Submarine Cable Analysis for US Marine Renewable Energy Development

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Executive Summary

Operation and maintenance of submarine cables may conflict with marine renewable energy development. Although submarine cable locations are publicly accessible, safe setback distances are not readily available for planning new marine renewable energy development.

We applied industry-advised safety buffers that varied with depth to existing submarine cables for "minimum" (2*depth, i.e. "2z") and "recommended" (3*depth, i.e. "3z") horizontal distances, both having a minimum 500 m buffer. Of the original 230,835 km in the "NOAA Charted Submarine cables in the United States as of December 2012" dataset (Figure 1), 97,321 km fell within the 200 nm of the US exclusive economic zone (EEZ), which was analyzed across 12 territories that overlapped with the cables (Figure 2). A custom Equal Area Albers projection based on 1/6th the extent of each territory was individually applied to minimize spatial distortion when buffering distances at 100 m depth increments using the GEBCO 30 arc-second global grid. The cable buffer area ranged from 29.35% (242,042 km^2 [3z] of 824,679 km^2 total) in the West owing to many cables present and the steep continental shelf, to virtually nill 0.01% (42 km^2 [2z] of 406,970 km^2 total) in Wake Island (Table 2).

Overlap of cable buffers with marine renewable energy was assessed for tidal, wave and wind energy based on estimates from the National Renewable Energy Lab (NREL). Generally the highest proportion of energy is in the lower classes least likely for development where the highest area of overlap with cable buffers also exist (Figure 3; Table 3). The highest wind speed classes (10-11 & 11-12 m/s) are however also occupied by the highest percentage of cable buffer overlap (55.7% & 39.8% for 3z, 39.8% & 15.9% for 2z respectively). These uncommon high wind speed areas are limited to Hawaii and West territories (Table 6; Figure 6 for bargraph; Figure 21 for Hawaii wind map; Figure 35 for West wind map). Overall wave energy has a bimodal distribution, most abundant in the lowest class (997,570 km^2 for 0-10 kW/m) with a sharp drop at the next lowest class (292,692 km^2 for 0-10 kW/m) and then ramping up to roughly half the highest class (532,533 km^2 for >30 kW/m). Overlap with cable buffers for the highest two classes (20-30 & >30 kW/m) is just over 5% (5.2% & 5% for 2z, 6.8% & 6.7% for 3z). Similar to wind, these high energy wave classes are limited to the Pacific territories of Hawaii, West and Alaska (wind for Alaska was not available) (Table 5; Figure 5 for bargraph; Figure 20 for Hawaii wave map; Figure 34 for West wave map; Figure 9 for Alaska wave map). Tidal power is extremely dominated by the lowest energy class of 0-500 W/m^2 covering 403,781 km^2, which is 99.6% of the total area assessed. The cable overlap for the rare higher energy areas is at most 20.1% (12 of 59 km^2) for 500-1,000 W/m^2 in the West and less than 3% for the even rarer higher energy classes of 1,000-1,500 or >1,500 found only in Alaska or the East.

1 Background

Demand for abundant and diverse resources in the oceans is growing, necessitating marine spatial planning. To inform development of Marine Hydrokinetic (MHK) and Offshore Wind (OSW) resources, the Department of Energy (DOE) has asked NREL to identify — and mitigate where possible — the competing uses between MHK/OSW technologies and subsea power/telecom cables. The first step in this work is to identify and quantify the overlap between the MHK/OSW resource availability and existing cable routes. Several publicly available data layers are available that identify cable routes (e.g. MarineCadastre.gov currently hosts an offshore cables geographical information system (GIS) data layer) and MHK/OSW resource density (MHK Atlas, Wind Prospector). The cable route linear features, however, do not indicate the setback distance necessary to accommodate subsea cable maintenance requirements. Preliminary work was done within NREL to evaluate the influence of subsea cable setback distance on the overlap with MHK/OSW for the west coast of the U.S (Amante et al. 2016). Industry reports (Communications Security, Reliability and Interoperability

Council IV 2014, 2016) from the International Cable Protection Committee (ICPC) of the North American Submarine Cable Association (NASCA)[1] advise on setback distances that inform this analysis.

2 Methods

2.1 Study Area, Submarine Cables, Depth and Energy Data

The study area consisted of the US waters (Flanders Marine Institute 2016), i.e. the 200 nm extent deemed the exclusive economic zone (EEZ), that overlapped with the offshore cable dataset "NOAA Charted Submarine cables in the United States as of December 2012" available through MarineCadastre.gov.[2] The territory of the contiguous US was further divided into West, East and Gulf of Mexico territories based on the Gulf of Mexico description from the International Hydrographic Organization (IHO) Sea Areas (VLIZ 2017). To accomodate territories overlapping the international dateline (Hawaii and Alaska), all input and output products were shifted from [-180,180] to [0,360]. For more details on the 12 territories used in this analysis, see Table 1 and Figure 1.

Table 1: Territories within the United States exclusive economic zone (EEZ) and having submarine cables.

Id	Territory	Area (km2)
1	Alaska	3,682,912
2	East	932,351
3	Guam	208,234
4	Gulf of Mexico	1,553,288
5	Hawaii	2,474,715
6	Johnston Atoll	442,443
7	N Mariana Islands	763,626
8	Palmyra Atoll	353,670
9	Puerto Rico	172,958
10	US Virgin Islands	38,275
11	Wake Island	406,970
12	West	824,679

Bathymetric depth comes from the GEBCO 30 arc-second grid[3].

The marine renewable energy datasets are from NREL and accessible online via NREL's Wind Prospector[4] and MHK Atlas[5]. Tidal data were modeled using the Regional Ocean Modeling System and calibrated with available measurements of tidal current speed and water level surface in terms of watts per square meter (W/m^2) (Haas et al. 2011). Wave data is based on a 51-month Wavewatch III hindcast database developed by the National Oceanographic and Atmospheric Administration's (NOAA's) National Centers for Environmental Prediction for estimation of wave power density in terms of kilowatts per meter (kW/m) (P. T. Jacobson et al. 2011). Wind data is for average offshore wind speed in meters per second (m/s) at a 90 m hub height.[6]

[1] North American Submarine Cable Association (NASCA): https://www.n-a-s-c-a.org

[2] MarineCadastre.gov cable metadata: https://coast.noaa.gov/dataservices/Metadata/TransformMetadata?u=https://coast.noaa.gov/data/Documents/Metadata/harvest/MarineCadastre/NOAAChartedSubmarineCables.xml&f=html

[3] GEBCO_2014 Grid, version 20150318, www.gebco.net

[4] NREL Wind Prospector: https://maps.nrel.gov/wind-prospector/

[5] NREL MHK Atlas: https://maps.nrel.gov/mhk-atlas

[6] Wind data for 90-meter offshore: http://www.nrel.gov/gis/data_wind.html

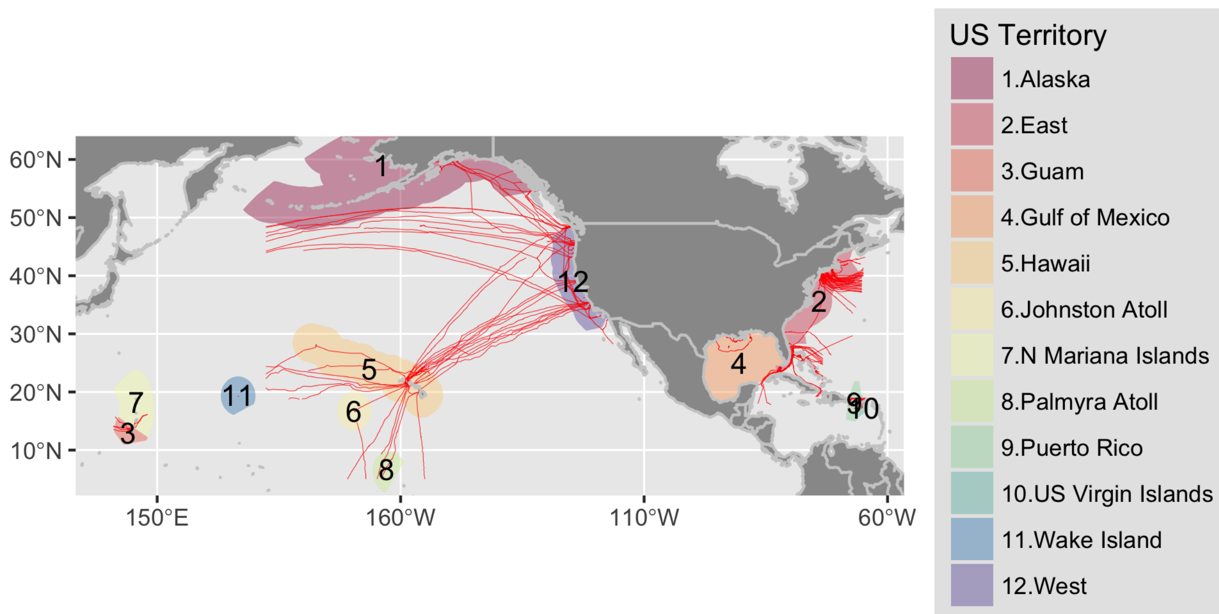

Figure 1: Map of NOAA Charted Submarine cables as of December 2012 within the exclusive economic zone (EEZ; 200 nm) of United States territories.

2.2 Submarine Cable Avoidance Zones

The International Cable Protection Committee (ICPC) of the North American Submarine Cable Association (NASCA) outlined recommendations for siting new offshore renewable wind energy facilities and routing new cables. For new facilities they recommend a minimum of 500 m and further offshore twice the depth to the seafloor, per ICPC Recommendation 13 No. 2 (Communications Security, Reliability and Interoperability Council IV 2014). So for depths <= 250 m, a 500 m buffer from the cables applies and for depths > 250 m, 2 * depth is to be used. For placing new submarine cables, seperation distances are specified for minimum (2 * depth) and recommended (3 * depth), per related to ICPC Recommendation 2 No. 10 (Communications Security, Reliability and Interoperability Council IV 2014). We combined these two criteria into 2 sets of buffer distances for minimum ("2z": 2 * depth) and recommended ("3z": 3 * depth) avoidance zones, both with a minimum 500 m width.

2.3 Depth-Varying Cable Buffer

A depth-varying buffer for "minimum" (2z) and "recommended" (3z) was achieved by intersecting depth with cables and buffering out by depth. Depth from the GEBCO grid was reclassed into 100 m increments starting with 250 m to apply a 500 m minimum for the 2z and 3z products, and converted to polygons for intersecting with the cable linear features. A custom Albers Equal Area Conic projection based on 1/6th the extent[7] of each territory was individually applied to minimize spatial distortion when buffering.

3 Results

All analytical code to generate outputs, inclulding this data driven report, are available in a publicly accessible online repository: http://github.com/ecoquants/nrel-cables. Here are particularly noteworthy files:

- `data/`
  - `lns_d1x.geojson`: lines of submarine cables segmented at 100 m increments with depth value for buffering, ie minimum 500 m and depth (z) for multiplying by 2 (2z) or 3 (3z).
  - `buf_2xdepth_incr100m.geojson`: polygons for "minimum" avoidance zone for buffer at twice the depth (2z), mimimum 500 m.
  - `buf_3xdepth_incr100m.geojson`: polygons for "recommended" avoidance zone for buffer at three times the depth (3z), mimimum 500 m.
- `docs/`
  - `packages_vars.R`: R code with variables and packages used across analysis (`create_cable-buffer.R`, `extract_cable-energy.R`) and reporting (`report.Rmd`)
  - `create_cable-buffer.R`: R code to generate cable buffers at 100 m depth increments.
  - `extract_cable-energy.R`: R code to extract renewable energy for cabled territories.
  - `report.Rmd`: R markdown document for reproducible, data-driven generation of various report output file formats (`report.pdf`, `report.docx`, `report.html`)

3.1 Cable Buffer

Of the original 230,835 km in the "NOAA Charted Submarine cables in the United States as of December 2012" dataset (Figure 1), 97,321 km fell within the 200 nm of the US exclusive economic zone (EEZ), which was analyzed across 12 territories that overlapped with the cables (Figure 2). The cable buffer area ranged from 29.35% (242,042 km^2 [3z] of 824,679 km^2 total) in the West owing to many cables present and the steep continental shelf, to virtually nill 0.01% (42 km^2 [2z] of 406,970 km^2 total) in Wake Island (Table 2).

[7] The "one-sixth rule" for Albers Equal Area Conic projection: http://desktop.arcgis.com/en/arcmap/latest/map/projections/albers-equal-area-conic.htm#GUID-2158C4F9-F197-458E-94F0-84933C1BE6B7

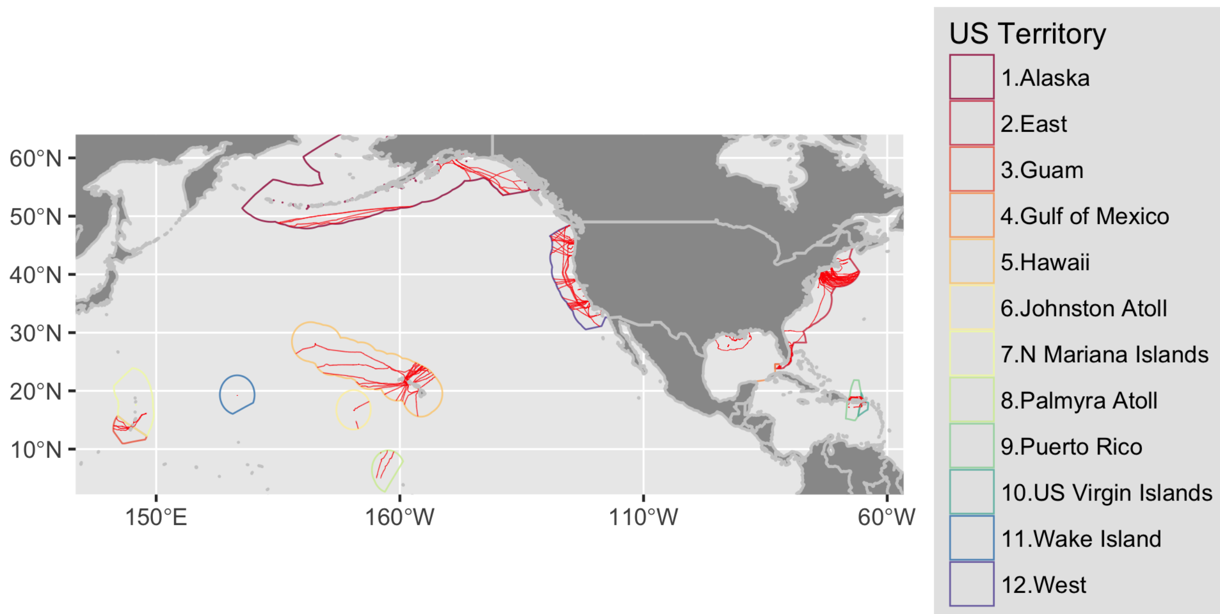

Figure 2: Map of submarine cable buffers within the exclusive economic zone (EEZ; 200 nm) of United States territories. In order to see the area covered by the buffers, please visit the Detailed Maps section.

Table 2: Overlap of Cable Buffers with US Territories.

Territory	Area (km^2)	Min. Cable (2z)		Rec. Cable (3z)	
		Area (km^2)	(%)	Area (km^2)	(%)
Alaska	3,682,912	167,375	4.5%	237,639	6.5%
East	932,351	130,775	14.0%	161,764	17.4%
Guam	208,234	21,533	10.3%	30,775	14.8%
Gulf of Mexico	1,553,288	6,133	0.4%	9,211	0.6%
Hawaii	2,474,715	302,352	12.2%	419,347	16.9%
Johnston Atoll	442,443	11,026	2.5%	16,821	3.8%
N Mariana Islands	763,626	11,446	1.5%	16,041	2.1%
Palmyra Atoll	353,670	23,546	6.7%	35,617	10.1%
Puerto Rico	172,958	18,483	10.7%	24,908	14.4%
US Virgin Islands	38,275	4,798	12.5%	6,828	17.8%
Wake Island	406,970	42	0.0%	76	0.0%
West	824,679	183,116	22.2%	242,042	29.3%

3.2 Overlap of Cable Buffer with Renewable Energy

Generally the highest proportion of energy is in the lower classes least likely for development where the highest area of overlap with cable buffers also exist (Figure 3; Table 3). The highest wind speed classes (10-11 & 11-12 m/s) are however also occupied by the highest percentage of cable buffer overlap (55.7% & 39.8% for 3z, 39.8% & 15.9% for 2z respectively). These uncommon high wind speed areas are limited to Hawaii and West territories (Table 6; Figure 6 for bargraph; Figure 21 for Hawaii wind map; Figure 35 for West wind map). Overall wave energy has a bimodal distribution, most abundant in the lowest class (997,570 km^2 for 0-10 kW/m) with a sharp drop at the next lowest class (292,692 km^2 for 0-10 kW/m) and then ramping up to roughly half the highest class (532,533 km^2 for >30 kW/m). Overlap with cable buffers for the highest two classes (20-30 & >30 kW/m) is just over 5% (5.2% & 5% for 2z, 6.8% & 6.7% for 3z). Similar to wind, these high energy wave classes are limited to the Pacific territories of Hawaii, West and Alaska (wind for Alaska was not available) (Table 5; Figure 5 for bargraph; Figure 20 for Hawaii wave map; Figure 34 for West wave map; Figure 9 for Alaska wave map). Tidal power is extremely dominated by the lowest energy class of 0-500 W/m^2 covering 403,781 km^2, which is 99.6% of the total area assessed. The cable overlap for the rare higher energy areas is at most 20.1% (12 of 59 km^2) for 500-1,000 W/m^2 in the West and less than 3% for the even rarer higher energy classes of 1,000-1,500 or >1,500 found only in Alaska or the East.

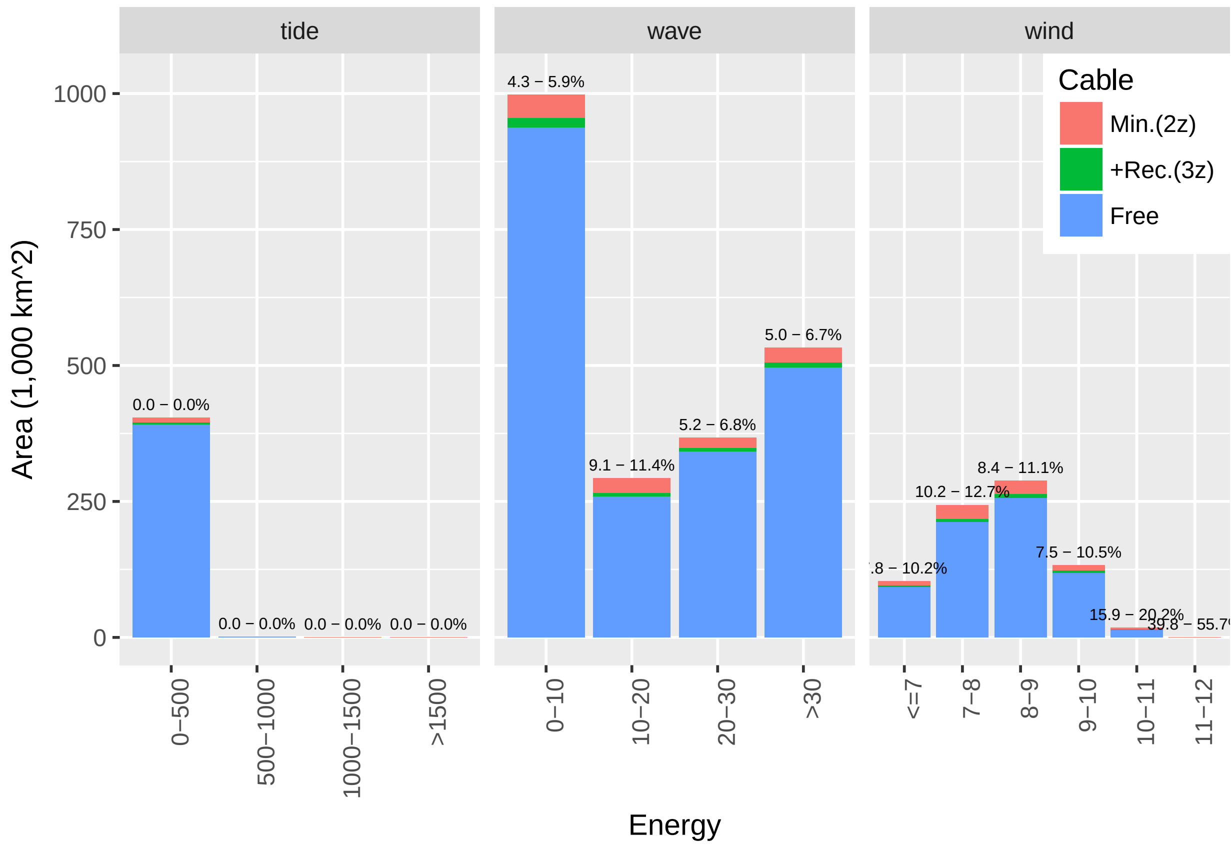

Figure 3: Energy by area and power class per US territory with cable overlay (minimum - recommended %).

Table 3: Area overlap with cables by form of energy broken into size classes across all territories.

Energy	Class	Area (km^2)	Min. Cable (2z)		Rec. Cable (3z)	
			Area (km^2)	(%)	Area (km^2)	(%)
Wind Speed (m/s)	<=7	103,422	8,018	7.8%	10,547	10.2%
	7-8	243,393	24,933	10.2%	31,023	12.7%
	8-9	288,111	24,134	8.4%	32,020	11.1%
	9-10	132,712	9,925	7.5%	13,987	10.5%
	10-11	17,415	2,776	15.9%	3,524	20.2%
	11-12	546	217	39.8%	304	55.7%
Wave Energy (kW/m)	0-10	997,570	42,714	4.3%	59,316	5.9%
	10-20	292,692	26,684	9.1%	33,337	11.4%
	20-30	367,372	19,196	5.2%	24,800	6.8%
	>30	532,533	26,702	5.0%	35,669	6.7%
Tidal Power (W/m2)	0-500	403,781	8,916	0.0%	12,407	0.0%
	500-1000	1,245	42	0.0%	60	0.0%
	1000-1500	325	6	0.0%	9	0.0%
	>1500	224	2	0.0%	3	0.0%

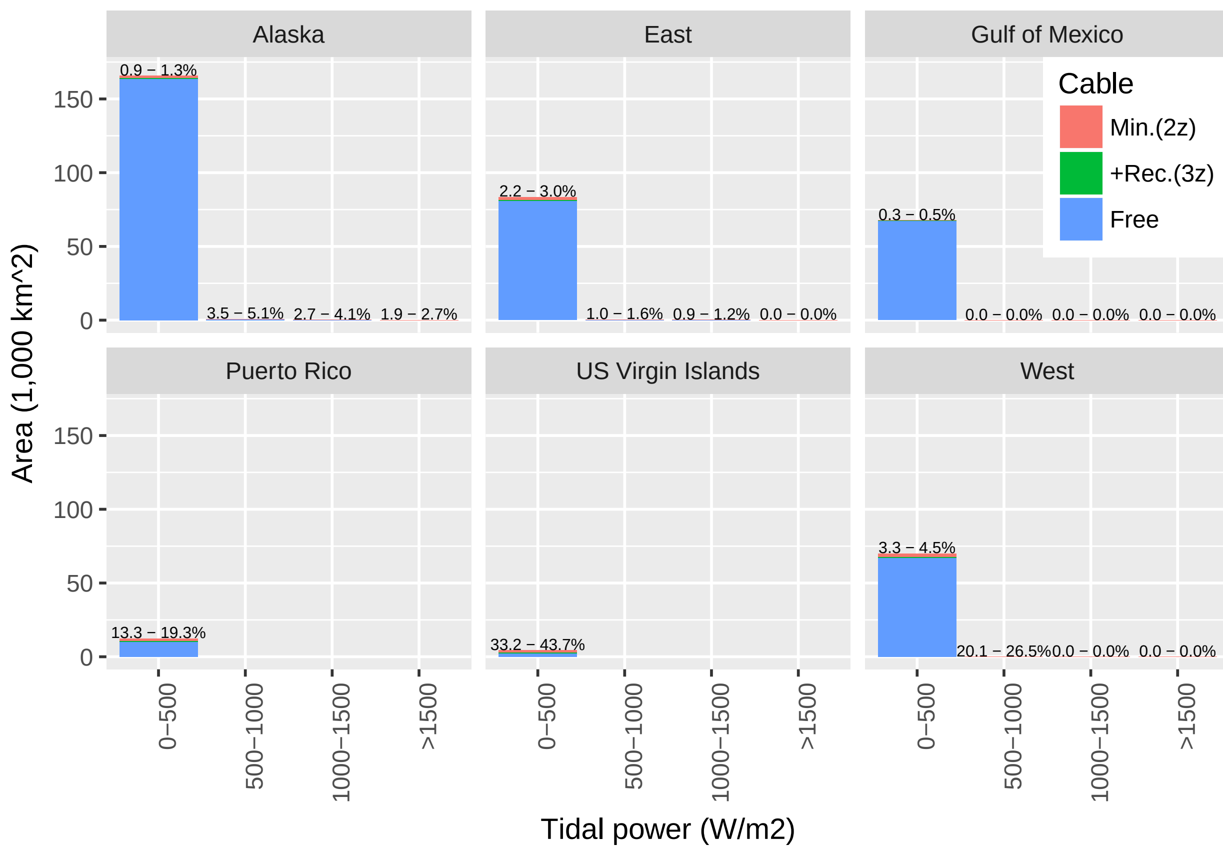

Figure 4: Tidal power (W/m2) and area per US territory with cable overlay (minimum - recommended %).

3.2.1 Tidal

Table 4: Area overlap with cables for tidal power (W/m2) by territory.

Territory	Tidal power (W/m2)	Area (km^2)	Min. Cable (2z)		Rec. Cable (3z)	
			Area (km^2)	(%)	Area (km^2)	(%)
Alaska	0-500	165,671	1,459	0.9%	2,111	1.3%
	500-1000	737	26	3.5%	37	5.1%
	1000-1500	173	5	2.7%	7	4.1%
	>1500	114	2	1.9%	3	2.7%
East	0-500	83,474	1,797	2.2%	2,490	3.0%
	500-1000	412	4	1.0%	7	1.6%
	1000-1500	130	1	0.9%	2	1.2%
	>1500	90	0	0.0%	0	0.0%
Gulf of Mexico	0-500	67,752	236	0.3%	345	0.5%
	500-1000	38	0	0.0%	0	0.0%
	1000-1500	8	0	0.0%	0	0.0%
	>1500	3	0	0.0%	0	0.0%
Puerto Rico	0-500	12,532	1,667	13.3%	2,418	19.3%
US Virgin Islands	0-500	4,289	1,424	33.2%	1,876	43.7%
West	0-500	70,063	2,334	3.3%	3,167	4.5%
	500-1000	59	12	20.1%	16	26.5%
	1000-1500	15	0	0.0%	0	0.0%
	>1500	17	0	0.0%	0	0.0%

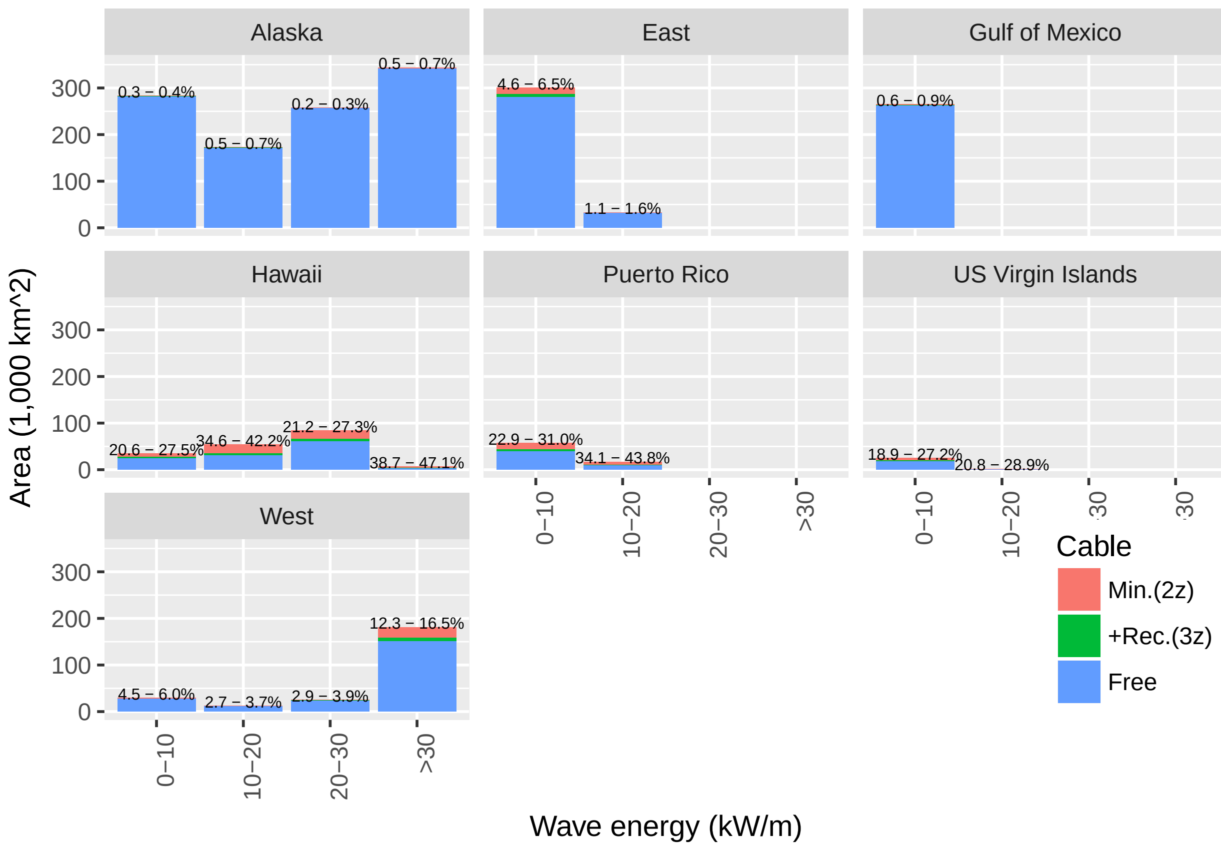

Figure 5: Wave energy (kW/m) and area per US territory with cable overlay (minimum - recommended %).

3.2.2 Wave

Table 5: Area overlap with cables for wave energy (kW/m) by territory.

Territory	Wave Energy (kW/m)	Area (km^2)	Min. Cable (2z)		Rec. Cable (3z)	
			Area (km^2)	(%)	Area (km^2)	(%)
Alaska	0-10	283,698	767	0.3%	1,106	0.4%
	10-20	173,017	814	0.5%	1,194	0.7%
	20-30	258,071	614	0.2%	868	0.3%
	>30	344,236	1,652	0.5%	2,533	0.7%
East	0-10	300,822	13,810	4.6%	19,624	6.5%
	10-20	33,099	363	1.1%	541	1.6%
Gulf of Mexico	0-10	265,084	1,621	0.6%	2,436	0.9%
Hawaii	0-10	35,095	7,213	20.6%	9,639	27.5%
	10-20	54,495	18,872	34.6%	23,010	42.2%
	20-30	84,179	17,849	21.2%	22,949	27.3%
	>30	6,929	2,683	38.7%	3,264	47.1%
Puerto Rico	0-10	57,391	13,145	22.9%	17,787	31.0%
	10-20	17,136	5,844	34.1%	7,507	43.8%
US Virgin Islands	0-10	25,477	4,820	18.9%	6,919	27.2%
	10-20	2,123	441	20.8%	613	28.9%
West	0-10	30,004	1,339	4.5%	1,805	6.0%
	10-20	12,821	351	2.7%	472	3.7%
	20-30	25,122	733	2.9%	984	3.9%
	>30	181,368	22,367	12.3%	29,872	16.5%

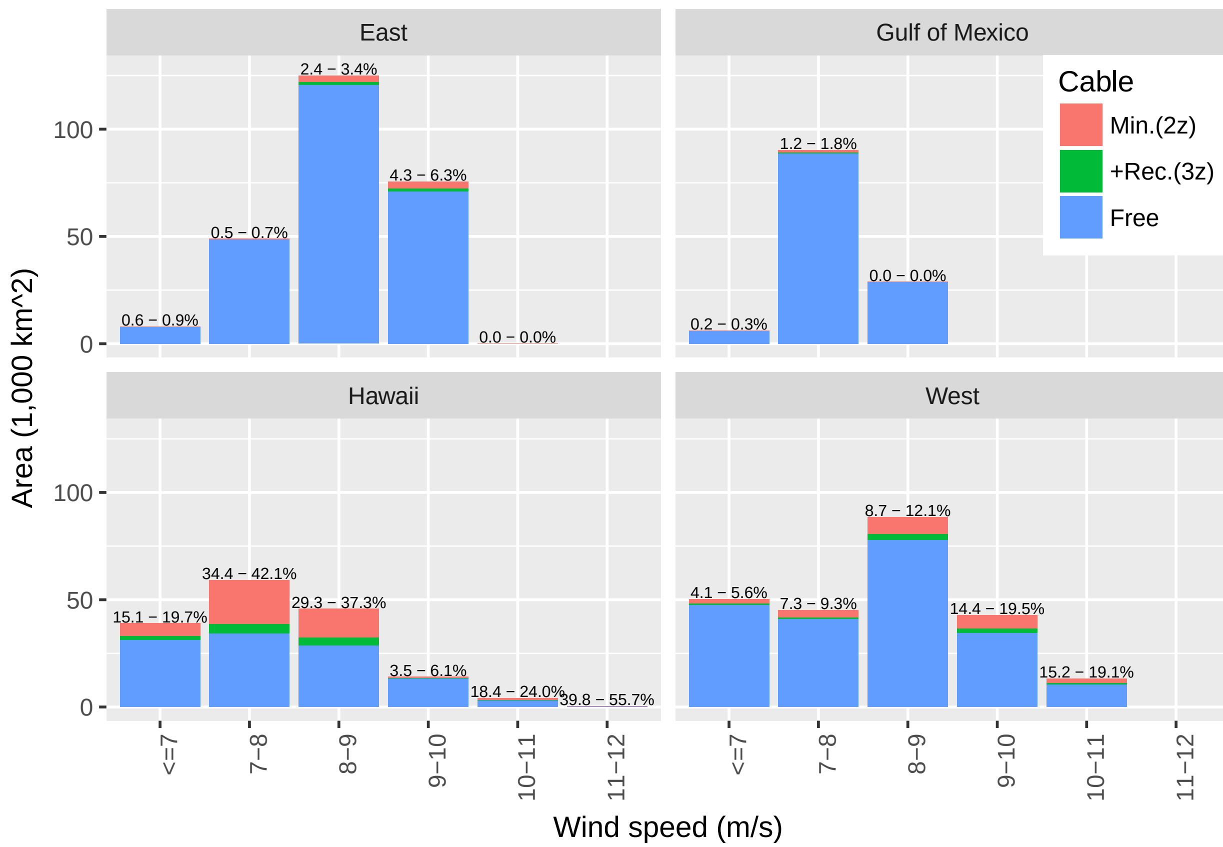

Figure 6: Wind speed (m/s) at 90m hub height and area per US territory with cable overlay (minimum - recommended %).

3.2.3 Wind

Table 6: Area overlap with cables for wind speed (m/s) at 90m hub height by territory.

Territory	Wind Speed (m/s)	Area (km^2)	Min. Cable (2z)		Rec. Cable (3z)	
			Area (km^2)	(%)	Area (km^2)	(%)
East	<=7	8,006	50	0.6%	70	0.9%
	7-8	48,890	240	0.5%	352	0.7%
	8-9	124,946	2,991	2.4%	4,213	3.4%
	9-10	75,695	3,235	4.3%	4,735	6.3%
	10-11	41	0	0.0%	0	0.0%
Gulf of Mexico	<=7	6,083	12	0.2%	18	0.3%
	7-8	90,254	1,079	1.2%	1,620	1.8%
	8-9	28,855	0	0.0%	0	0.0%
Hawaii	<=7	38,998	5,871	15.1%	7,664	19.7%
	7-8	59,131	20,335	34.4%	24,876	42.1%
	8-9	45,787	13,400	29.3%	17,091	37.3%
	9-10	14,099	488	3.5%	866	6.1%
	10-11	4,184	772	18.4%	1,004	24.0%
	11-12	546	217	39.8%	304	55.7%
West	<=7	50,335	2,085	4.1%	2,795	5.6%
	7-8	45,119	3,278	7.3%	4,175	9.3%
	8-9	88,522	7,744	8.7%	10,716	12.1%
	9-10	42,918	6,201	14.4%	8,386	19.5%
	10-11	13,190	2,005	15.2%	2,520	19.1%

4 Conclusions

Given climate change impacts of fossil fuel energy production (Pachauri et al. 2015), development of clean renewable energy alternatives are imperative for the sustainable future of the United States and rest of the planet. These energy sources however vary widely in geographic and temporal availability and may compete with other uses. The submarine cable industry provides critical power and telecommunication services, such that safe operation and maintenance must be heeded as marine renewable energy sources are developed (Communications Security, Reliability and Interoperability Council IV 2014, 2016). The submarine cable safety avoidance zones created and evaluated through this report are products intended to minimize conflict at the plannnig stage between these competing uses.

Although the US currently only has one marine renewable energy facility in full production at Block Island NJ, many more are in pilot and proposal phases with much future potential (Beiter et al. 2017; Lehmann et al. 2017; Uihlein and Magagna 2016). These spatial avoidance zones are advisory. Should there be overlapping interest, negotiations between renewable energy developers and cable operators should be sought.

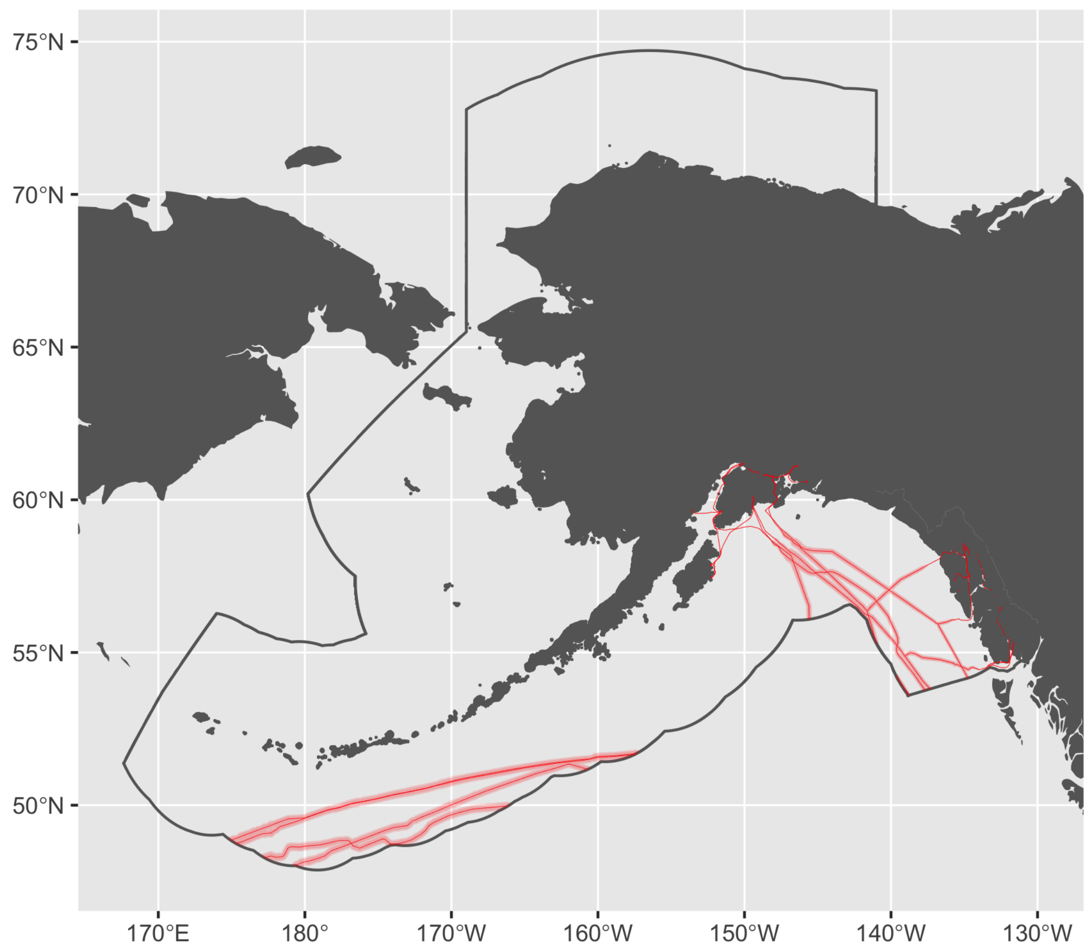

Figure 7: Cable buffers for Alaska.

A Detailed Maps by US Territory of Cable Buffer and Renewable Energy

A.0.1 Alaska

See Figure 7.

A.0.1.1 Tidal

See Figure 8.

A.0.1.2 Wave

See Figure 9.

A.0.2 East

See Figure 10.

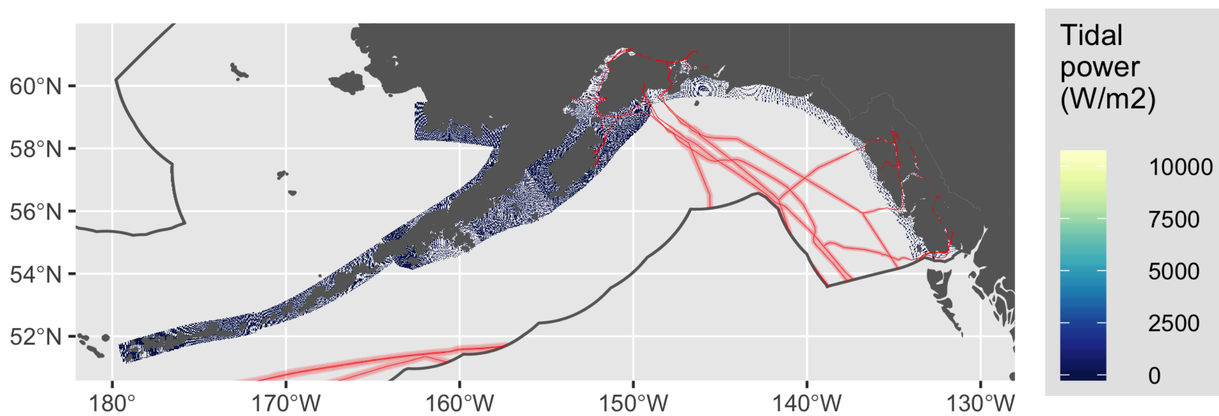

Figure 8: Tidal energy for Alaska.

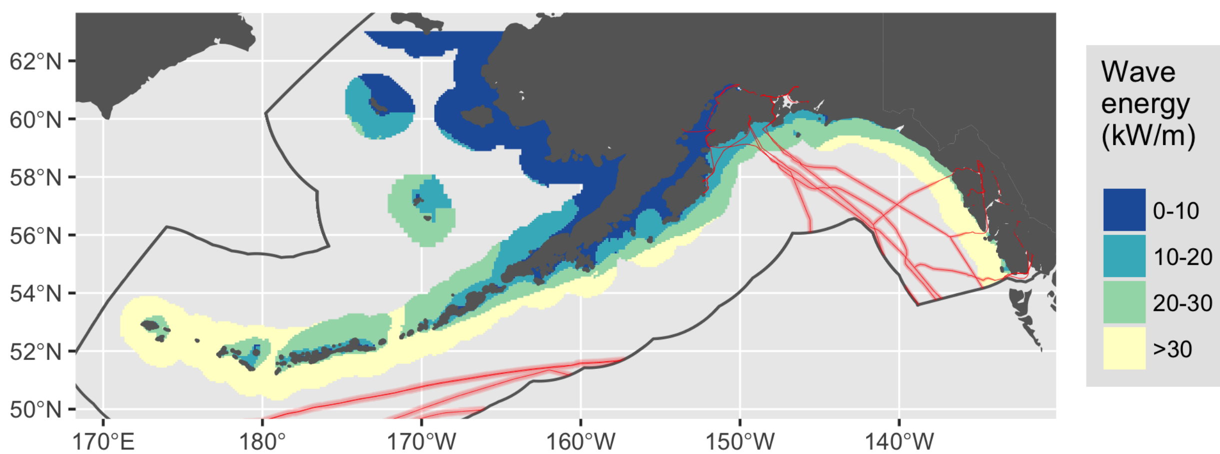

Figure 9: Wave energy for Alaska.

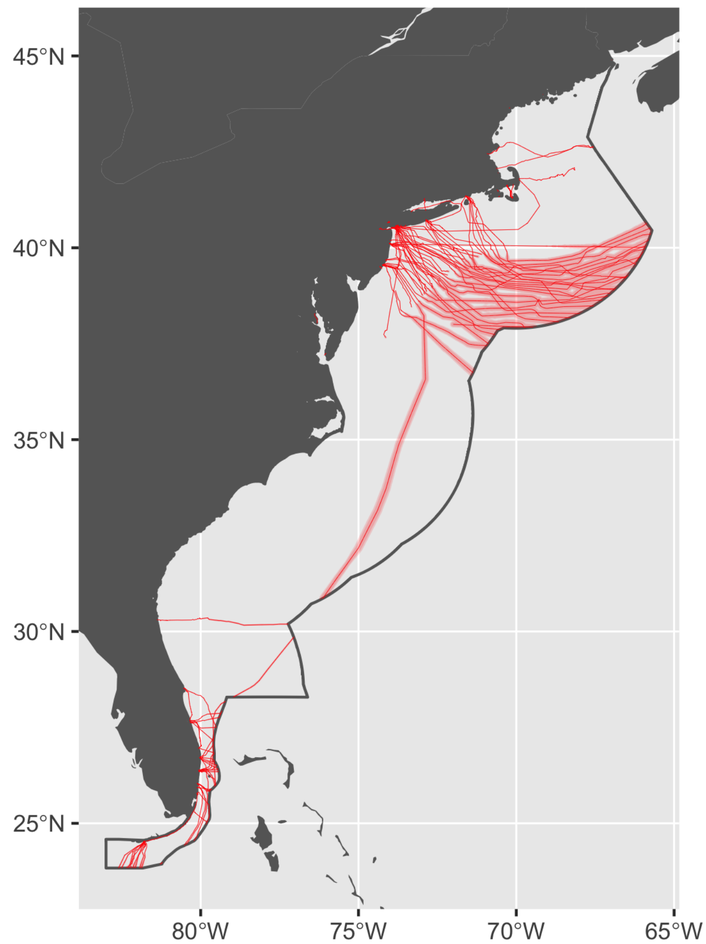

Figure 10: Cable buffers for East.

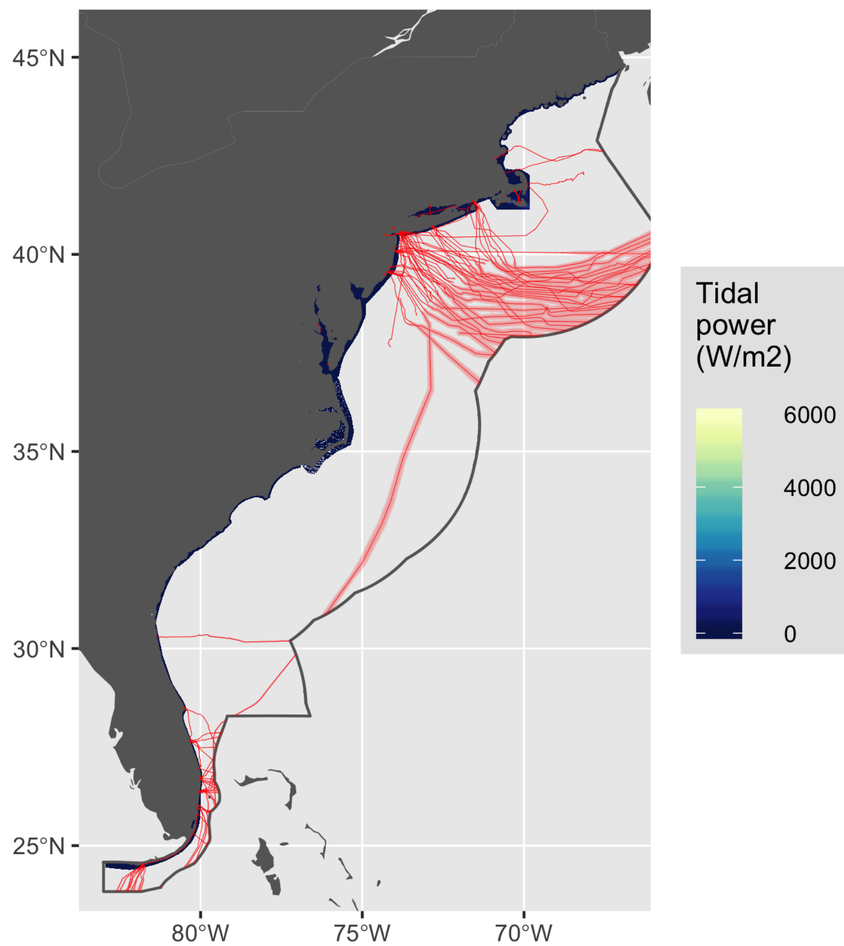

Figure 11: Tidal energy for East.

A.0.2.1 Tidal

See Figure 11.

A.0.2.2 Wave

See Figure 12.

A.0.2.3 Wind

See Figure 13.

A.0.3 Guam

See Figure 14.

A.0.4 Gulf of Mexico

See Figure 15.

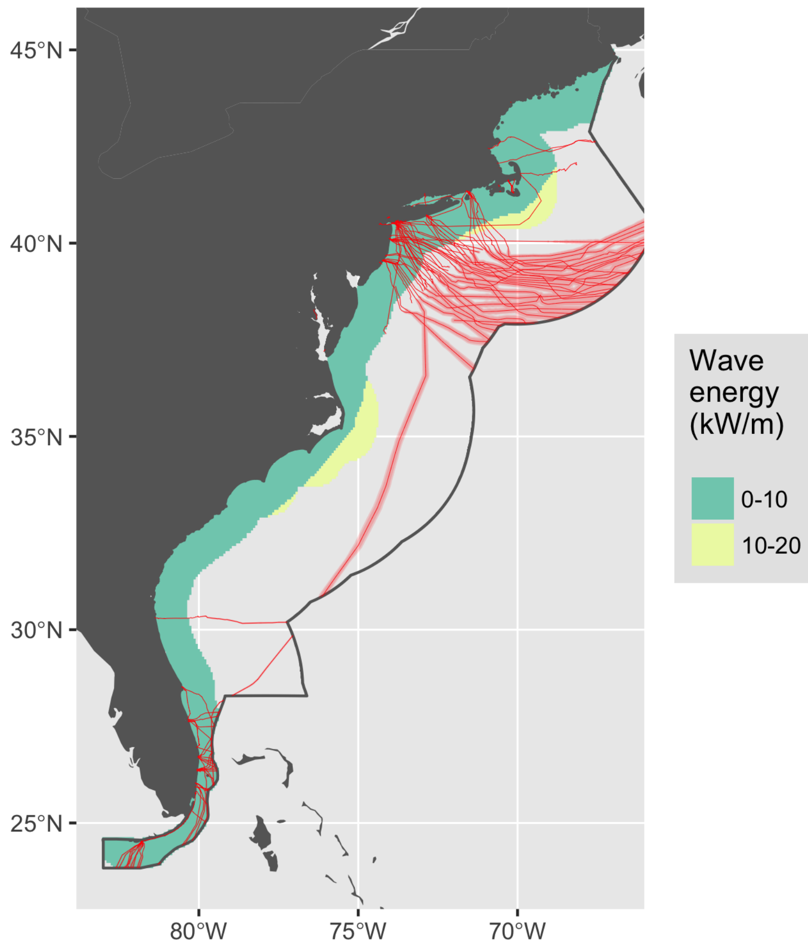

Figure 12: Wave energy for East.

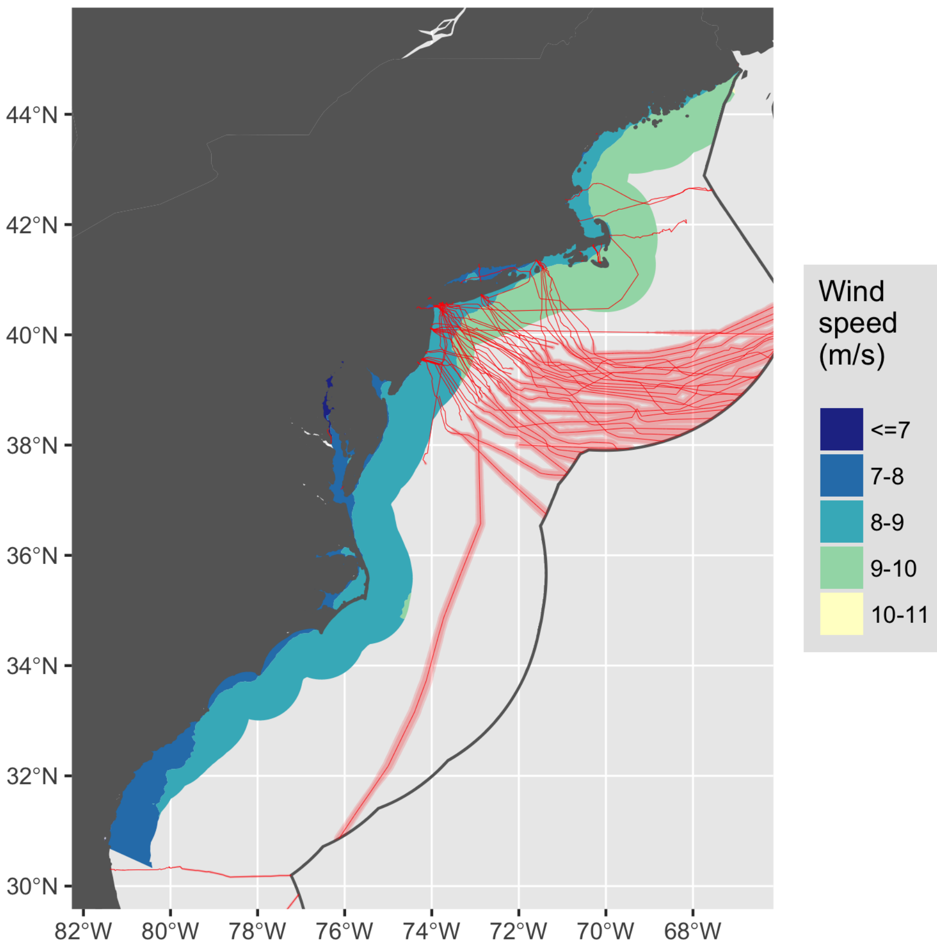

Figure 13: Wind energy for East.

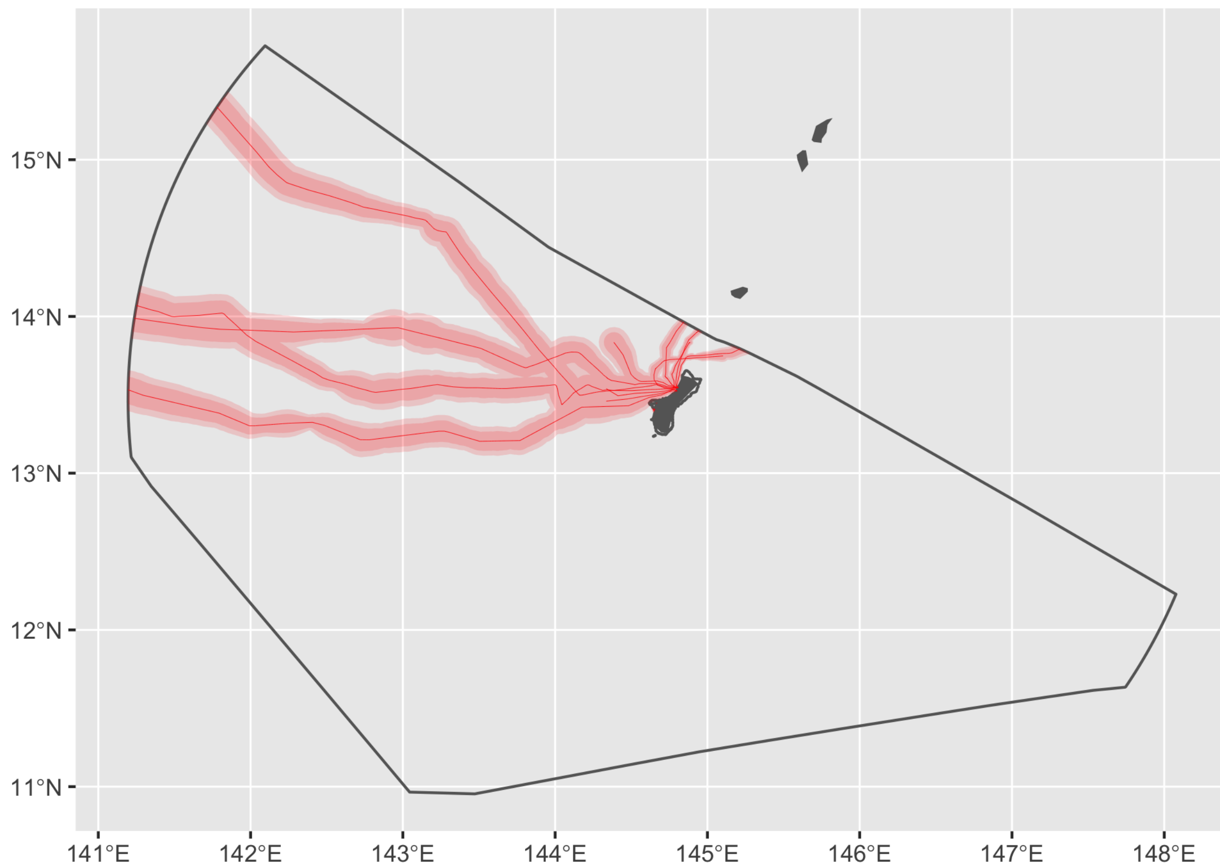

Figure 14: Cable buffers for Guam.

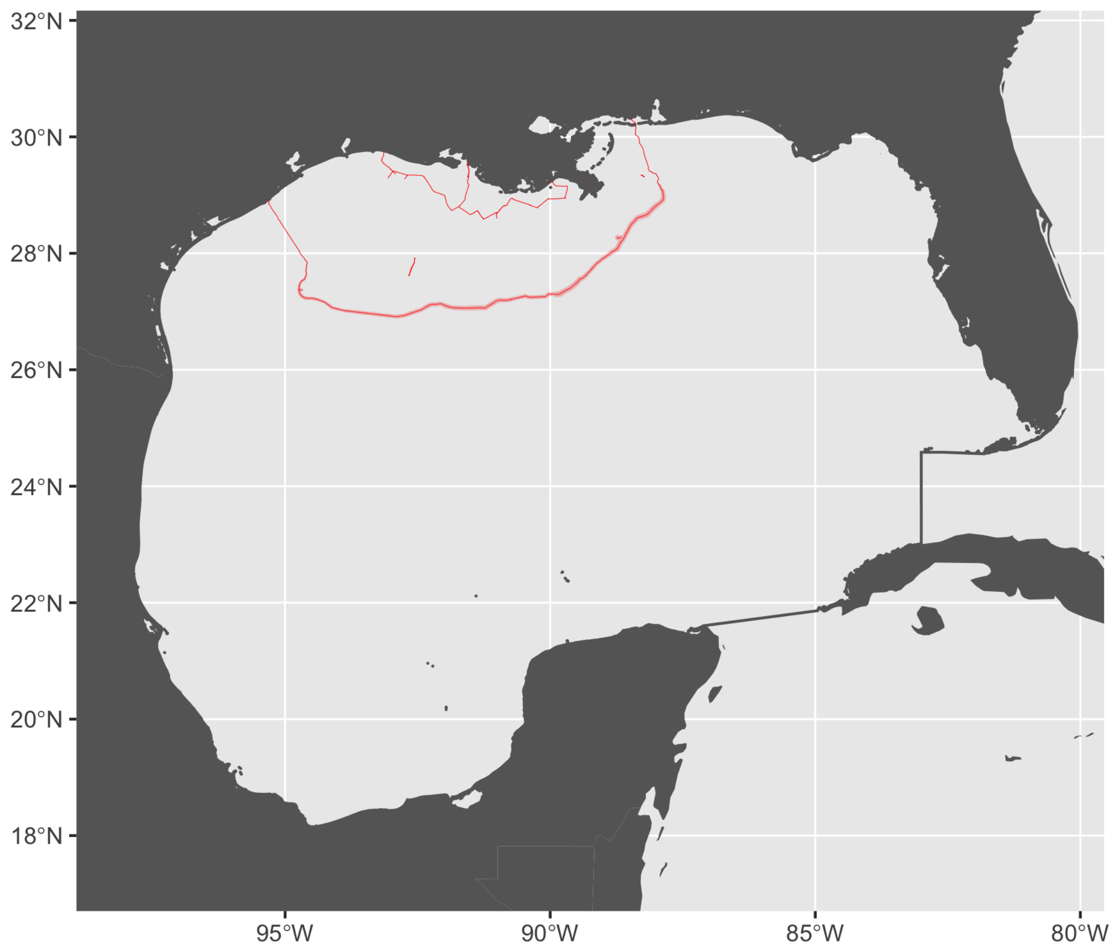

Figure 15: Cable buffers for Gulf of Mexico.

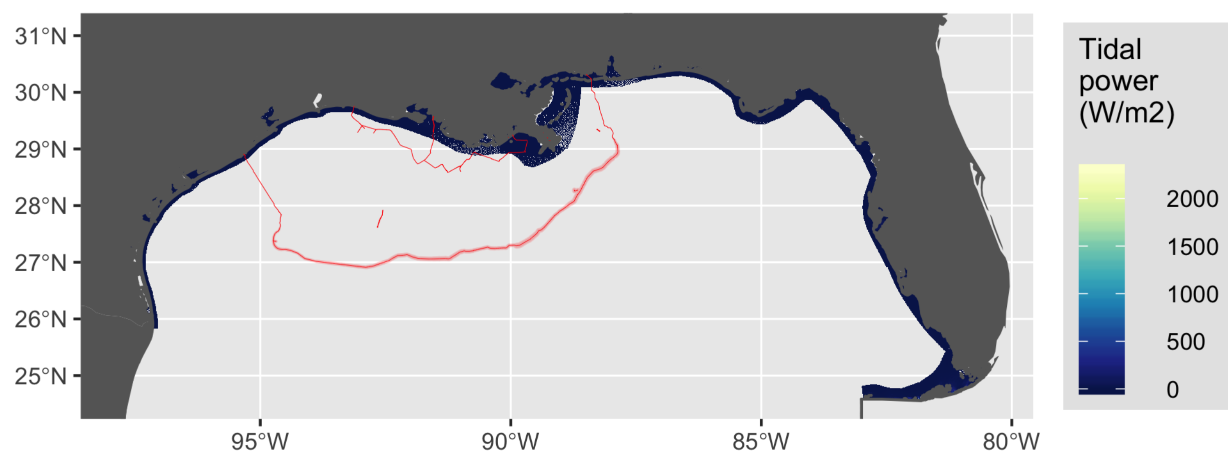

Figure 16: Tidal energy for Gulf of Mexico.

A.0.4.1 Tidal

See Figure 16.

A.0.4.2 Wave

See Figure 17.

A.0.4.3 Wind

See Figure 18.

A.0.5 Hawaii

See Figure 19.

A.0.5.1 Wave

See Figure 20.

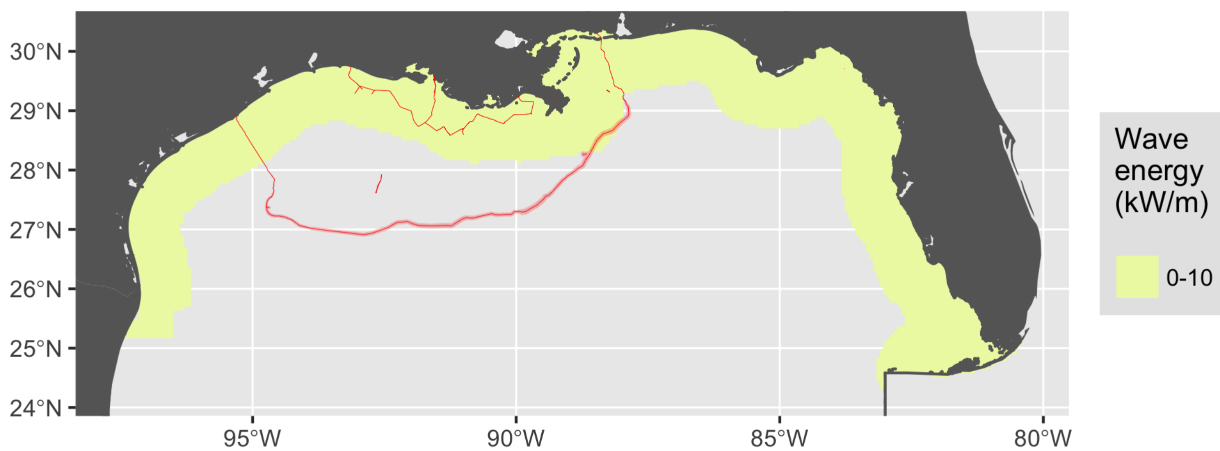

Figure 17: Wave energy for Gulf of Mexico.

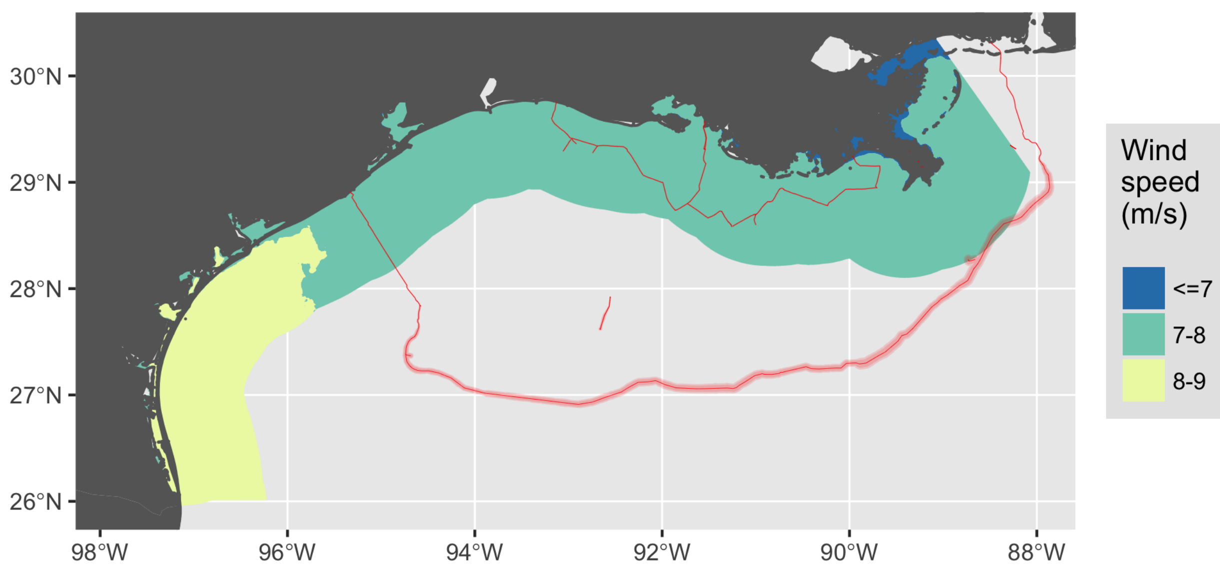

Figure 18: Wind energy for Gulf of Mexico.

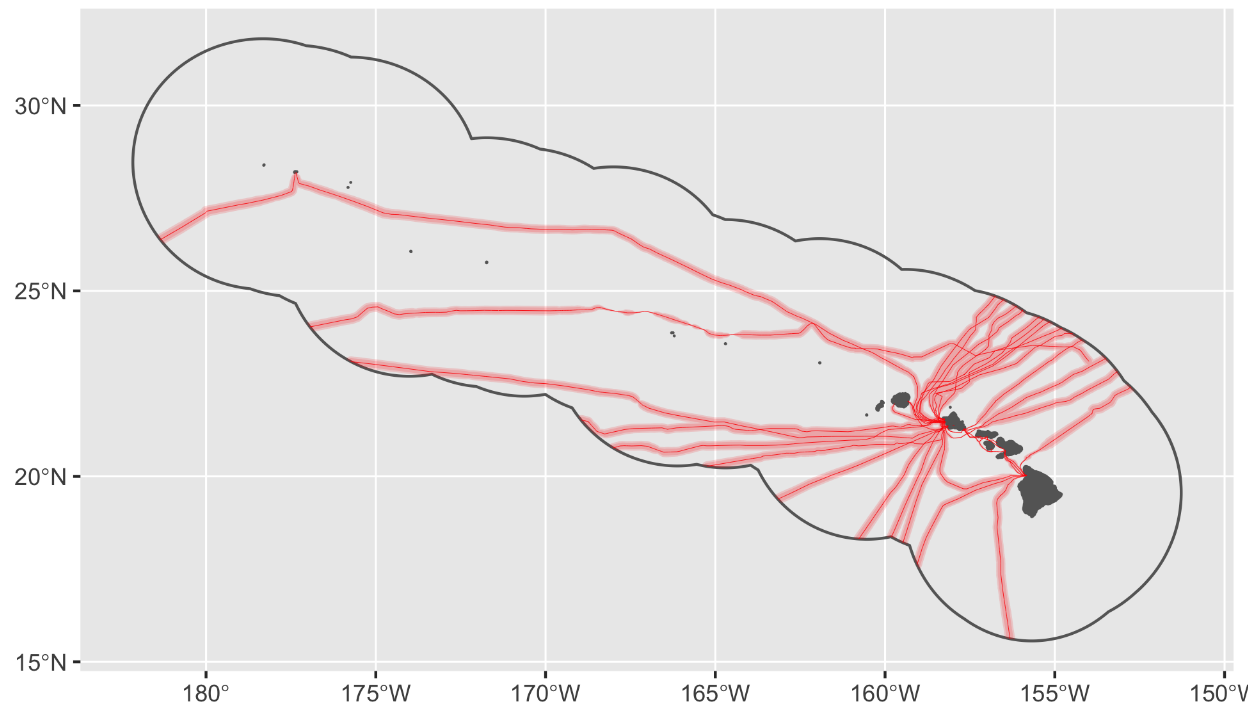

Figure 19: Cable buffers for Hawaii.

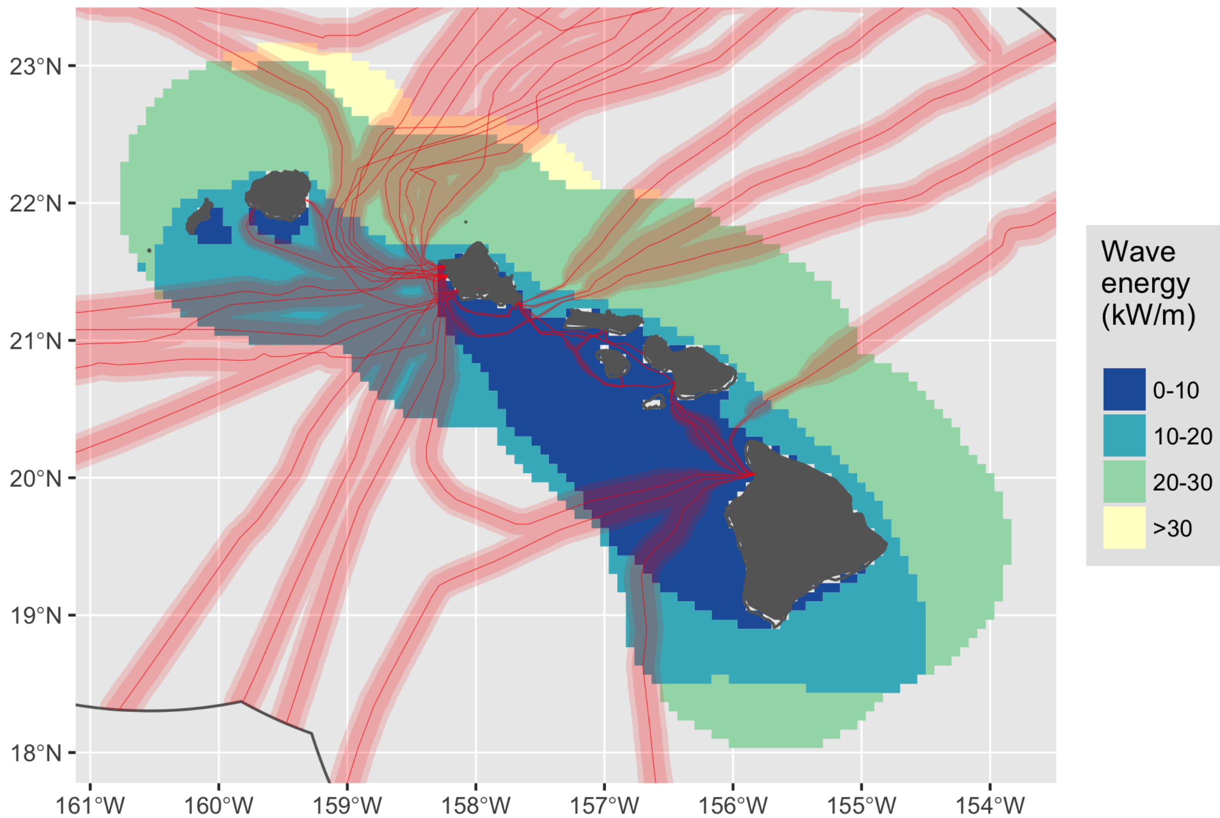

Figure 20: Wave energy for Hawaii.

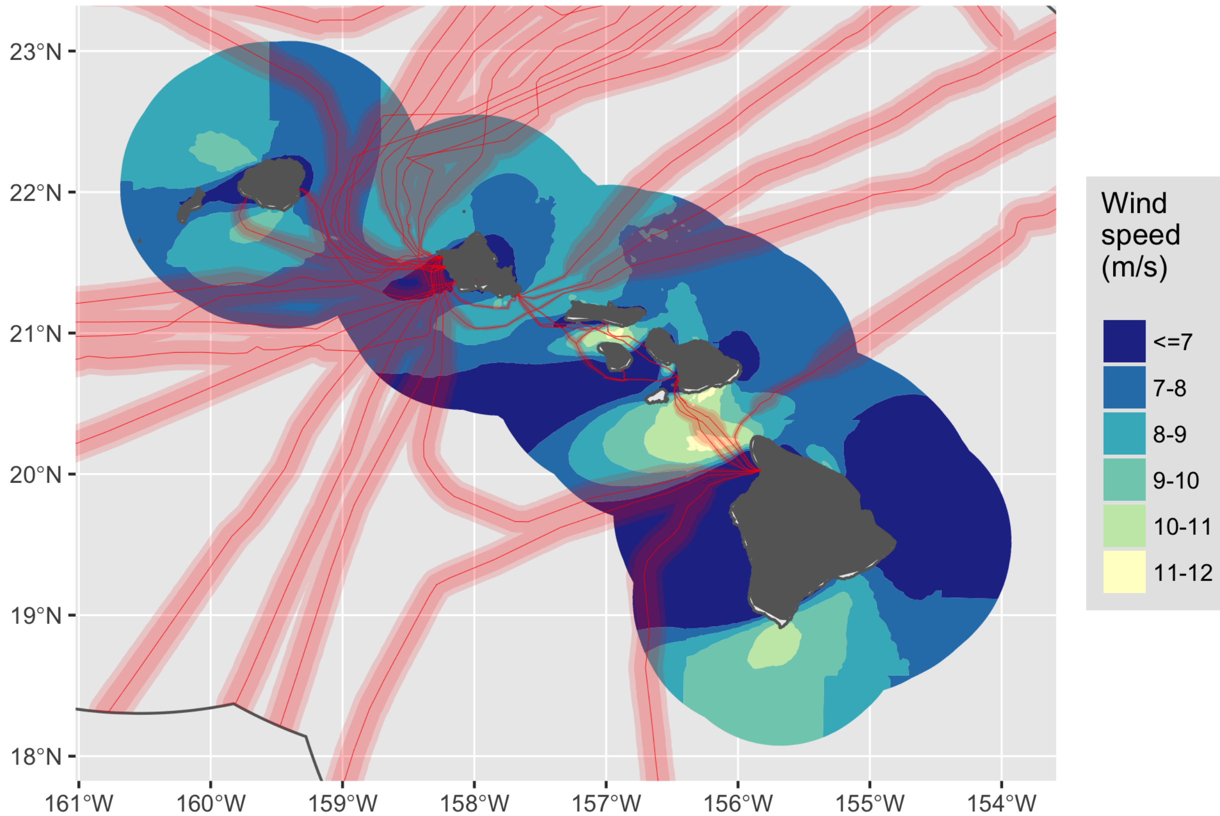

Figure 21: Wind energy for Hawaii.

A.0.5.2 Wind

See Figure 21.

A.0.6 Johnston Atoll

See Figure 22.

A.0.7 N Mariana Islands

See Figure 23.

A.0.8 Palmyra Atoll

See Figure 24.

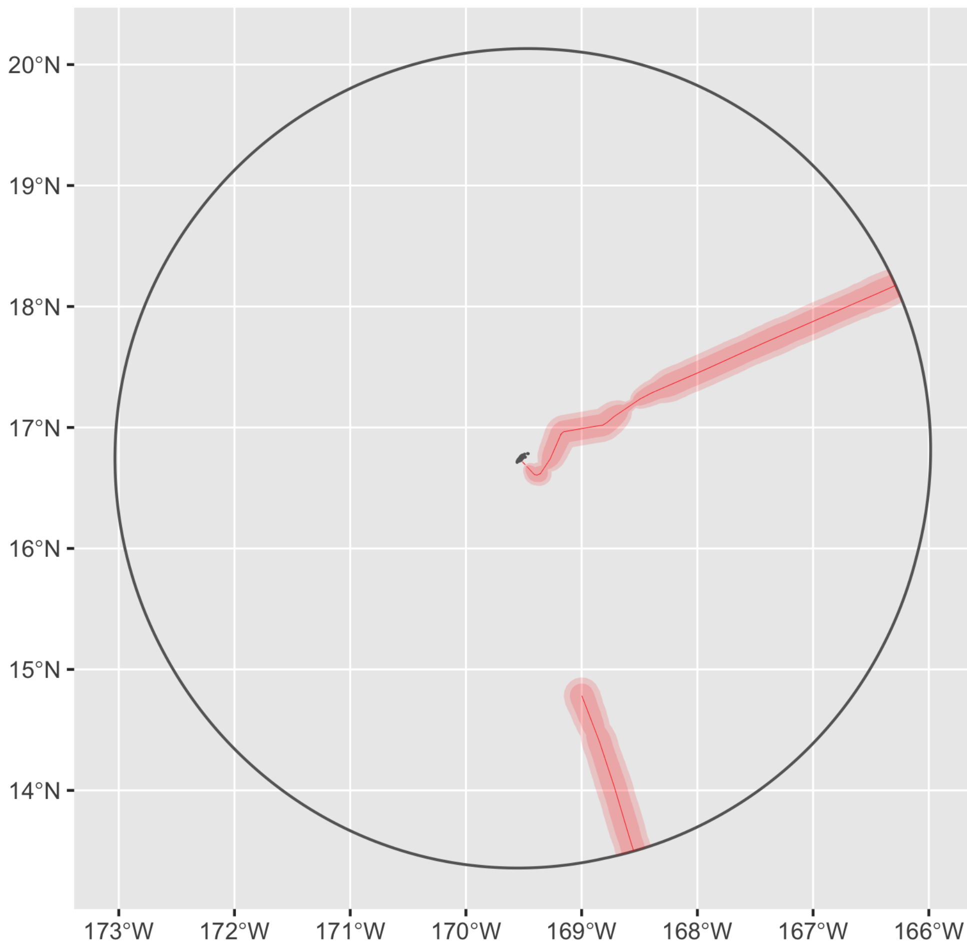

Figure 22: Cable buffers for Johnston Atoll.

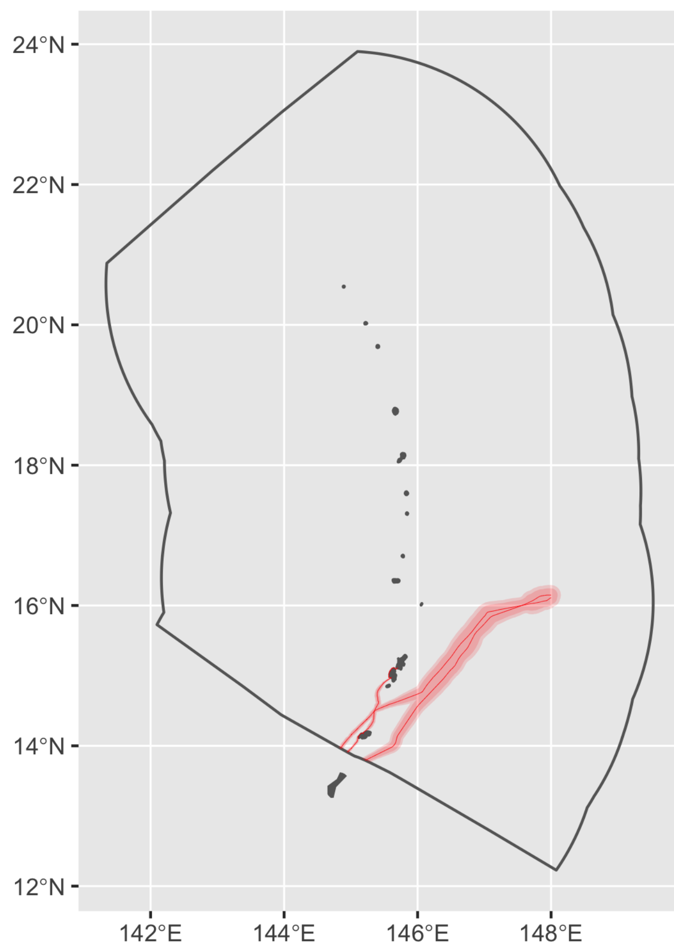

Figure 23: Cable buffers for N Mariana Islands.

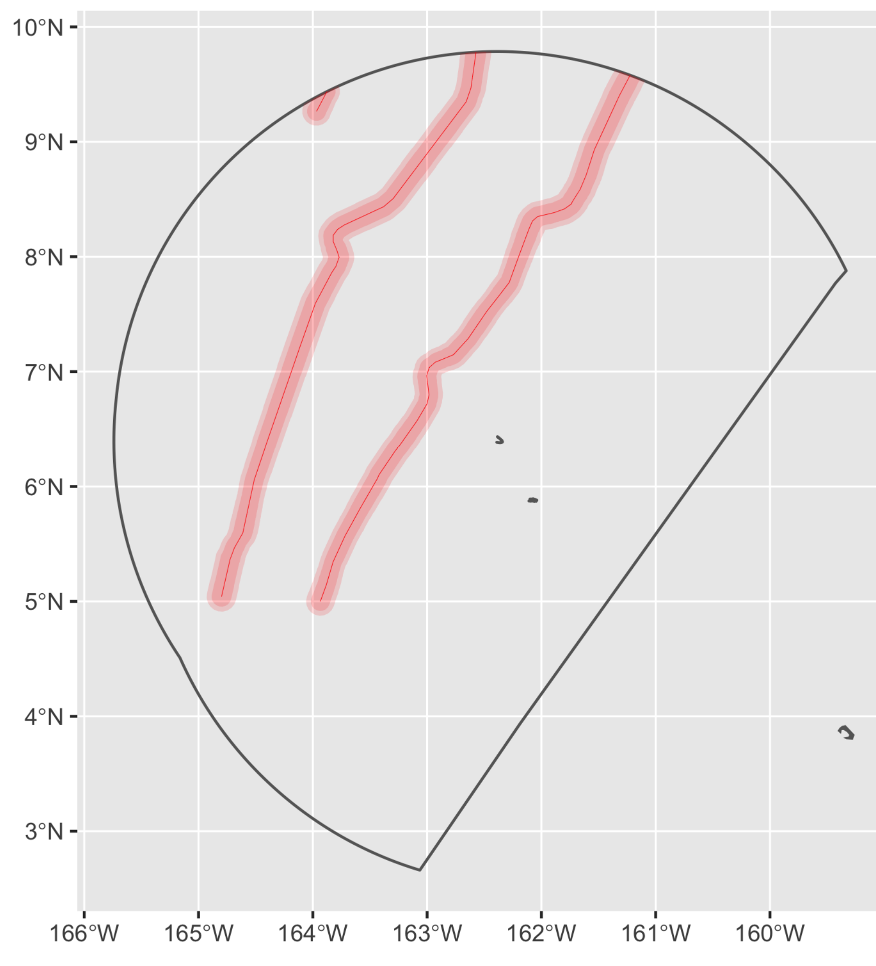

Figure 24: Cable buffers for Palmyra Atoll.

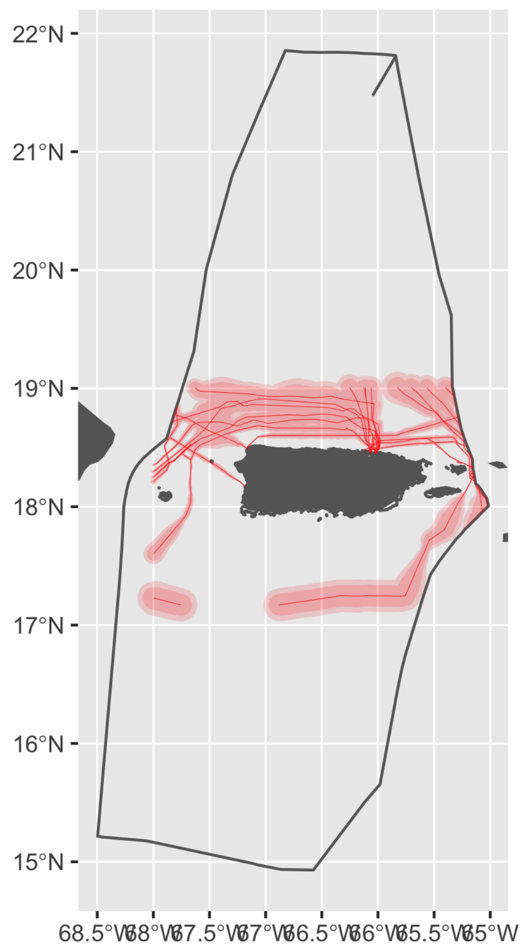

Figure 25: Cable buffers for Puerto Rico.

A.0.9 Puerto Rico

See Figure 25.

A.0.9.1 Tidal

See Figure 26.

A.0.9.2 Wave

See Figure 27.

A.0.10 US Virgin Islands

See Figure 28.

A.0.10.1 Tidal

See Figure 29.

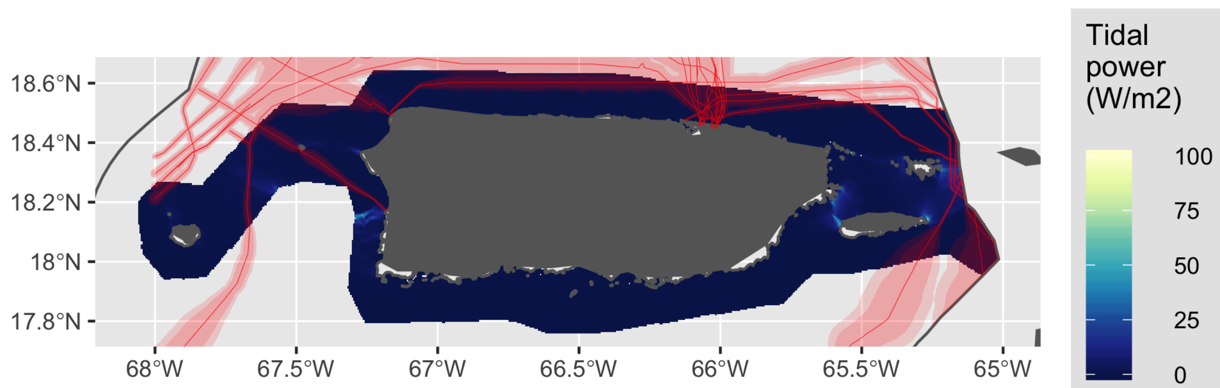

Figure 26: Tidal energy for Puerto Rico.

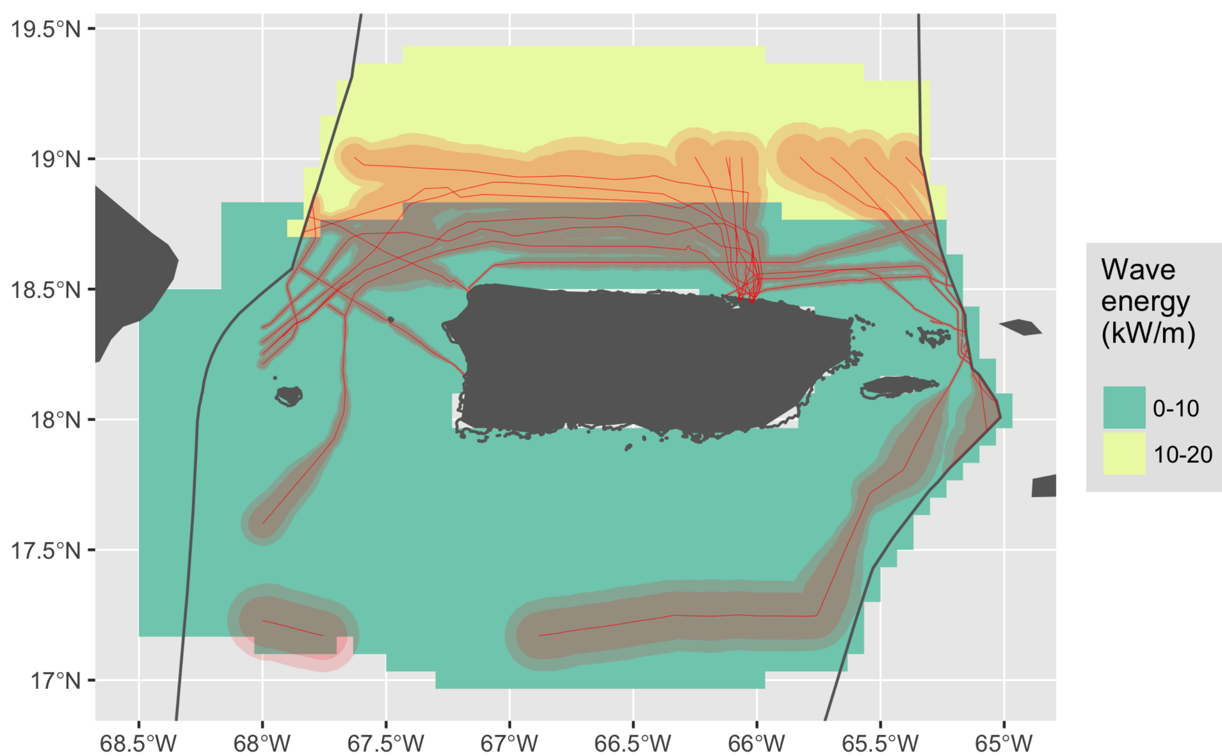

Figure 27: Wave energy for Puerto Rico.

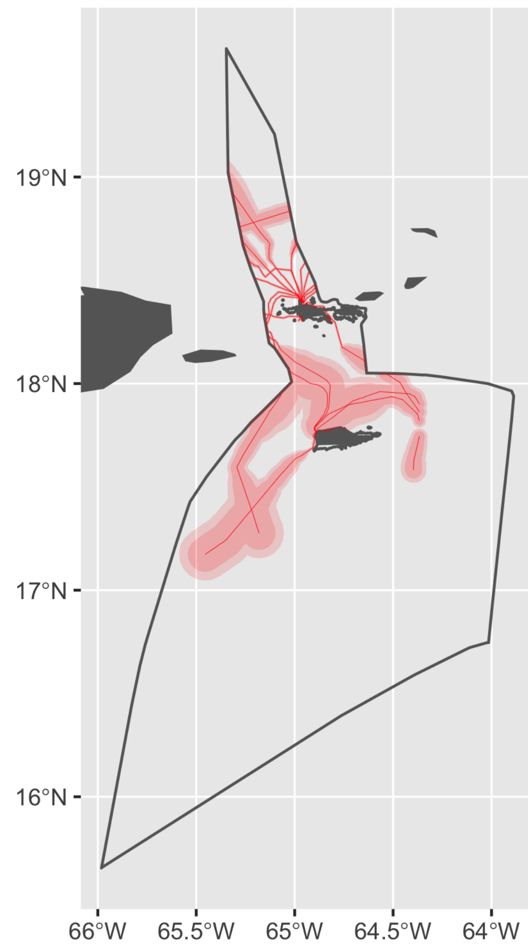

Figure 28: Cable buffers for US Virgin Islands.

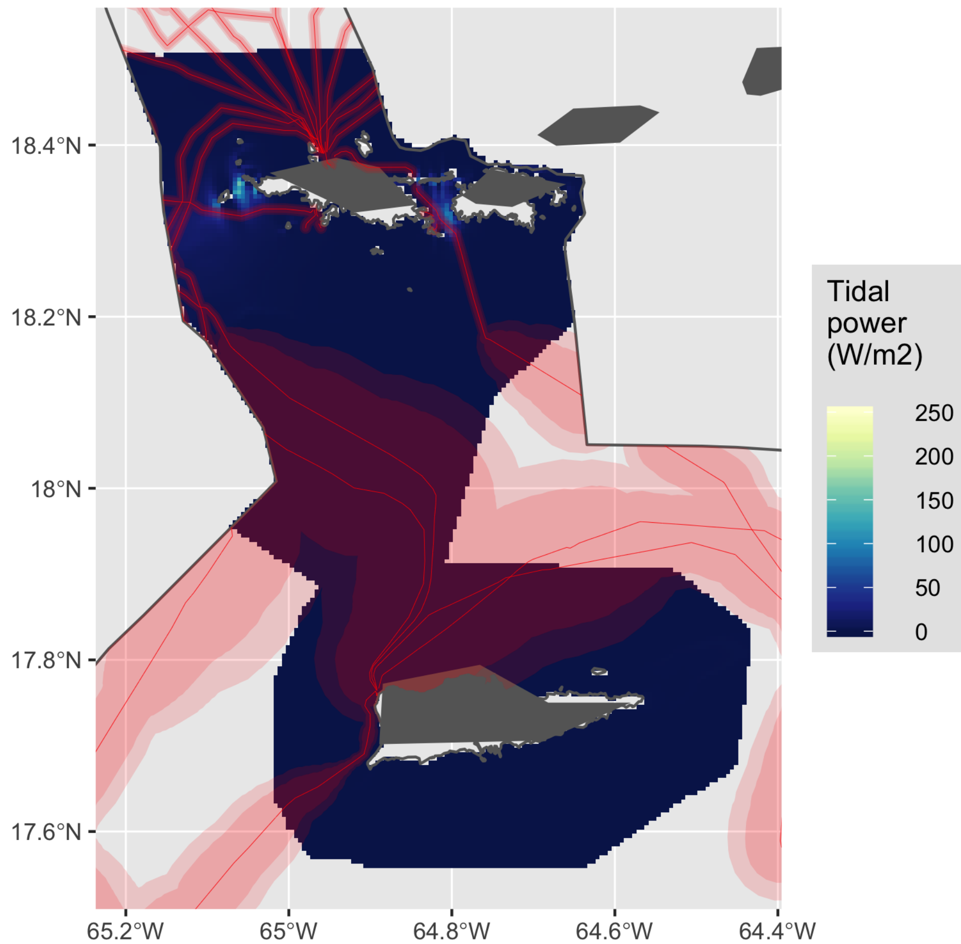

Figure 29: Tidal energy for US Virgin Islands.

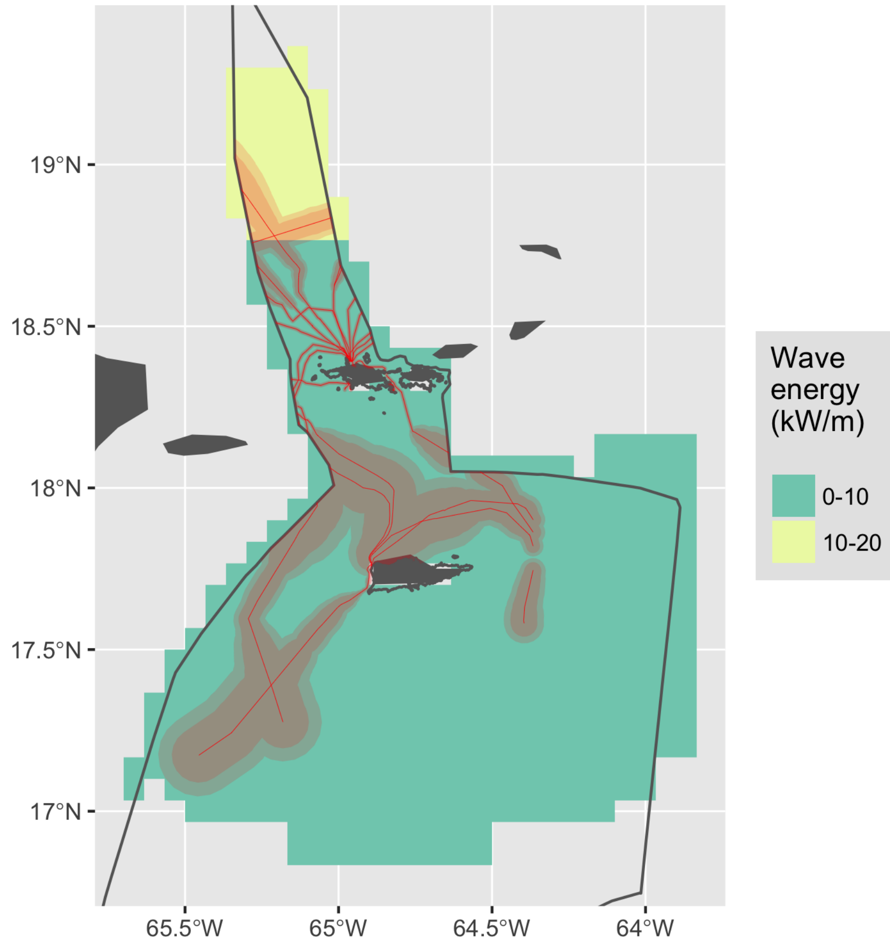

Figure 30: Wave energy for US Virgin Islands.

A.0.10.2 Wave

See Figure 30.

A.0.11 Wake Island

See Figure 31.

A.0.12 West

See Figure 32.

A.0.12.1 Tidal

See Figure 33.

A.0.12.2 Wave

See Figure 34.

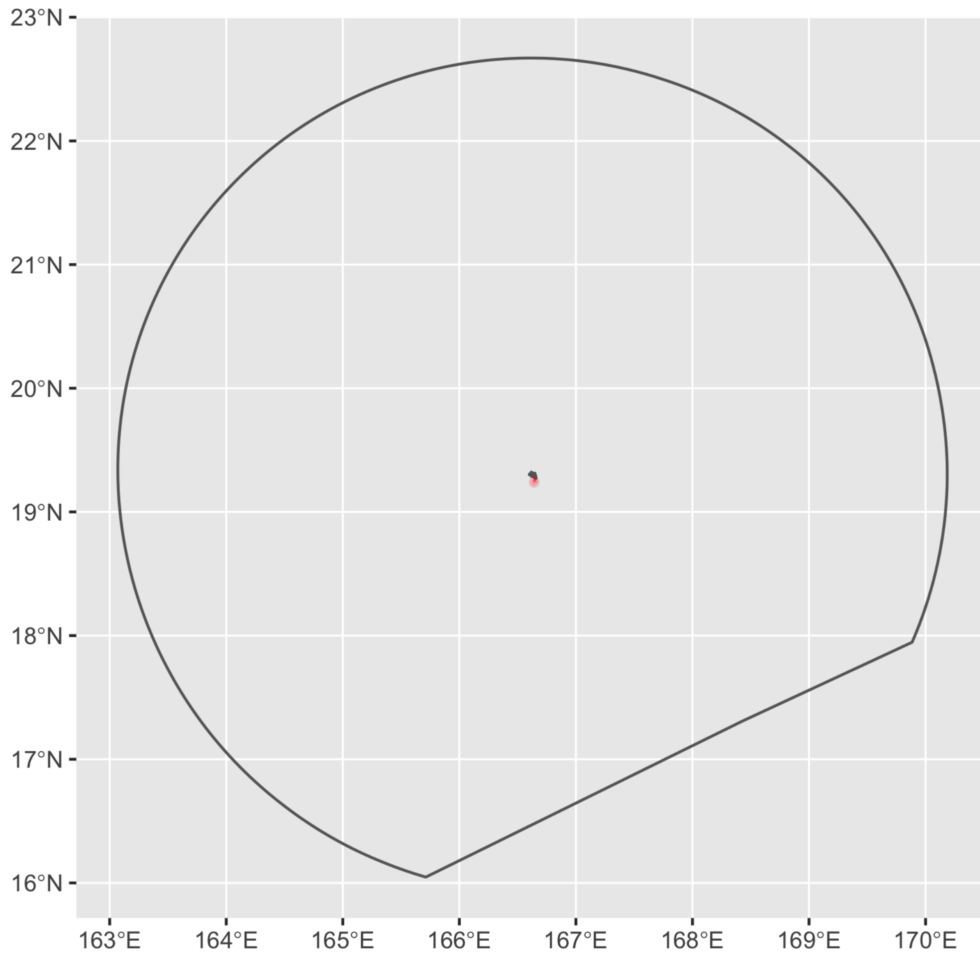

Figure 31: Cable buffers for Wake Island.

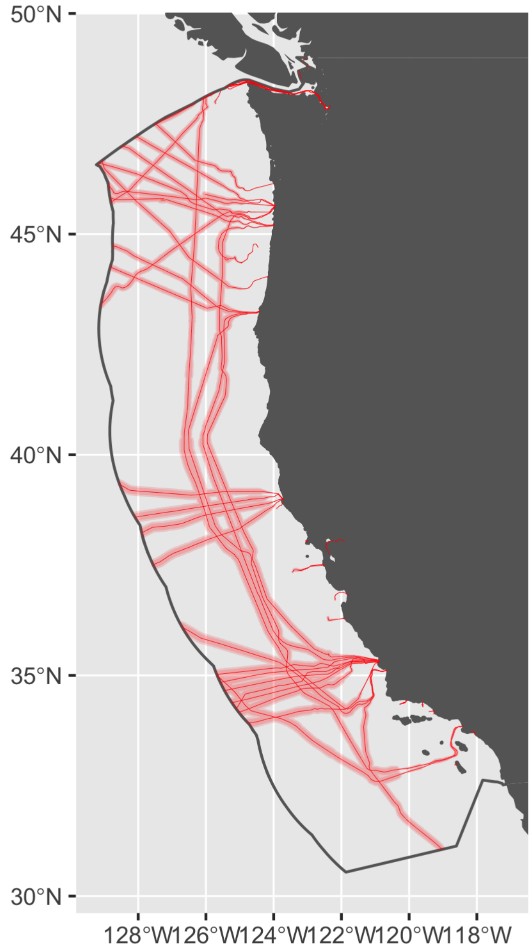

Figure 32: Cable buffers for West.

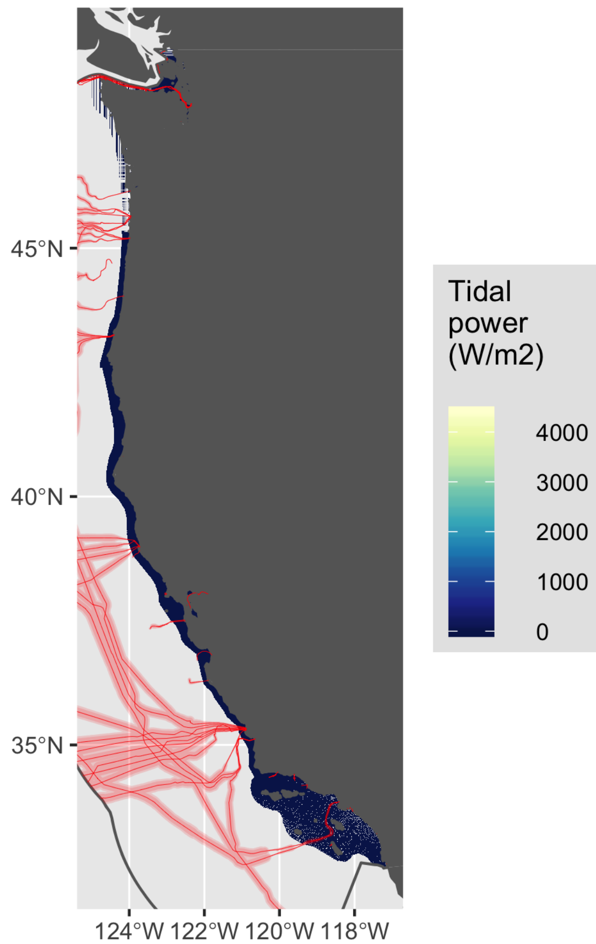

Figure 33: Tidal energy for West.

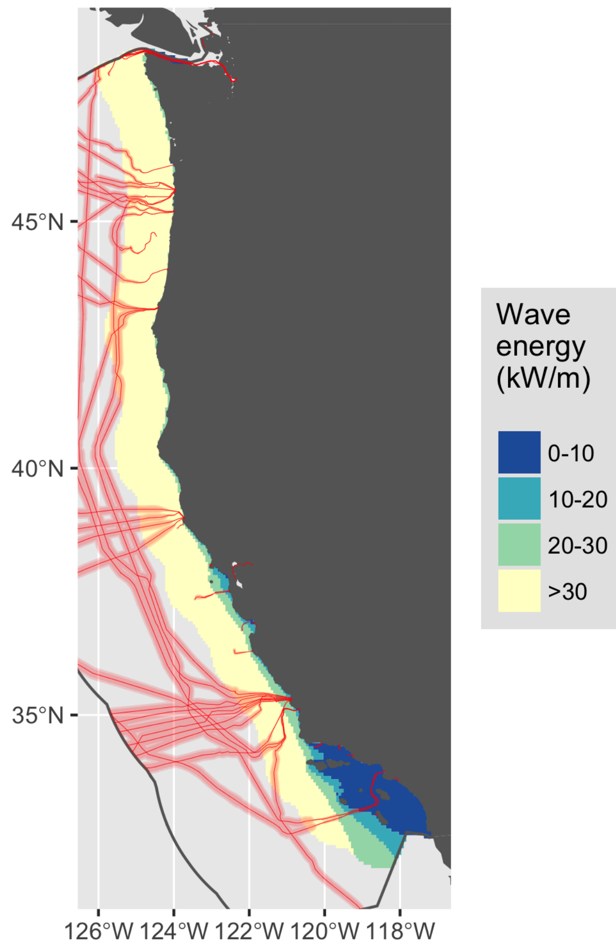

Figure 34: Wave energy for West.

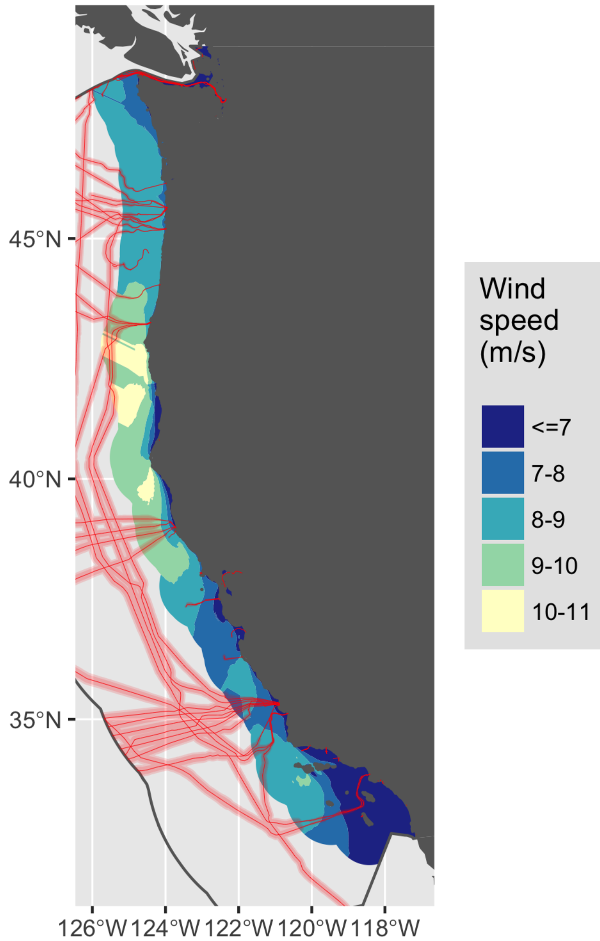

Figure 35: Wind energy for West.

A.0.12.3 Wind

See Figure 35.

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