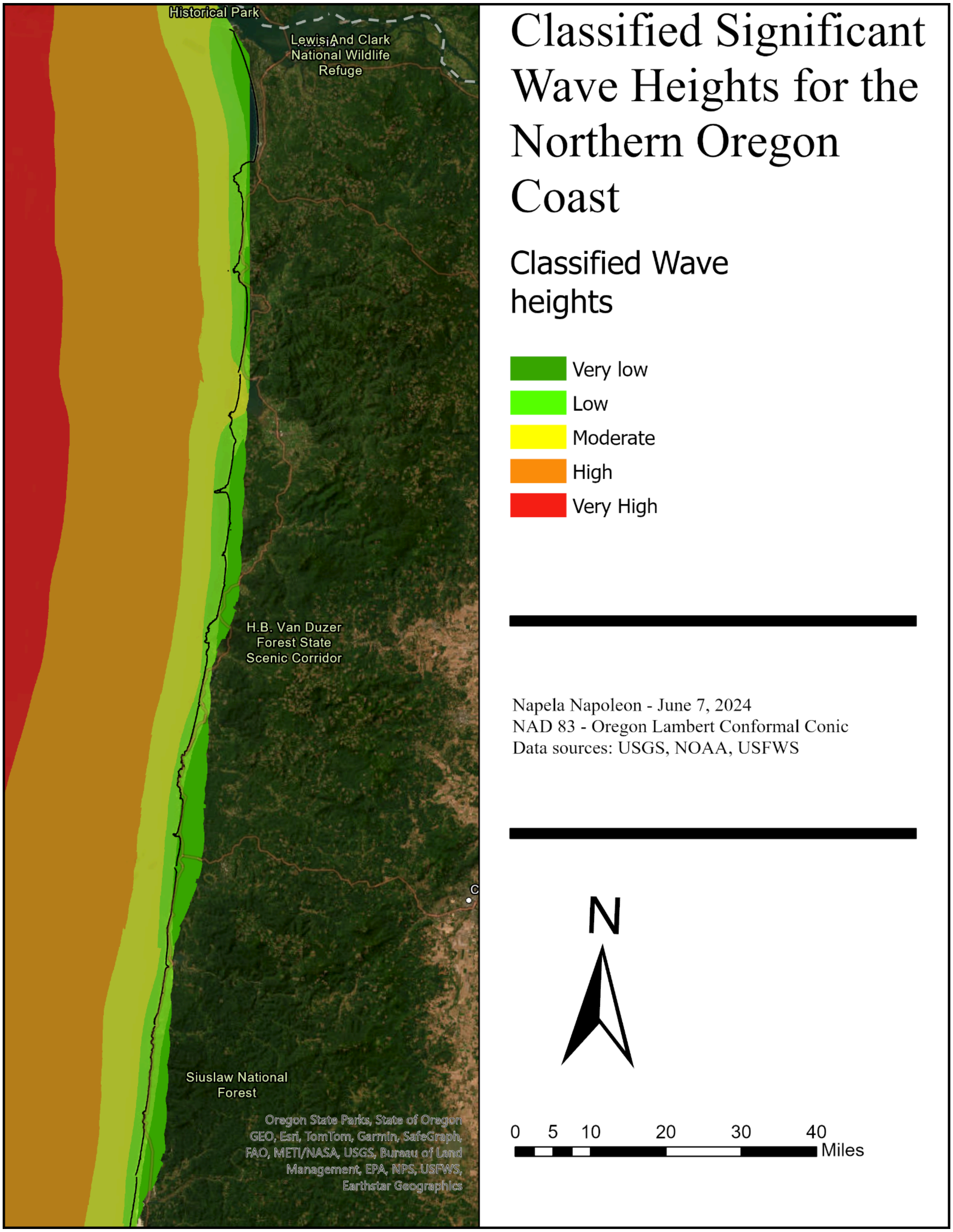

Figure 13: Classified wave heights along the northern Oregon coastline