Whales Curtailed : An Analysis of Cetacean Stranding in Washington and Oregon

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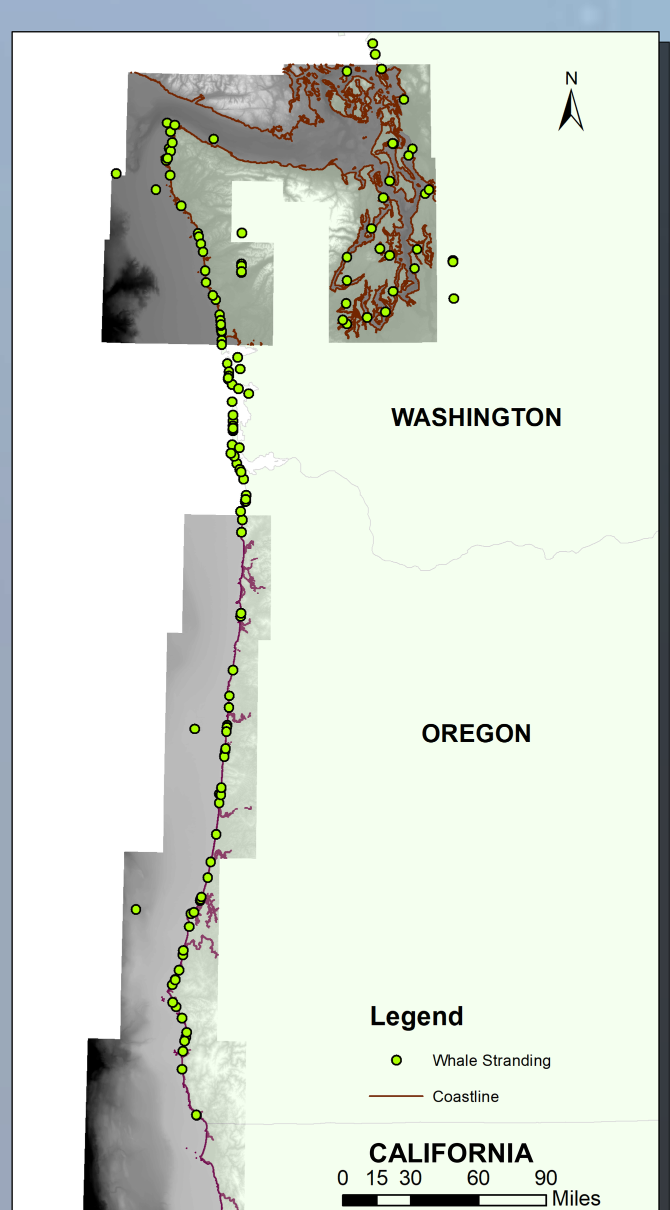
Introduction

Whale and other cetacean strandings are a common phenomenon in many coastal areas. However, despite the relative frequency of these events, not much is definitively known about their causality. As it is currently understood, a stranding might be incited by any of several factors, including disease or predation. In the latter case, this could mean whales' mis-navigation in chasing down, for instance, seals or sea lions, or injury induced by humans. Recently, it has been proposed that, excepting those cases of anthropogenic intervention (some including military exercises involving sonar and subsequent acoustic trauma), strandings are primarily a consequence of the affected functioning of echolocation in shallow, low-graded areas (e.g. sandy seabeds) (Evans).

The purpose of this project is, thus, to test the hypothesis that certain characteristics of the seafloor or coastline may increase the probability of whale stranding. More specifically, shallower terrains of low slope near the coast may correlate to relatively more frequent observations of whale strandings. Additionally, it is expected that the sinuosity of the coastline might present more navigational difficulty. Perhaps stretches of coastline that are more linear may have fewer counts of stranding than, say, a more sinuous, convoluted coastline spanning a similar distance. Here, the ruggedness of the benthic terrain and the sinuosity of the coastlines surrounding Washington and Oregon are examined in relation to the frequency of large whale strandings between 2006 and 2018.

Methodology

Whale Strandings, DEM Mosaics, and Coastline. An inquiry was placed with Stephen Manley of the Marine Mammal Health and Stranding Reponse Program's National Stranding Database for all large whale strandings (including baleen whales, sperm whales, and right whales) between 2006 and January 1, 2018. A series of bathymetric coastal digital elevation models (DEMs) were then obtained from NOAA National Centers for Environmental Information for the following regions of the northwestern coast of the US, surrounding Washington and Oregon. Contiguous DEMs were merged to create mosaic rasters for either Washington (WA) or Oregon (OR), using the UTM 10N projected coordinate system. The Contour tool then used to extract a single sea level contour line defined at a depth of 0 meters (*Map 1*).



Map 1. ***Bathymetric digital elevation model (DEM) coverage, along with whale stranding points and coast line.***

Sinuosity. The sinuosity of coastlines were subsequently determined in the following fashion: the Split tool was used to divide either coastline into lengths of approximately 10,000 m, the sinuosity of each segment of which was then calculated using an ArcGIS Python toolbox code example, as a function of total segment length over the length of a straight segment from the start and end point. A red-to-green color ramp (refer to sinuosity map) serves to symbolize values of lower (green) to higher (red) degrees of sinuosity of either coastline (*Map 2*).

Benthic Terrain Classification. A Benthic Terrain Modeler (BTM) toolbox, created by Wright *et al.*, was employed to Classify Benthic Terrain as well as create a map of the Terrain Ruggedness (VRM) of the region, for resampled .tifs (1000x1000 cell size) of both DEM mosaics to expedite processing time. Terrain Ruggedness in essence measures the extent of terrain variation, primarily taking slope and aspect into account (*Map 3*). Terrain classification required the input of both broad and fine scale grids of bathymetric position indices (BPIs) and slope rasters, which were also created using the toolbox, and was classified according to a pre-existing terrain 'dictionary' based on Fagatele Bay, American Samoa, and which was included in the BTM toolbox tutorial (*Maps 4 and 5*).

Start

Visualize whale stranding points *and* ***create state mosaics of bathymetry*** *digital elevation models (DEMs).*

...

Define coastline *by calculating Contour line for sea level*

Determine coastal sinuosity *of ≈ 10,000 m segments of coastline using the Split function and Python script.*

...

Classify bathymetric zones *using Benthic Terrain Modeler.*

End

Identity analysis *of whale stranding points, correlating stranding counts to respective benthic zone type.*

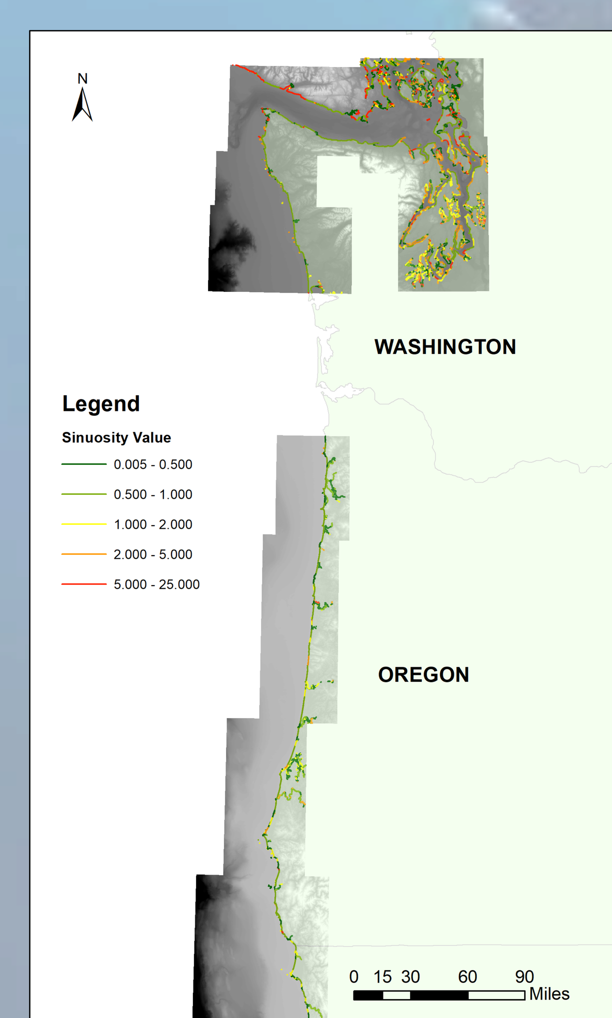
Spatial Join *targeting whale strandings and matching incidents to the closest segment of coastline and associated sinuosity value.*

Unweighted analysis of risk*, via Raster Calculator, multiplying coast line density, stranding point density, and ruggedness.*

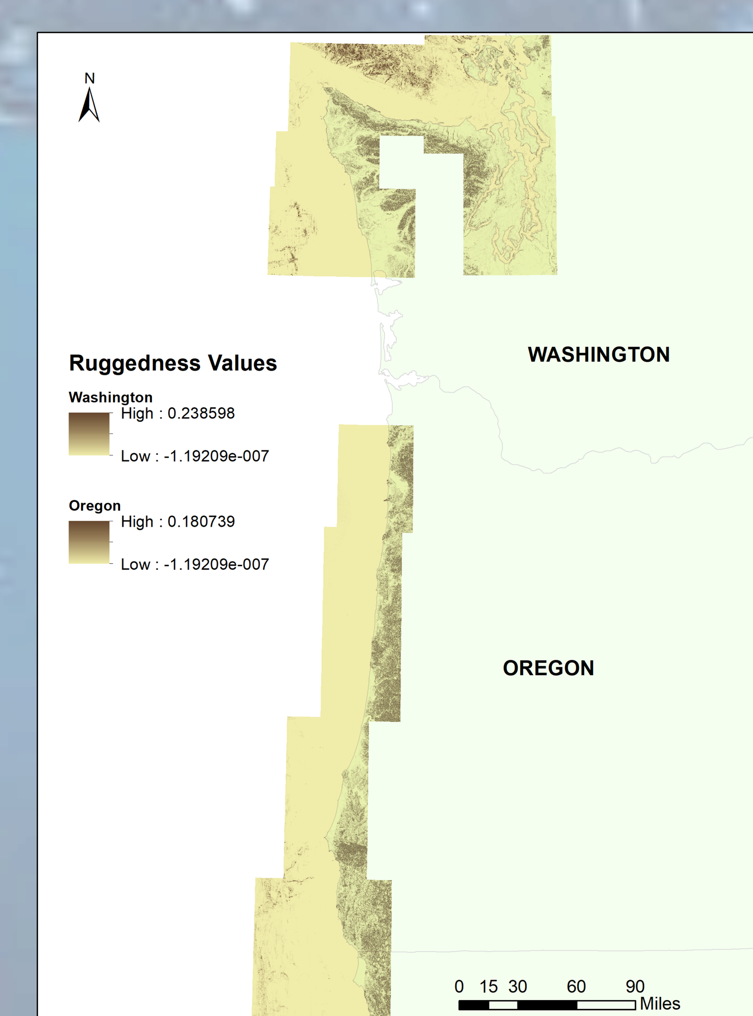
Flow chart illustrating the stepwise analysis of cetacean stranding.

TABLE1. Sinuosity and Stranding Counts in Washington and Oregon

Sinuosity Value Range	Washington	Oregon
0.005 – 0.500	5	10
0.500 – 1.000	48	26
1.000 – 2.000	6	6
2.000 – 5.000	7	4
5.000 – 25.000	8	5
Total Geographically Specific Incidents	74 (of 91)	51 (of 56)



Map 2. ***Sinuosity classifications of 1 km segments of Washington and Oregon coastlines.***



Map 3. ***Ruggedness of Washington and Oregon as determined by Benthic Terrain Modeler.***

Identity Analysis and Spatial Join. Individual whale strandings were analyzed in relationship to the sinuosity of the nearest stretch of coastline (*Table 1*). This was accomplished through the Spatial Join of whale point target features matched to the closest line segment (within 25 km) in each state's sinuosity coastline layer. Following the classification of benthic terrain, Identity analysis was carried out on for both states; input whale stranding point data was related to their respective, underlying terrain zones (*Table 2*).

Risk Map. Finally, a map assessing the risk of whale stranding was formed via an unweighted overlay analysis. Rasters for Point Density of whale strandings) as well as for the line densities for the WA and OR coastlines were created. Values for these rasters, and for those of each state's coastal ruggedness, were reclassified using Natural Jenks Breaks into four categories of risk (e.g. 1, Low ; 2, Medium; 3, High; 4, Highest). These rasters—featuring the factors of ruggedness, coastline density, and historic whale stranding density—were multiplied using the Raster Calculator to yield the risk map (*Map 6*). The risk output was thus based on the hypothesis that greater ruggedness, higher point density/sinuosity, and historical proneness to whale strandings might be associated with or predict future whale stranding hotspots.

Results and Conclusion

Of the 147 strandings recorded, 106 are within the coverage of the coastal DEMs for WA or OR, and could be assigned a terrain zone identity. **The majority of all strandings (roughly 86%) in both WA and OR occur in the Lower Bank Shelf**—an observation not too surprising considering the increasing shallowness in progressing further into that terrain type. A couple of strandings in mid-slope ridges perhaps could be attributed to rugosity or roughness of the immediate region, especially if near an imbricate zone; this relationship would need to be investigated further. Additionally, a few strandings occur in depressions, which isn't necessarily unexpected, but supplemental knowledge of a quantifiable degree of the depression, or notable characteristics of surrounding features, might better inform any conclusions about this terrain's potential tendency to inhibit whales' mobility.

Quite interestingly, whale strandings in OR are only found in the Lower Bank Shelf or Back Reefs (as defined in the navigable sense). This may be a consequence of a less varied landscape, or possibly, since OR appears to generally have a more linear coastline and coastal sinuosity might not have been as confounding a factor, this could implicate Back Reefs in greater stranding frequencies, for reasons not yet known. Generally, it might also be possible that the scale on which these or similar bathymetric features might drive stranding is not the same as that for this investigation.

In total, there are 147 whale strandings recorded with latitude and longitude coordinates between 2016 and 2018 by NOAA and its Marine Mammal Stranding Network partners. Ninety one (91) of these strandings were recorded as being in WA. Seventeen (17) of these incidents were not close enough (i.e. not within 25 km) to the coastline segments studied to be attributed any nearby sinuosity value. Fifty six (56) strandings were recorded for OR. Five (5) of these incidents could not be reasonably attributed a corresponding sinuosity value.

Contrary to the initial hypothesis, the majority of strandings, for both states, occur in areas of intermediate sinuosity. Perhaps a different trend might be observed with modified sinuosity value ranges (e.g. comprised of equal intervals), which in this case were arbitrarily assigned to accommodate a broad range of values within a small number of distinct categories. Summarily, it would seem sinuosity of nearby stretches of coastline is not a heavily weighted factor in strandings, at least not in an incrementally linear manner.

Future directions for further study might include an assessment of the effect of island density in cetacean stranding; maybe greater island densities confound navigation and thus lead to increased casualties. Among some other factors to consider: any seasonality or the timing of stranding; the average change in water depth at stranding sites; as well as any proximity and interaction between coastal whale travel and commercial shipping tracks. A more involved examination of cetacean echolocation and the tendency for acoustic rebound or distortion from the various structures or compositions of the seafloor might be informative. And perhaps in a similar vein, hotspots of ocean noise produced by humans from aquatic technologies, or areas where seaquakes could be incipient might be mapped alongside cetacean migration patterns as a means of estimating risk of future stranding, and would serve to redirect preventive or rehabilitative attention and action.

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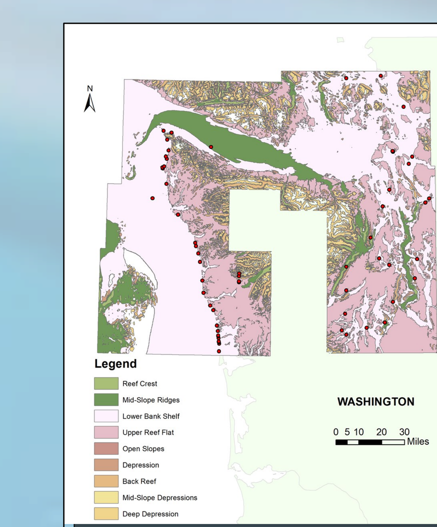
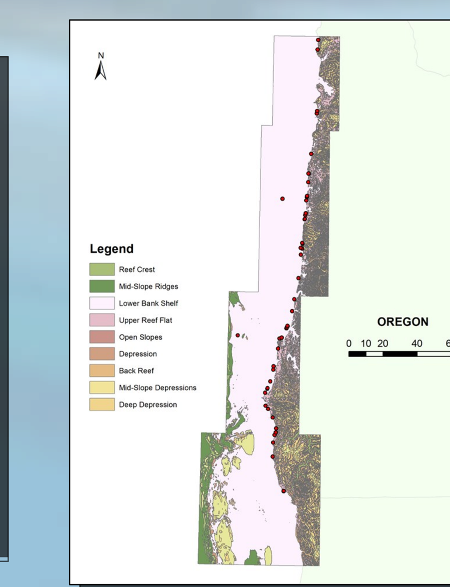
Background Image Source:

Spirit Animal. April 2018. Online. http://www.spiritanimal.info/wp-content/uploads/Whale-Spirit-Animal-1.jpg

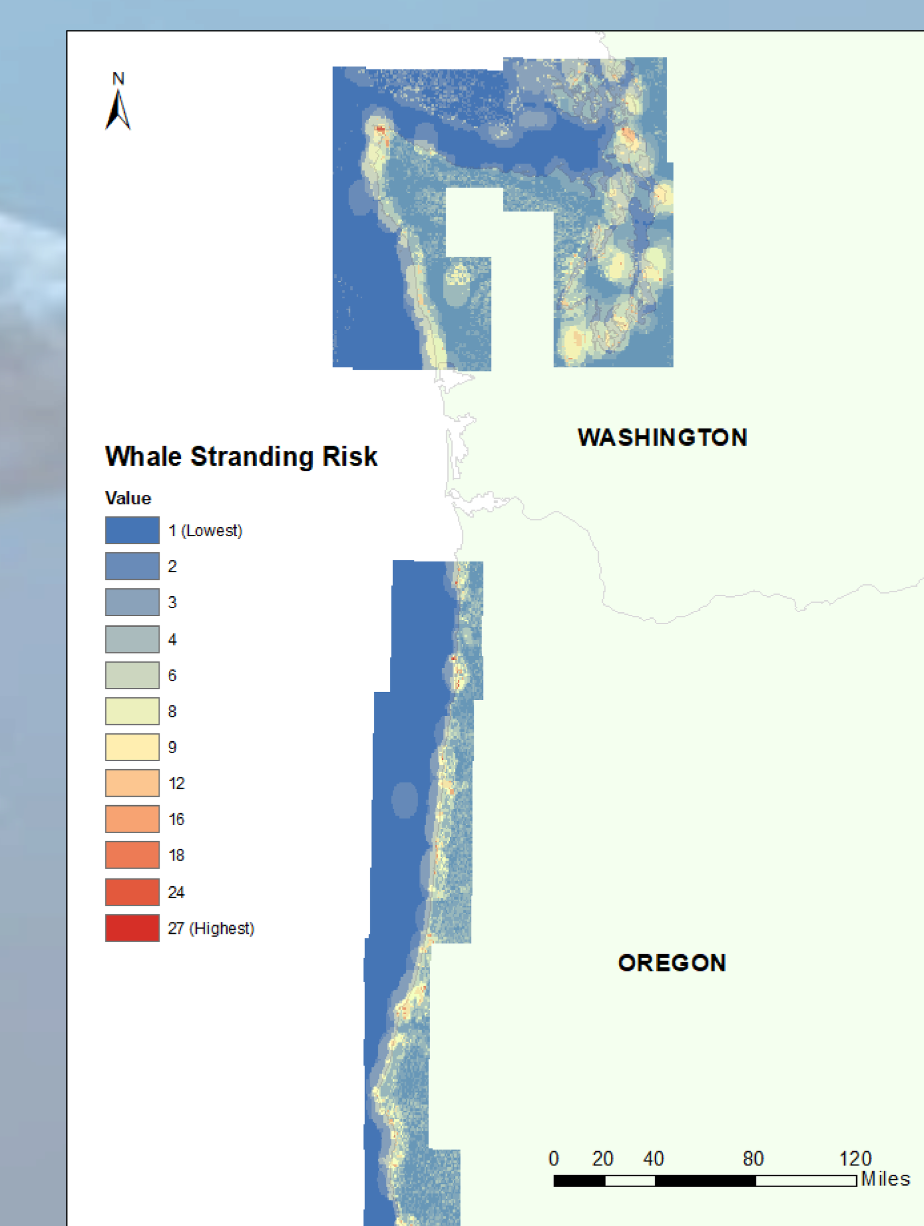
TABLE 2. Stranding Counts for Each Benthic Terrain Zone in Washington and Oregon

Terrain Code	Terrain Type	WA	OR	Total
1	Reef Crest	1	0	*1*
2	Mid-Slope Ridges	2	0	*2*
5	Lower Bank Shelf	49	42	*91*
6	Upper Reef Flat	5	0	*5*
8	Depression	1	0	*1*
9	Back Reef	0	5	*5*
11	Deep Depression	1	0	*1*
Total		*59*	*47*	*106*





Maps 4 and 5. ***Whale strandings situated in their respective Terrain Zones of WA (left) and OR (right).***



Map 6. ***Risk map of whale stranding based on ruggedness of terrain, line density of coastline, and point density of previously observed stranding.***