

# Submarine Cable Analysis for Marine Renewable Energy Development

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## 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, DOE has asked NREL to identify — and mitigate where possible — the competing uses between MHK/OSW technologies and subsea power/telecoms 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, Kilcher, Roberts, & Draxl, 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; n-a-s-c-a.org) advise on setback distances that inform this analysis.

## 2 Methods

### 2.1 Study Area and Submarine Cables

The study area included the 200 nm extent of US waters downloaded from MarineRegions.org<sup>1</sup> and overlapping the offshore cable data layer available through MarineCadastre.gov.<sup>2</sup> See Figure ??.

TODO: add citations to bibliography:

- MarineRegions.org > Exclusive Economic Zones Boundaries (EEZ), version: World EEZ v9 (2016-10-21, 123 MB). Suggested citation:
  - Flanders Marine Institute (2016). Maritime Boundaries Geodatabase, version 1. Available online at <http://www.marineregions.org/>. Consulted on 2017-04-25.
- MarineCadastre.gov cable metadata

See Table 1 and Figure ??.

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<sup>1</sup>MarineRegions.org US exclusive economic zone (EEZ) data, version World\_EEZ\_v9\_20161021

<sup>2</sup>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>

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

| <b>Id</b> | <b>Territory</b>  | <b>Area (km2)</b> |
|-----------|-------------------|-------------------|
| 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           |

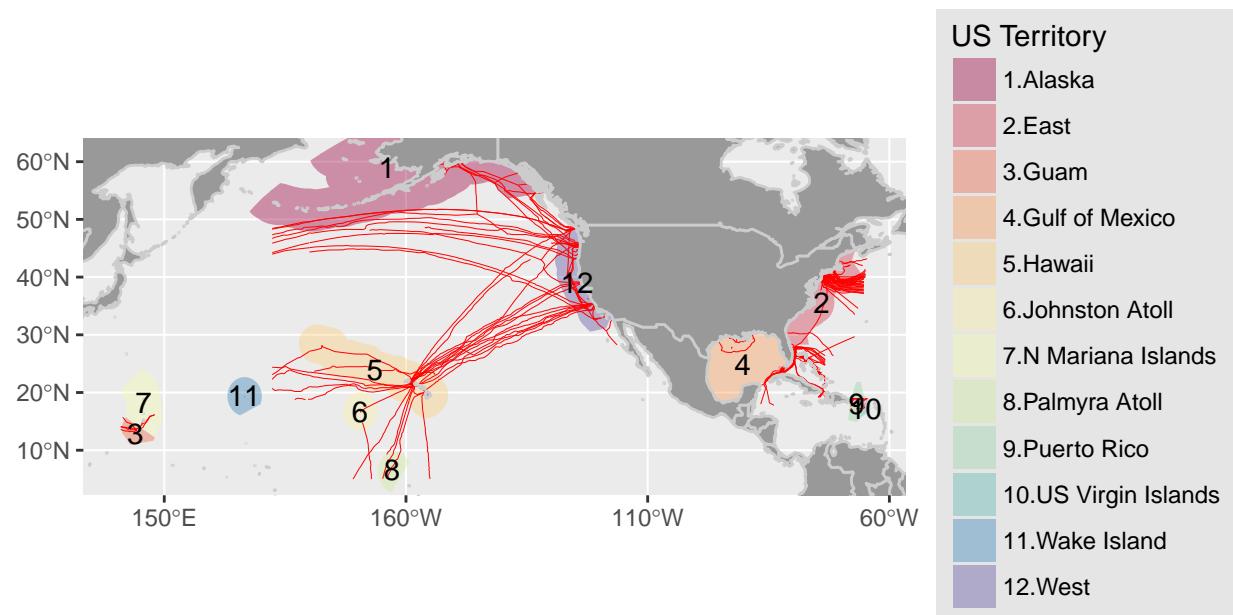


Figure 1: Map of NOAA Charted Submarine cables as of December 2012 within the exclusive economic zone (EEZ; 200 nm) of United States territories.

## 2.2 Depth

The bathymetric depth comes from the GEBCO 30 arc-second grid. Here's there requested attribution:

**GEBCO\_2014 Grid, version 20150318, www.gebco.net**

## 2.3 Renewable Energy

NREL.

## 2.4 Avoidance Zones for Siting New Facilities

“ICPC Recommendation 13 No. 2, which establishes a methodology for determining site-specific proximity limits between submarine cables and offshore wind facilities and a default separation distance in shallower waters of 500 meters on either side of an in-service submarine cable — a separation standard the principles of which also apply to other offshore renewable energy projects.”

“Subsea Cables UK Guideline No. 6 (endorsed by NASCA), which establishes principles for determining safe proximity distances and negotiating proximity agreements between offshore wind farms and submarine cables and reflects extensive experience in the United Kingdom with managing spatial conflicts between offshore wind farms and submarine cables.”

“endorse a default separation distance of 500 meters in water depths of less than 75 meters and the greater of 500 meters or two times the depth of water in greater water depths.”

### 1. Default separation distance by depth:

- $\leq 250 \text{ m}$ : 500 m
- $> 250 \text{ m}$ :  $2 \times \text{depth}$

Pseudocode:

```
# buffer based on depth
cables_buffers = list()
for (x in unique(cable_cells$depth)){
  cables_buffers[str(x)] = cable_cells %>%
    subset(depth == x) %>%
    buffer(x)
}
cable_buf = merge(cables_buffers)

# smooth out jagged edges between cells
cable_buf = simplify(cable_buf)
```

## 2.5 Separation Zones for Routing New Cables

“ICPC Recommendation 2 No. 10: parallel submarine cables maintain a separation distance of the lesser of 3 times depth of water or (where not achievable) 2 times the depth of water following consultation and agreement between affected parties — a separation standard the principles of which also apply to spacing of submarine cables and other marine infrastructure”

At least 2 separation zones based on depth:

### 1. Minimum: 2 times the depth of water

2. Recommended: 3 times depth of water

Psudocode:

```
# convert depth (GEBCO 30 sec resolution) to polygons of cells
depth_cells = as.polygon(depth_raster)

# intersect cables with depth cells
cable_cells = intersect(cables_lines, depth_cells)

# buffer based on depth
cables_buffers = list()
for (x in unique(cable_cells$depth)){

  cables_buffers[str(x)] = cable_cells %>%
    subset(depth == x) %>%
    buffer(x)

}
cable_buf = merge(cables_buffers)

# smooth out jagged edges between cells
cable_buf = simplify(cable_buf)
```

## 2.6 Depth-Varying Cable Buffer

A depth-varying buffer to the offshore cables, 2 \* depth for “minimum” and 3 \* depth for “recommended” separation zones for routing new cables, by first intersecting depth with cables, then iterating over each depth to apply the appropriate buffers before finally dissolving all buffers. In order to apply the buffer, I needed to project from geographic coordinates to a projection that minimizes area distortion, so chose Albers Equal Area and applied the “one-sixth rule” based on the extent of the cable features to minimize distortion.

## 3 Results

### 3.1 Cable Buffer

Generated by:

- create\_cable-buffer.R
- extract\_cable-energy.R

Google Earth files (\*.kml):

- buf\_2xdepth-incr100m.kml
- buf\_3xdepth-incr100m.kml
- lns\_d1x.kml

### 3.2 Overlap of Cable Buffer with Renewable Energy

Extract average and area of overlap between zones and renewable energy potential areas, possibly at various depth bins.

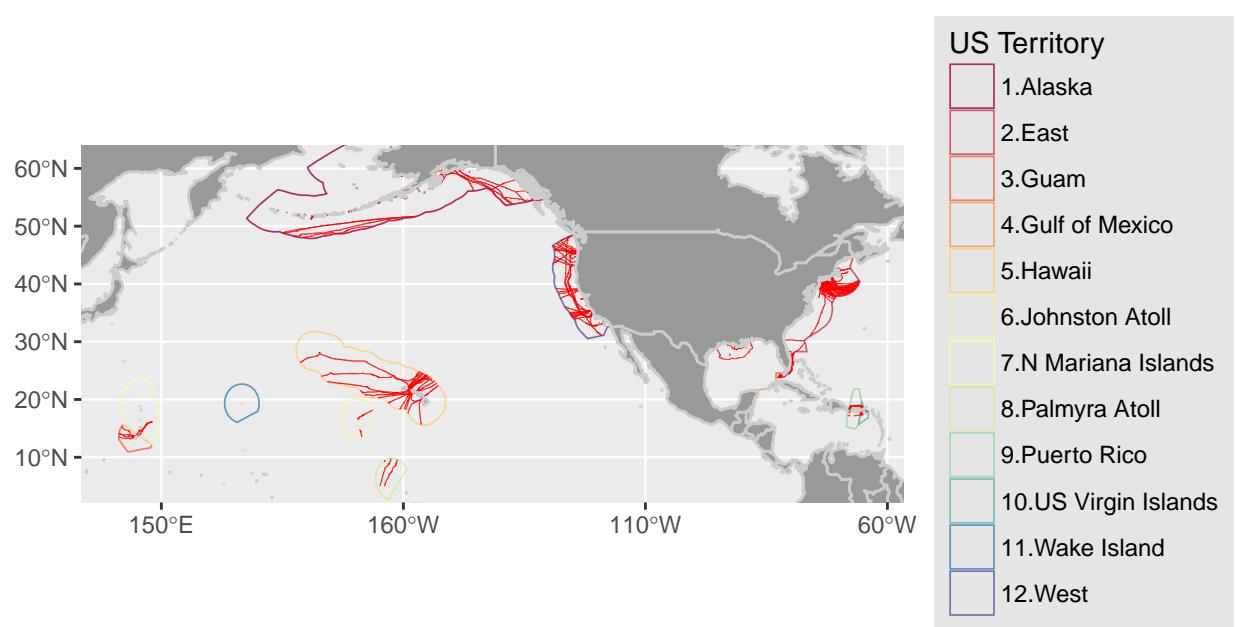


Figure 2: Map of submarine cable buffers within the exclusive economic zone (EEZ; 200 nm) of United States territories. In order to see the area covered by the buffers, please visit the Detailed Maps section.

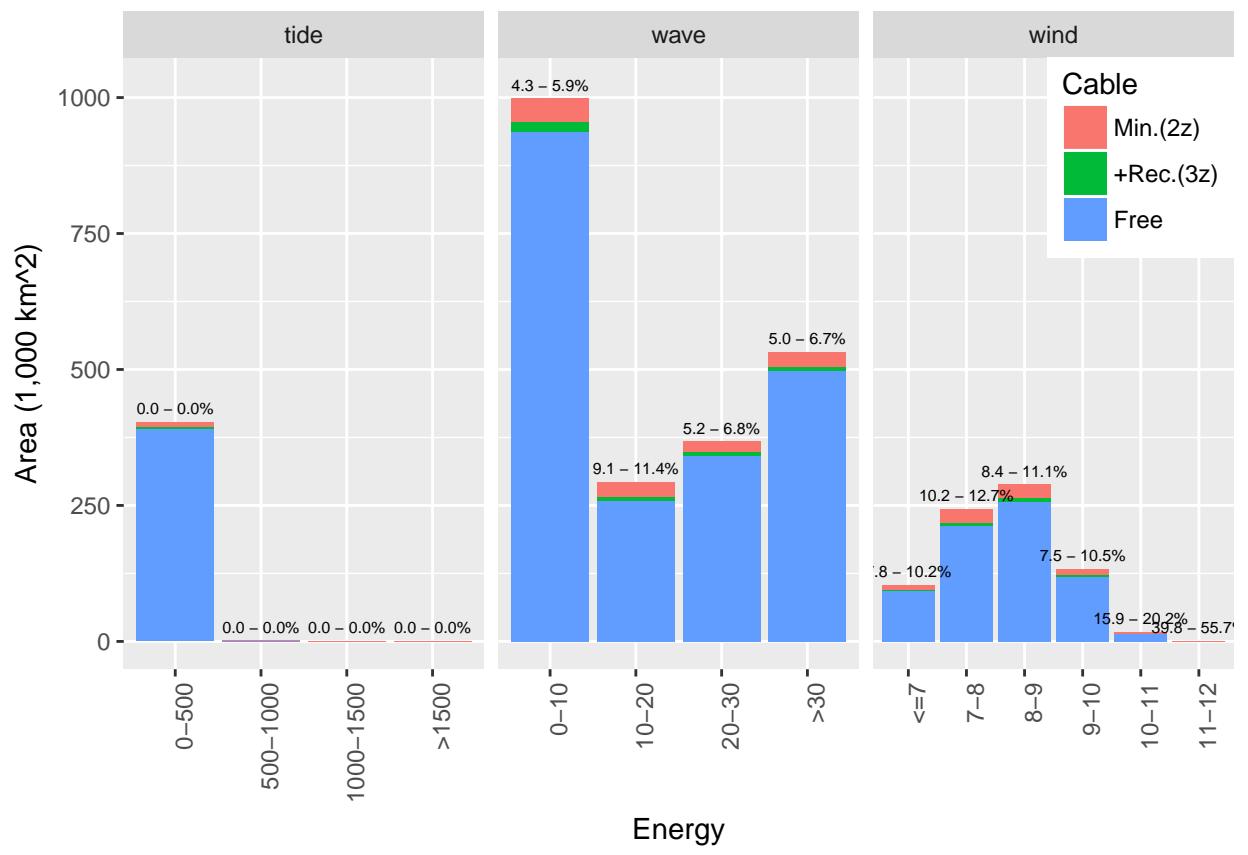


Figure 3: Energy by area and power class per US territory with cable overlay (minimum - recommended %).

Table 2: Area overlap with cables by form of energy broken into size classes across all territories.

| Energy             |           | Area (km2) | Min. Cable (2z) |       | Rec. Cable (3z) |       |
|--------------------|-----------|------------|-----------------|-------|-----------------|-------|
| Form               | Amount    |            | Area (km2)      | (%)   | Area (km2)      | (%)   |
| 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%  |

### 3.2.1 Wind

units: wind speed (m/s) at 90m hub height

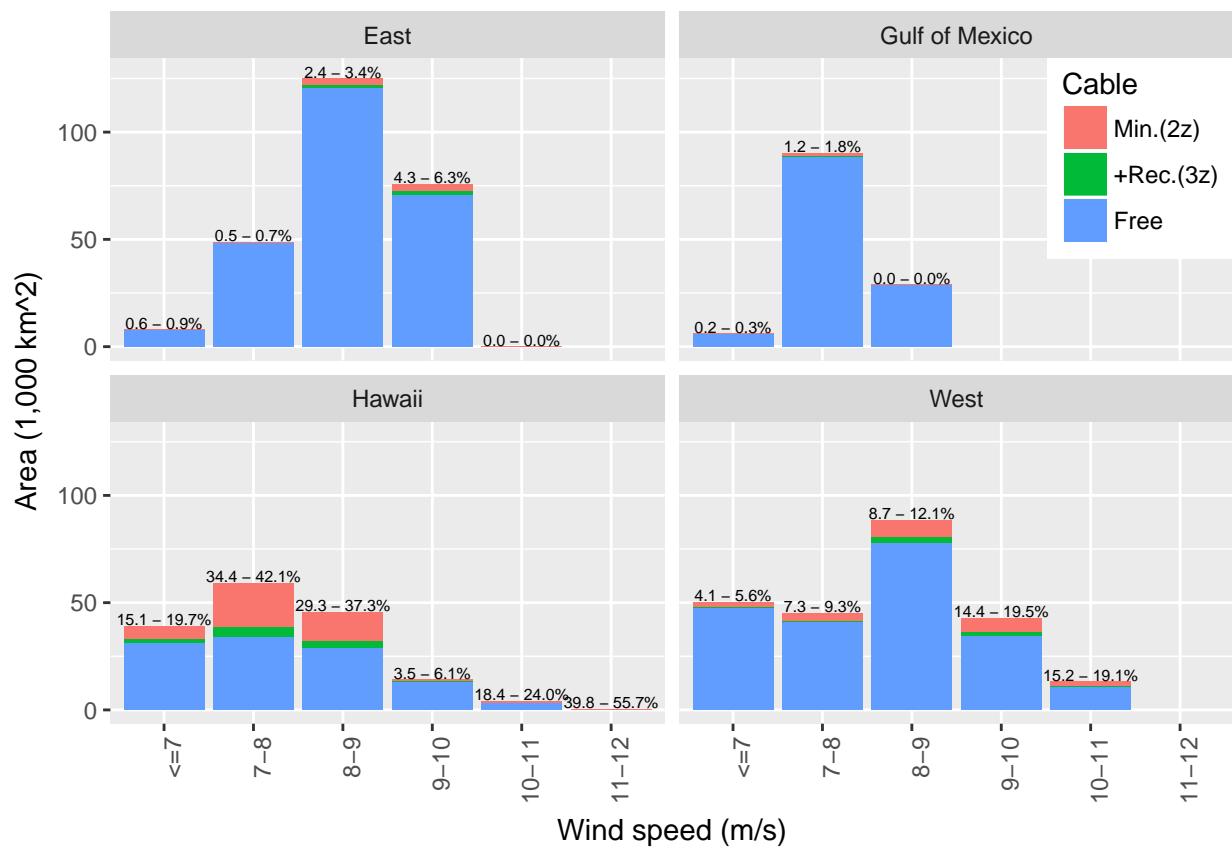


Figure 4: Wind speed (m/s) and area per US territory with cable overlay (minimum - recommended %).

Table 3: Area overlap with cables for wind speed (m/s) at 90m hub height by territory.

| Territory      | Wind Speed (m/s) | Area (km2) | Min. Cable (2z) |       | Rec. Cable (3z) |       |
|----------------|------------------|------------|-----------------|-------|-----------------|-------|
|                |                  |            | Area (km2)      | (%)   | Area (km2)      | (%)   |
| 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%  |
|                | 11-12            | 1          | 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%  |
|                | 9-10             | 14,099     | 488             | 3.5%  | 866             | 6.1%  |
| 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% |

### 3.2.2 Wave

units: wave energy flux (kW/m)

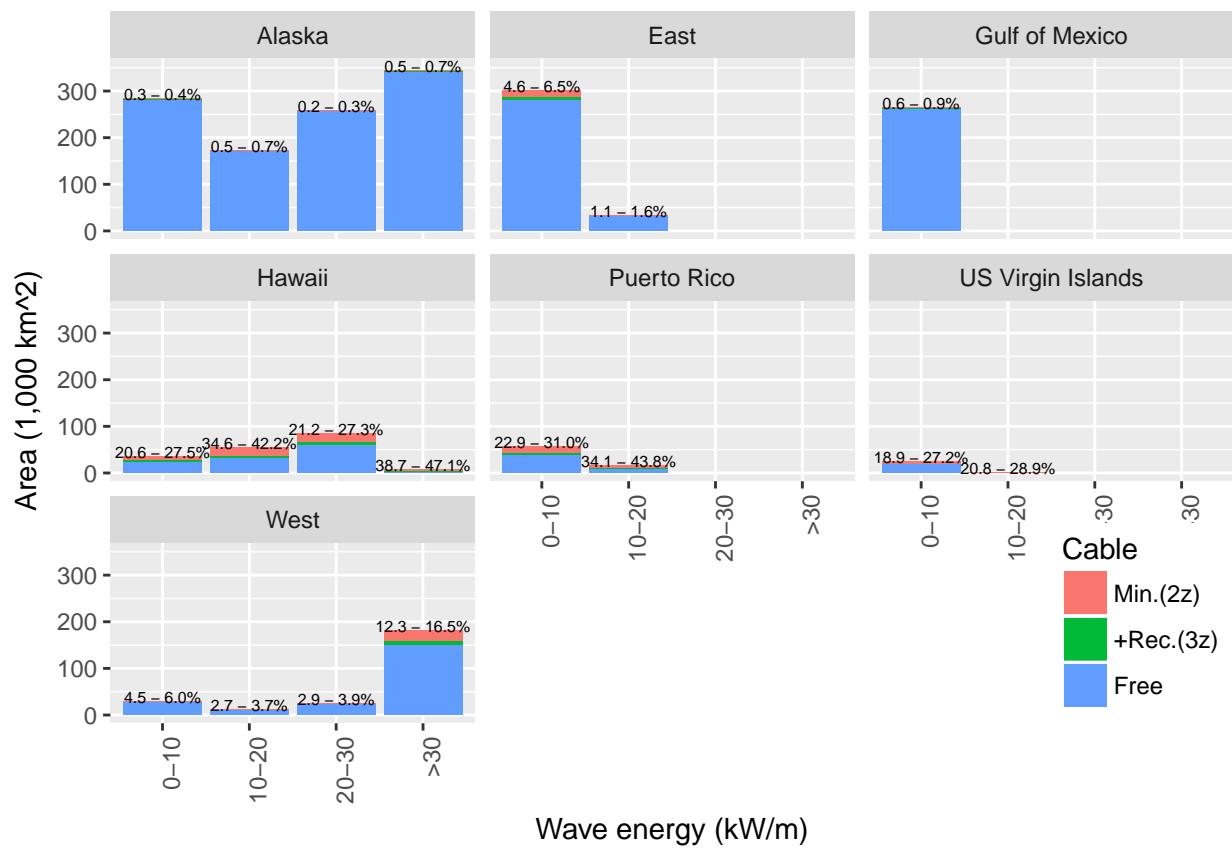


Figure 5: Wave energy (kW/m) and area per US territory with cable overlay (minimum - recommended %).

Table 4: Area overlap with cables for wave energy (kW/m) by territory.

| Territory         | Wave Energy (kW/m) | Area (km2) | Min. Cable (2z) |       | Rec. Cable (3z) |       |
|-------------------|--------------------|------------|-----------------|-------|-----------------|-------|
|                   |                    |            | Area (km2)      | (%)   | Area (km2)      | (%)   |
| 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% |

### 3.2.3 Tidal

units: mean power (W/m<sup>2</sup>)

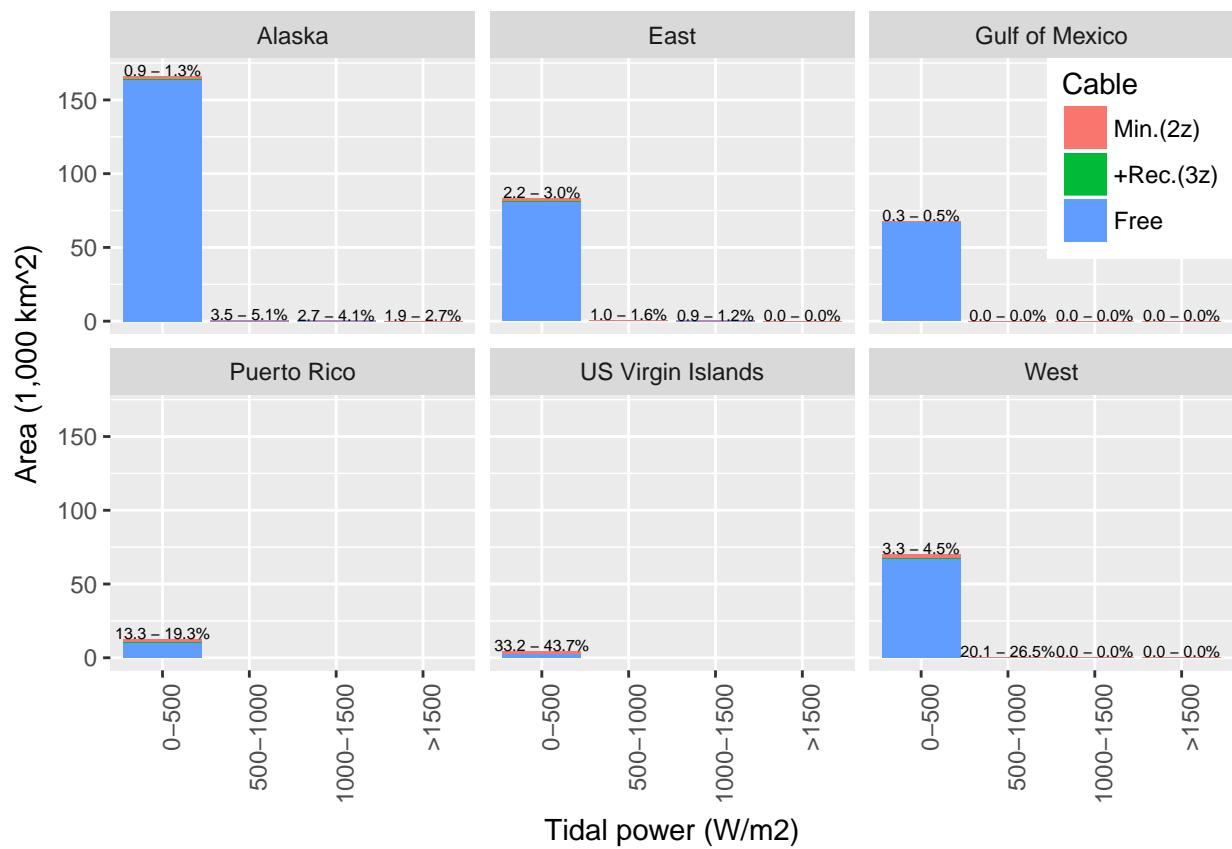


Figure 6: Tidal power (W/m<sup>2</sup>) and area per US territory with cable overlay (minimum - recommended %).

Table 5: Area overlap with cables for tidal power (W/m<sup>2</sup>) by territory.

| Territory         | Tidal power (W/m <sup>2</sup> ) | Area (km <sup>2</sup> ) | Min. Cable (2z)         |       | Rec. Cable (3z)         |       |
|-------------------|---------------------------------|-------------------------|-------------------------|-------|-------------------------|-------|
|                   |                                 |                         | Area (km <sup>2</sup> ) | (%)   | Area (km <sup>2</sup> ) | (%)   |
| 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%  |

### 3.3 Detailed Maps by US Territory of Cable Buffer and Renewable Energy

#### 3.3.1 Alaska

See Figure 7.

##### 3.3.1.1 Tidal

See Figure 8.

##### 3.3.1.2 Wave

See Figure 9.

#### 3.3.2 East

See Figure 10.

##### 3.3.2.1 Tidal

See Figure 11.

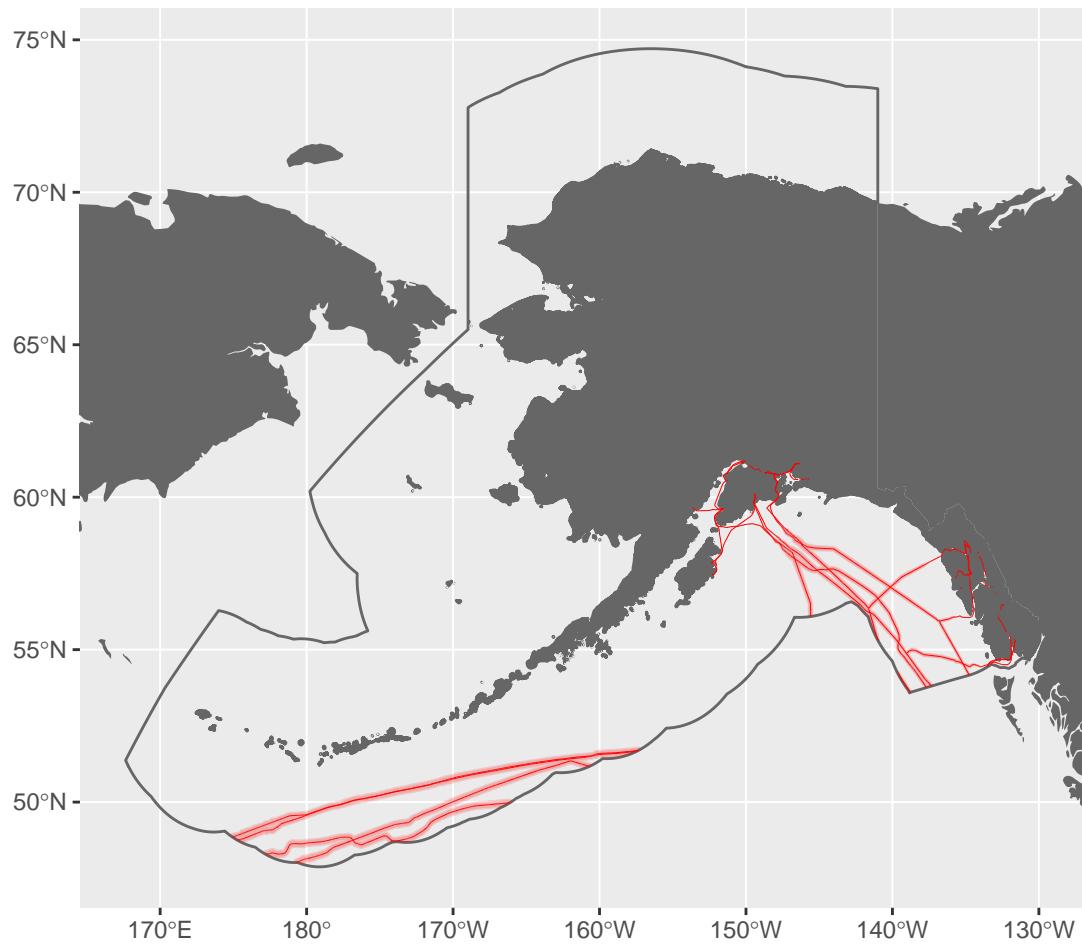


Figure 7: Cable buffers for Alaska.

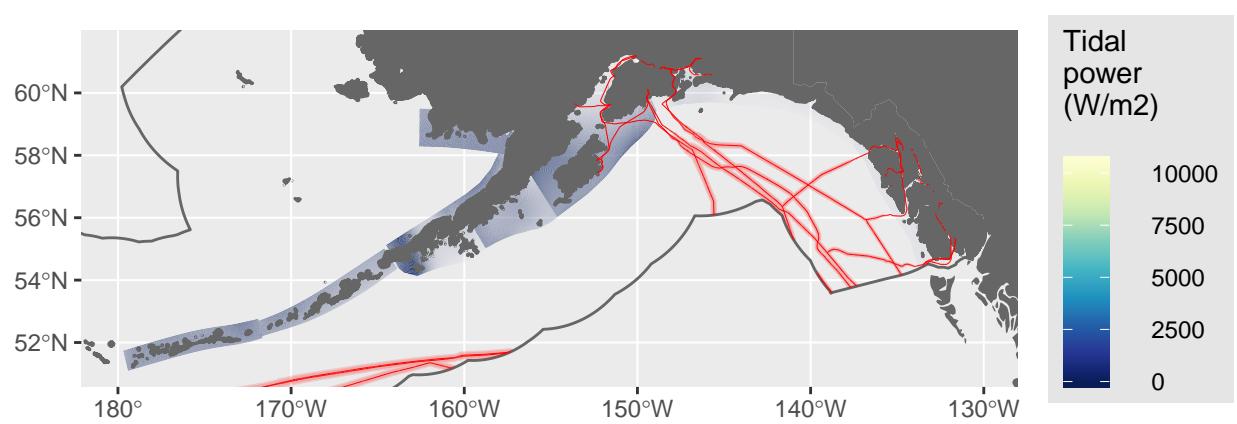


Figure 8: Tidal energy for Alaska.

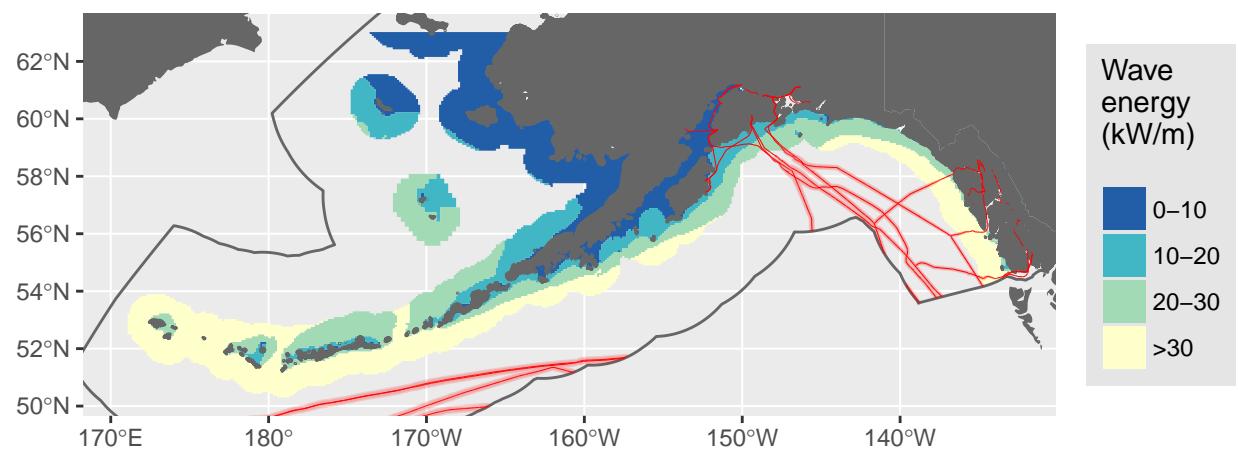


Figure 9: Wave energy for Alaska.

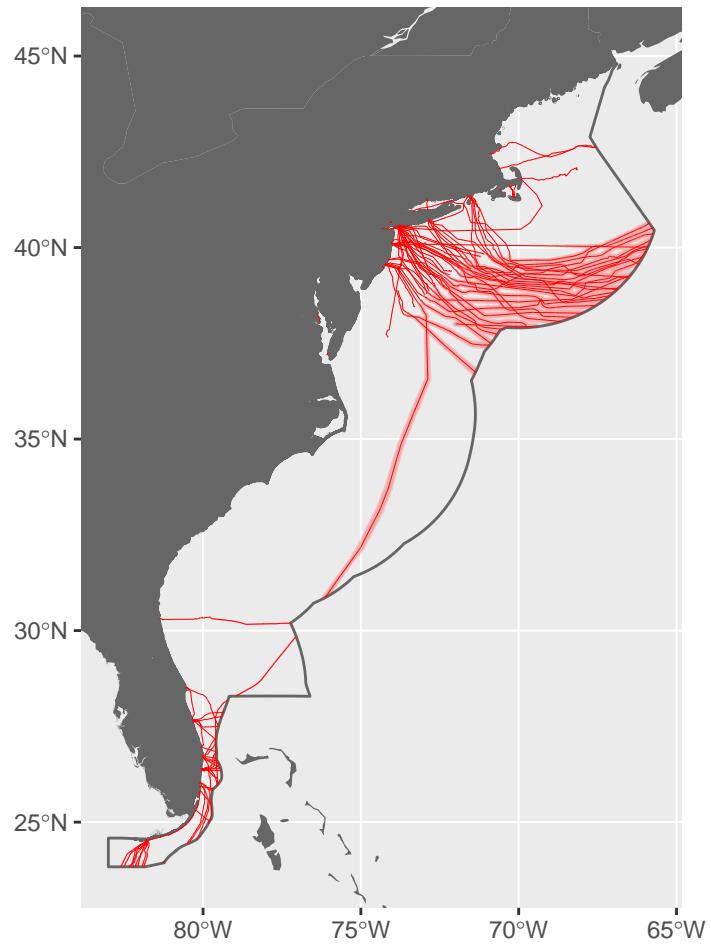


Figure 10: Cable buffers for East.

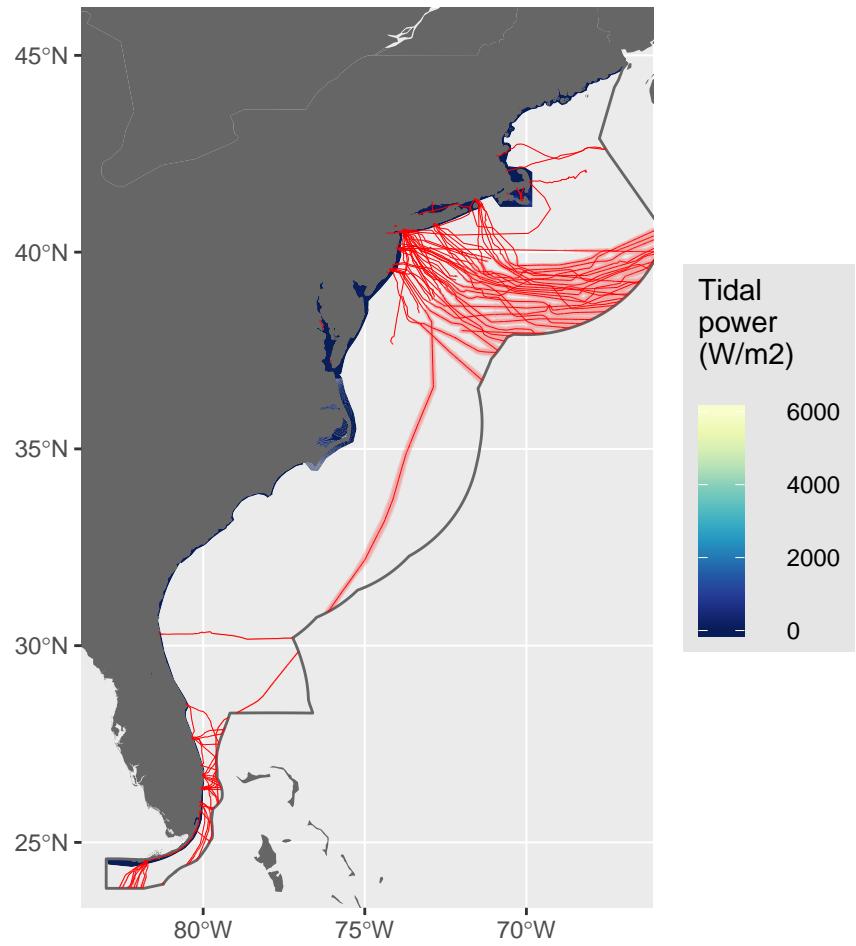


Figure 11: Tidal energy for East.

### **3.3.2.2 Wave**

See Figure 12.

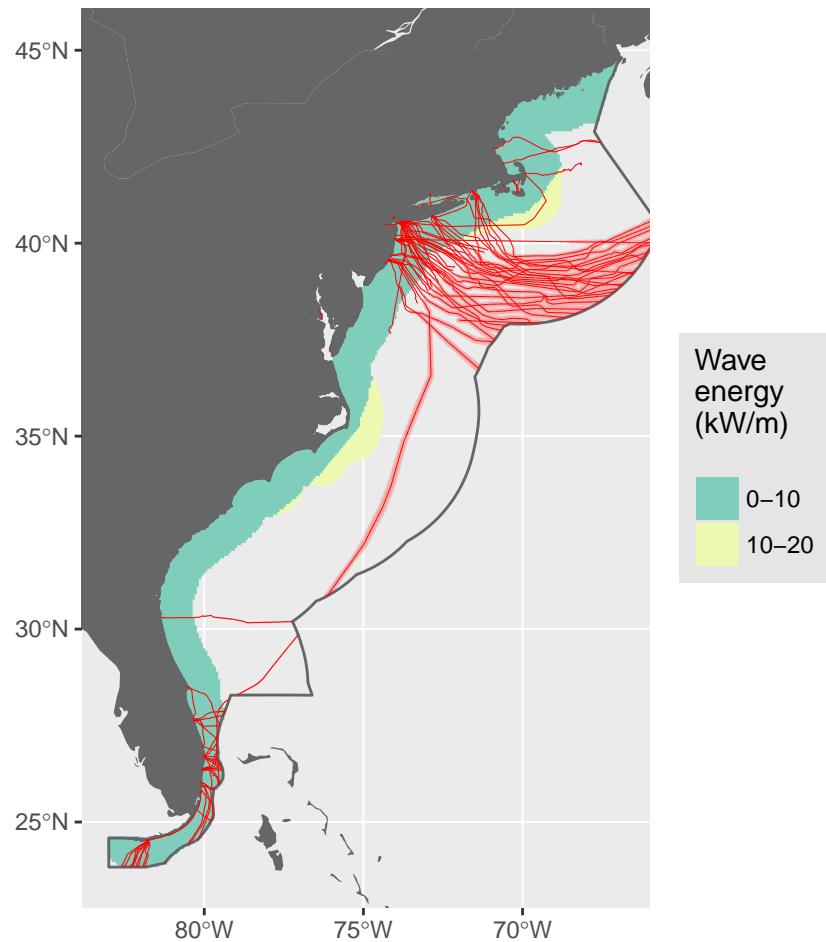


Figure 12: Wave energy for East.

### **3.3.2.3 Wind**

See Figure 13.

### **3.3.3 Guam**

See Figure 14.

### **3.3.4 Gulf of Mexico**

See Figure 15.

#### **3.3.4.1 Tidal**

See Figure 16.

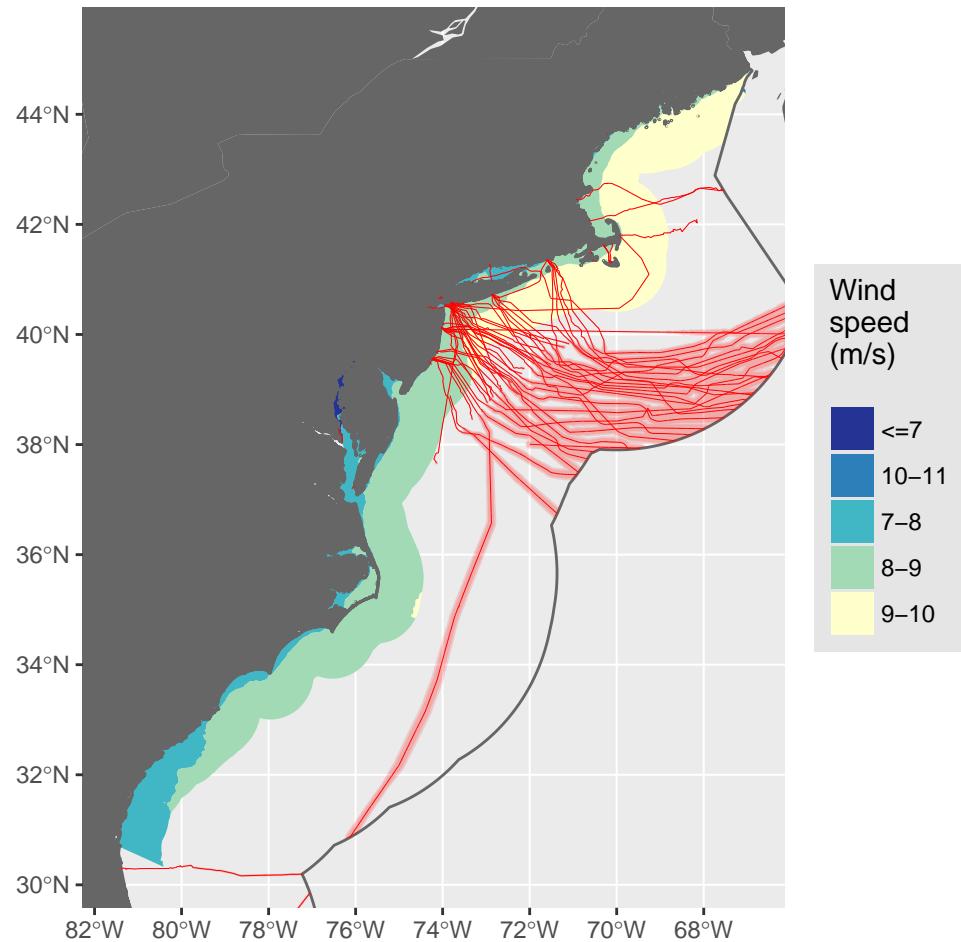


Figure 13: Wind energy for East.

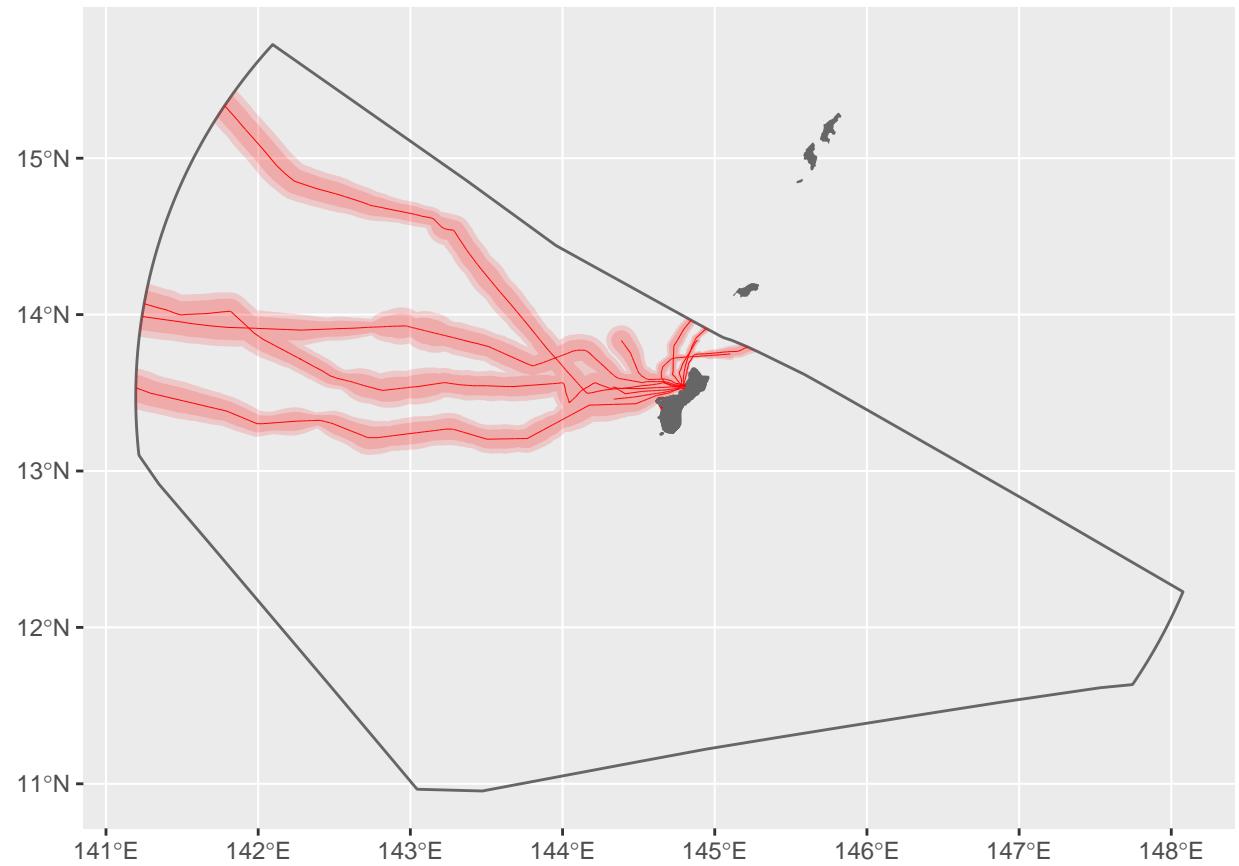


Figure 14: Cable buffers for Guam.

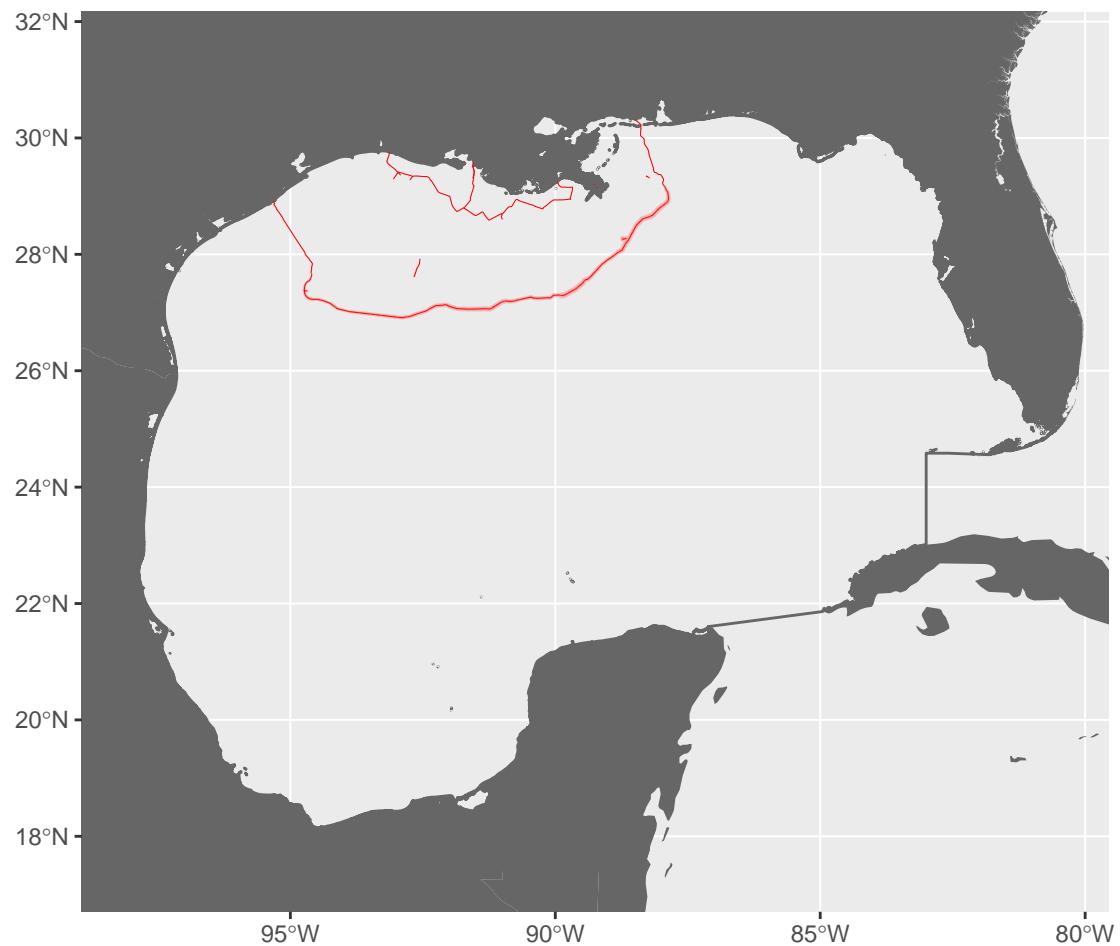


Figure 15: Cable buffers for Gulf of Mexico.

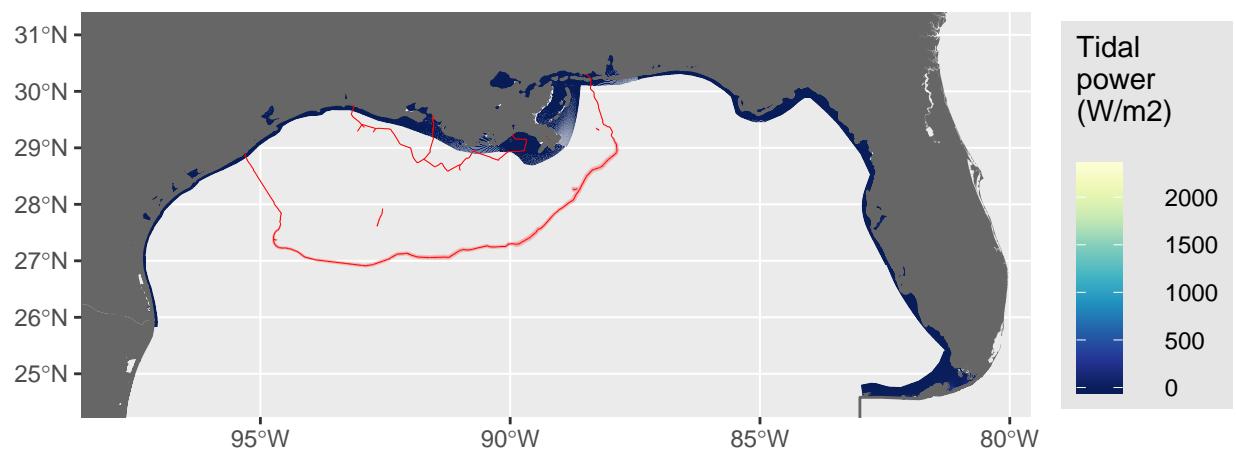


Figure 16: Tidal energy for Gulf of Mexico.

### **3.3.4.2 Wave**

See Figure 17.

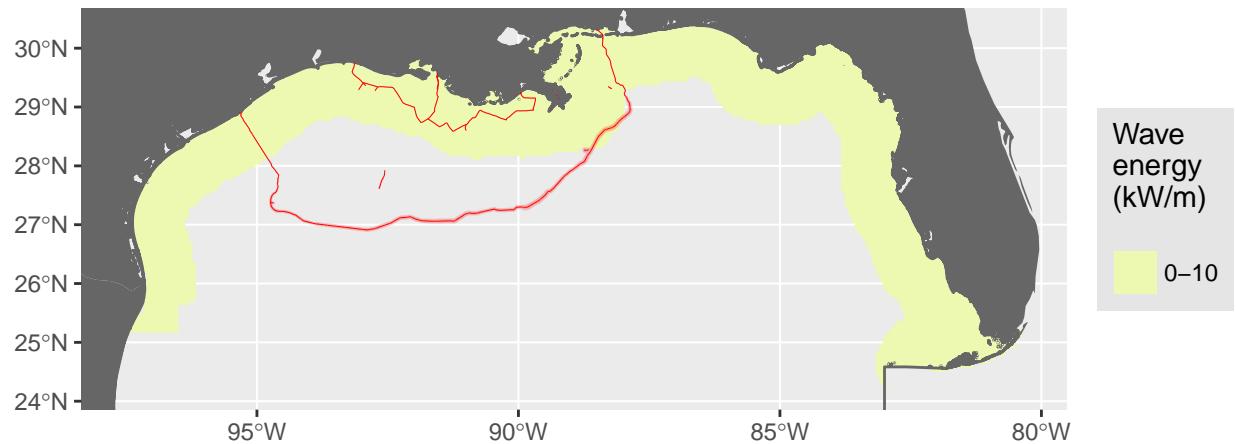


Figure 17: Wave energy for Gulf of Mexico.

### **3.3.4.3 Wind**

See Figure 18.

## **3.3.5 Hawaii**

See Figure 19.

### **3.3.5.1 Wave**

See Figure 20.

### **3.3.5.2 Wind**

See Figure 21.

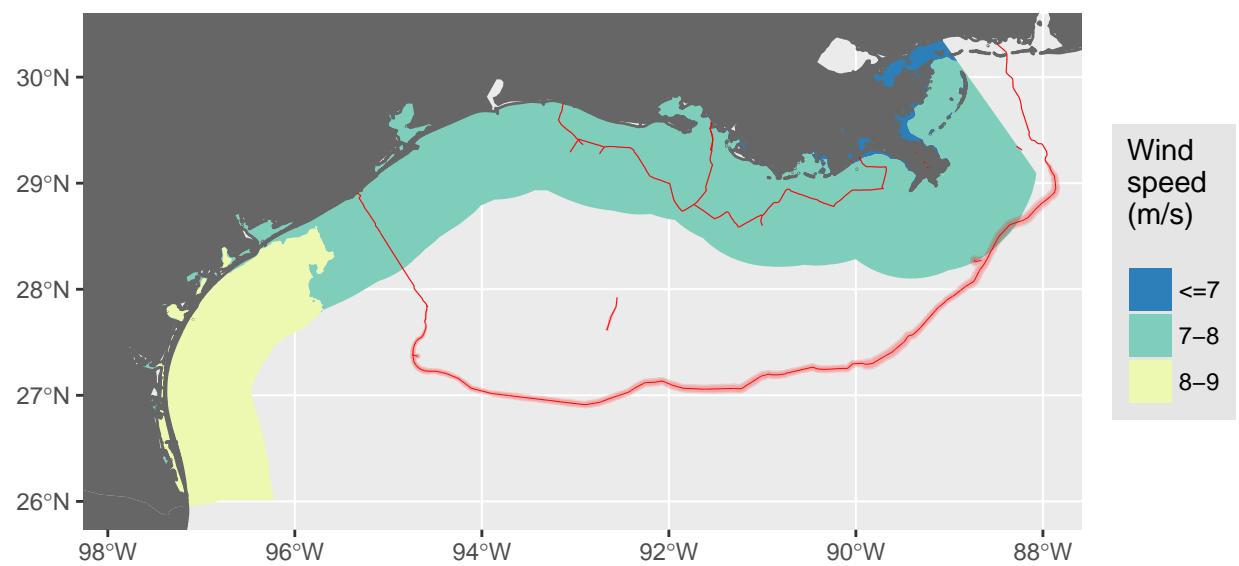


Figure 18: Wind energy for Gulf of Mexico.

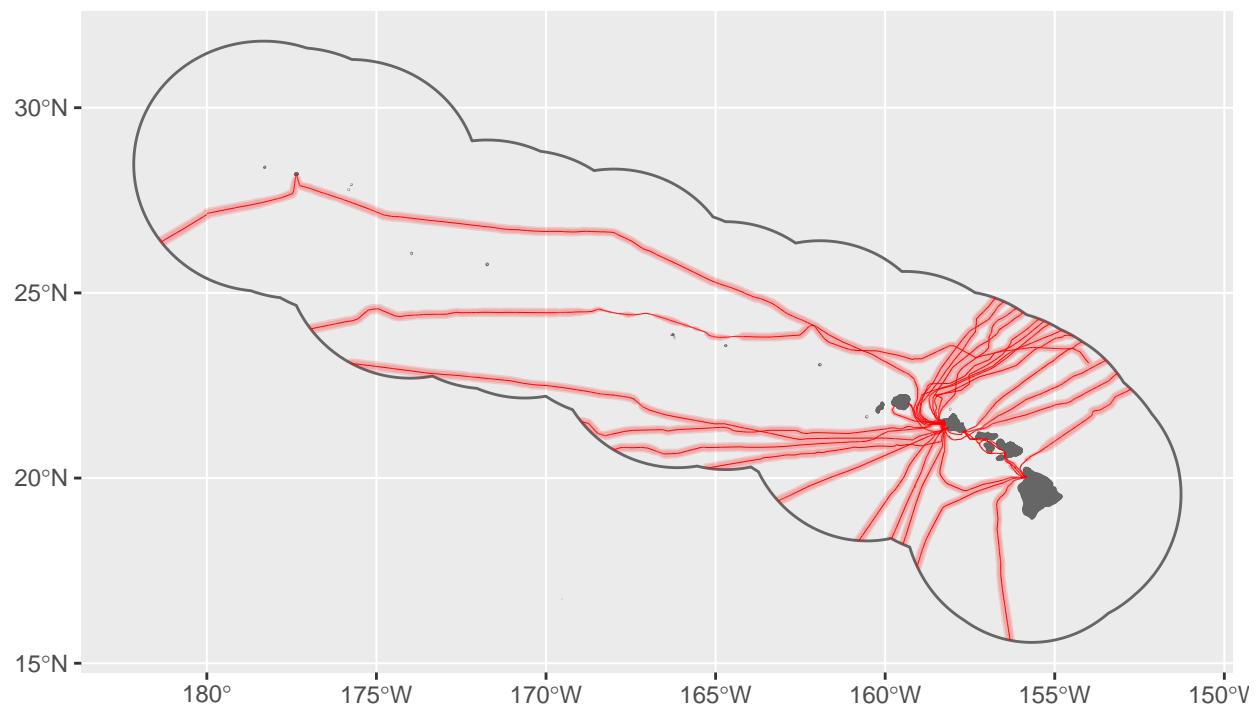


Figure 19: Cable buffers for Hawaii.

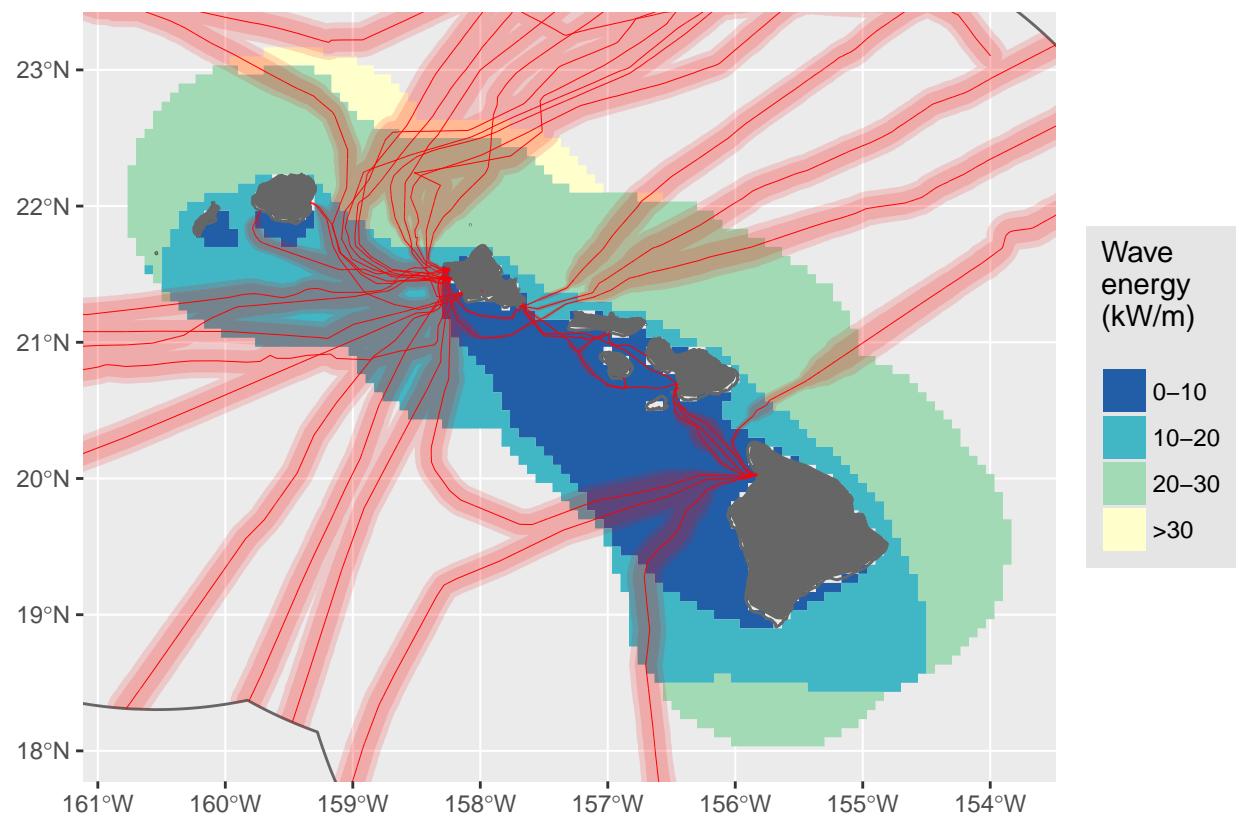


Figure 20: Wave energy for Hawaii.

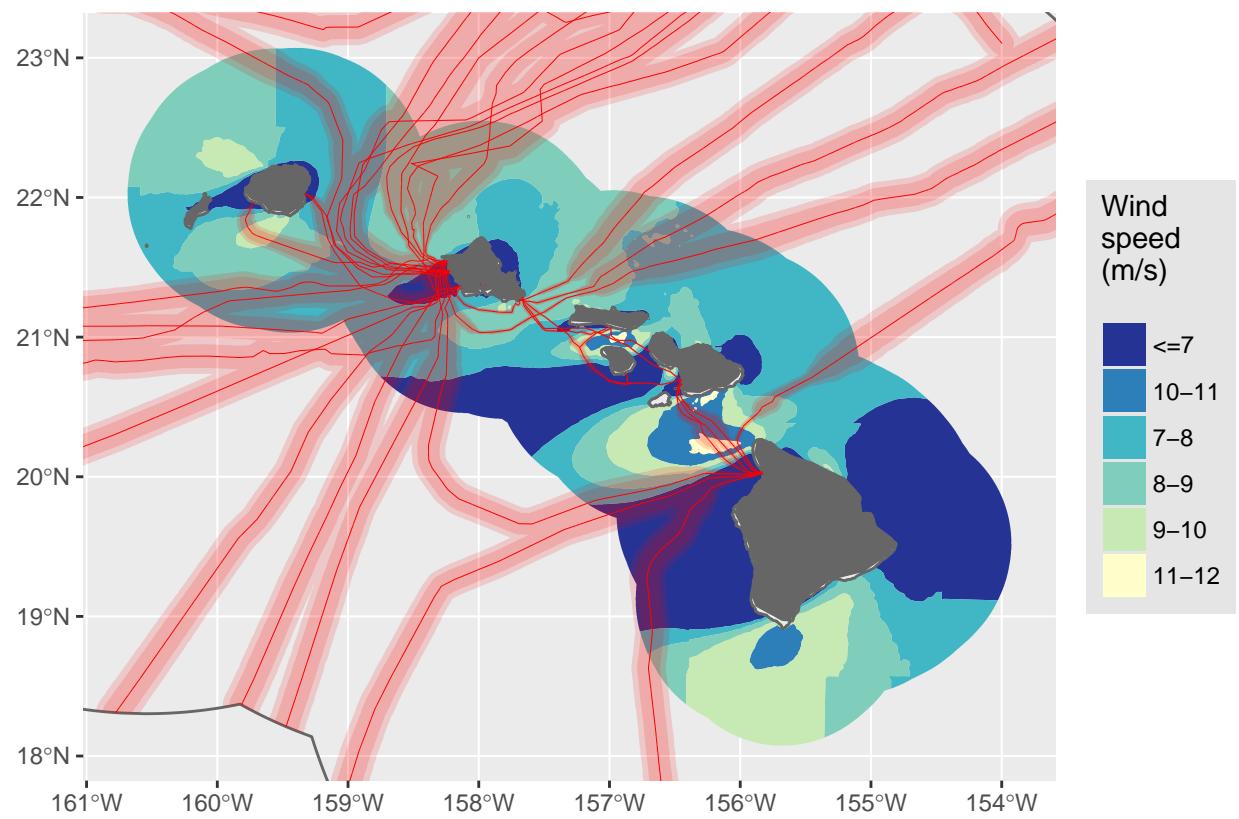


Figure 21: Wind energy for Hawaii.

### **3.3.6 Johnston Atoll**

See Figure 22.

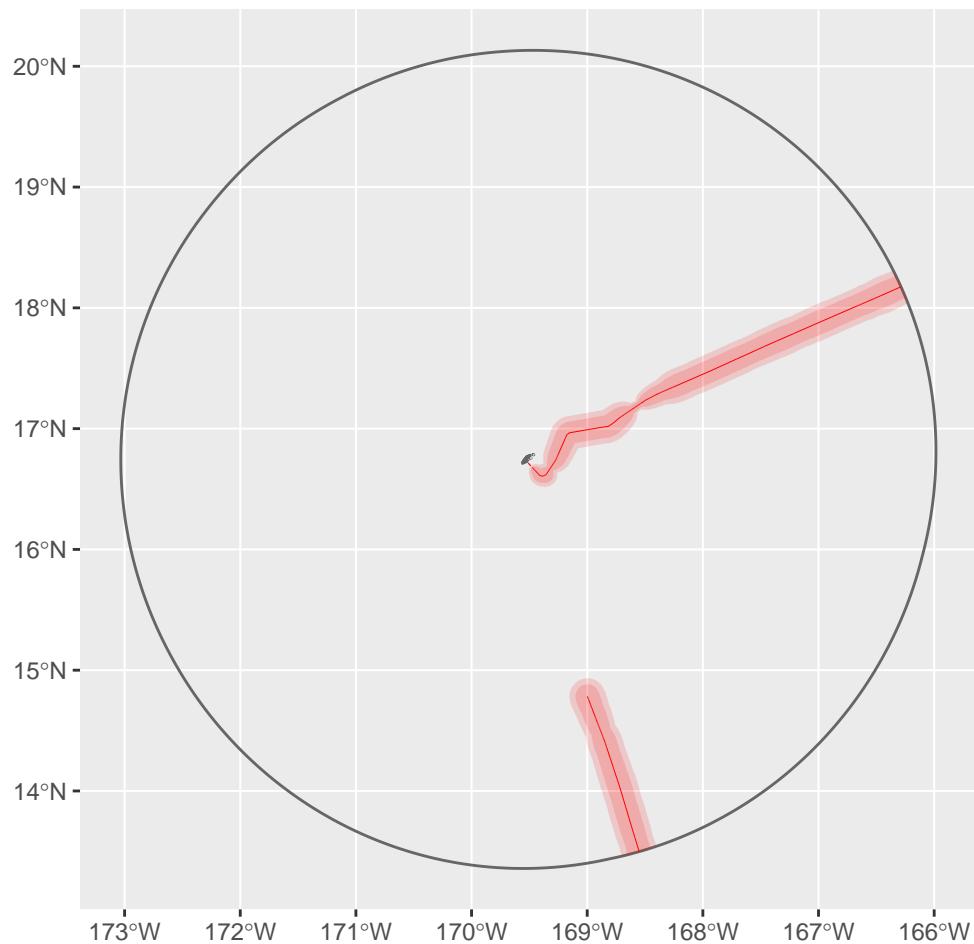


Figure 22: Cable buffers for Johnston Atoll.

### **3.3.7 N Mariana Islands**

See Figure 23.

### **3.3.8 Palmyra Atoll**

See Figure 24.

### **3.3.9 Puerto Rico**

See Figure 25.

#### **3.3.9.1 Tidal**

See Figure 26.

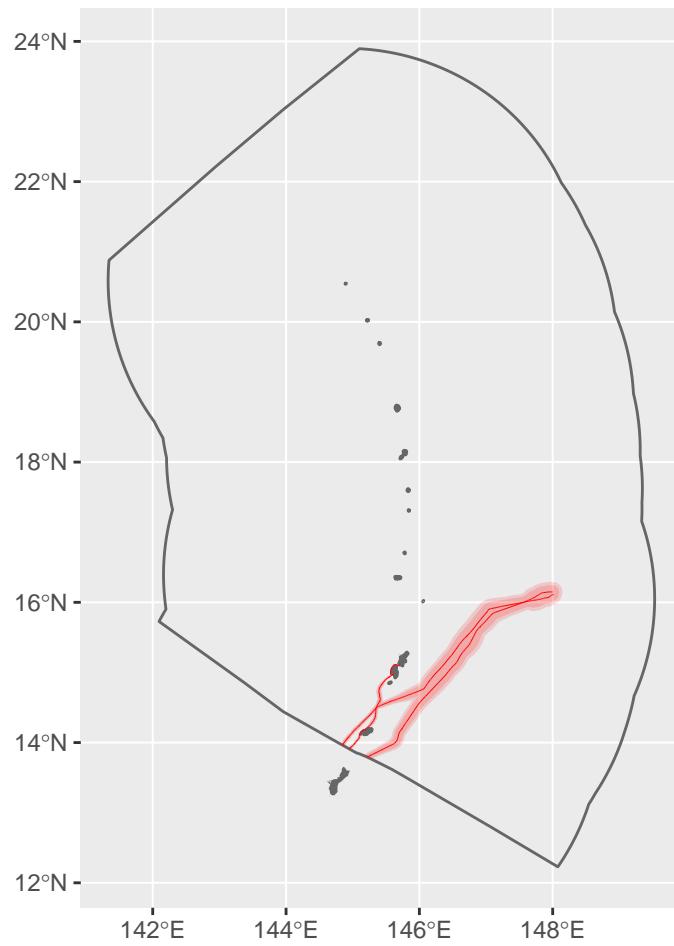


Figure 23: Cable buffers for N Mariana Islands.

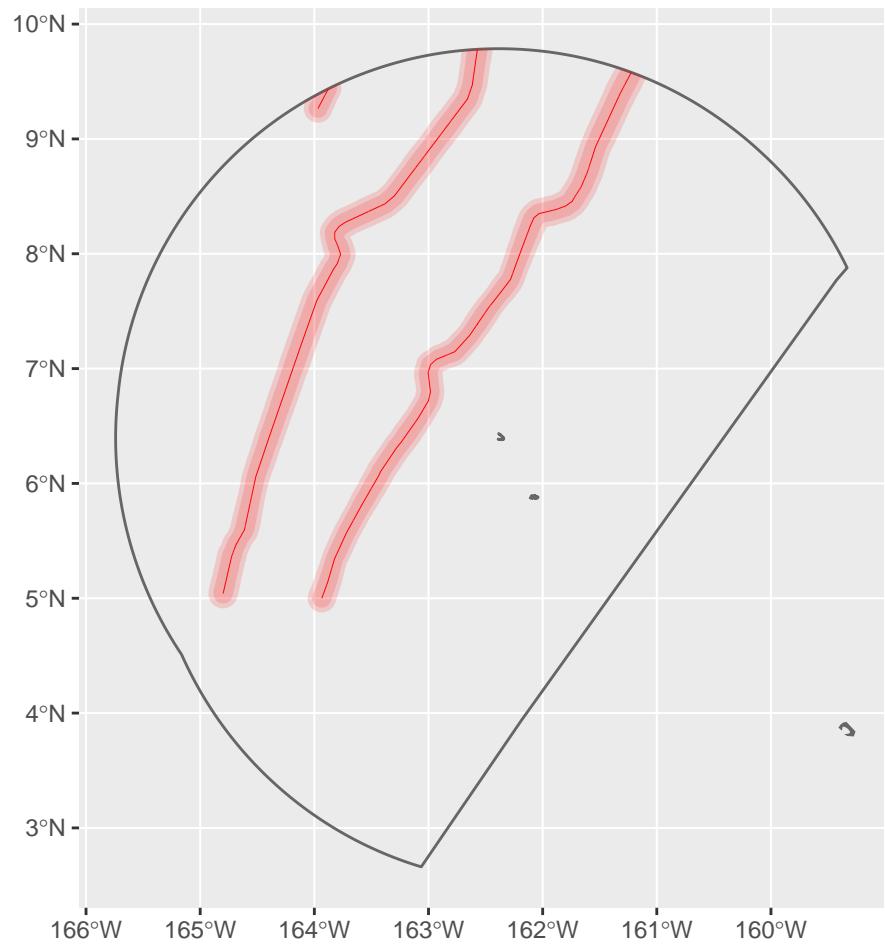


Figure 24: Cable buffers for Palmyra Atoll.

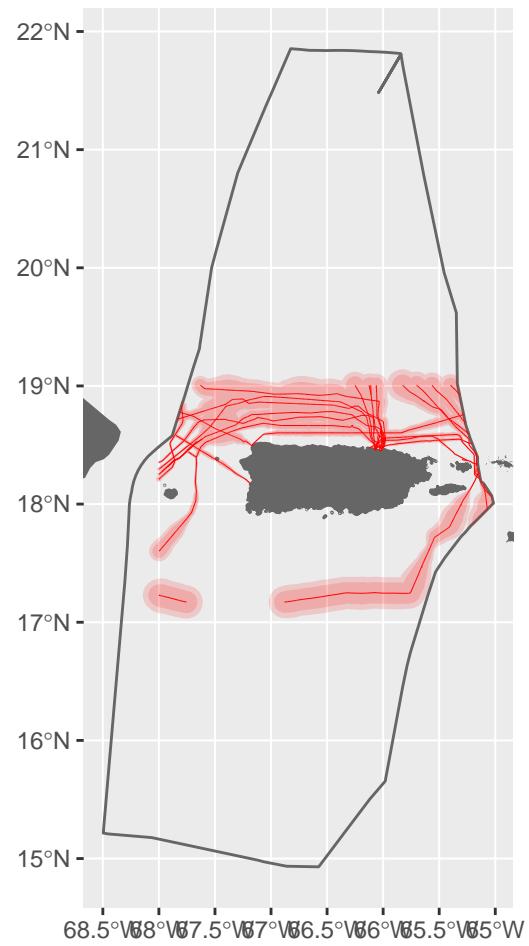


Figure 25: Cable buffers for Puerto Rico.

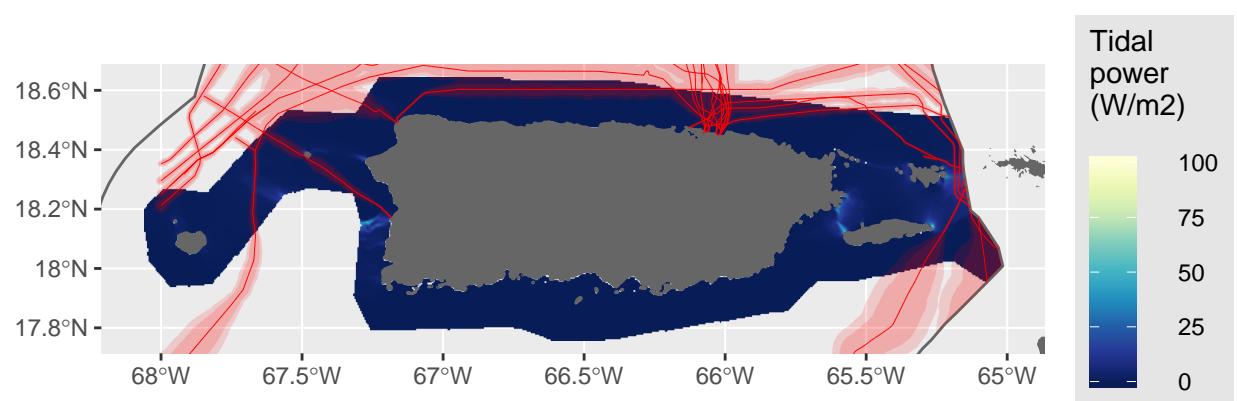


Figure 26: Tidal energy for Puerto Rico.

### **3.3.9.2 Wave**

See Figure 27.

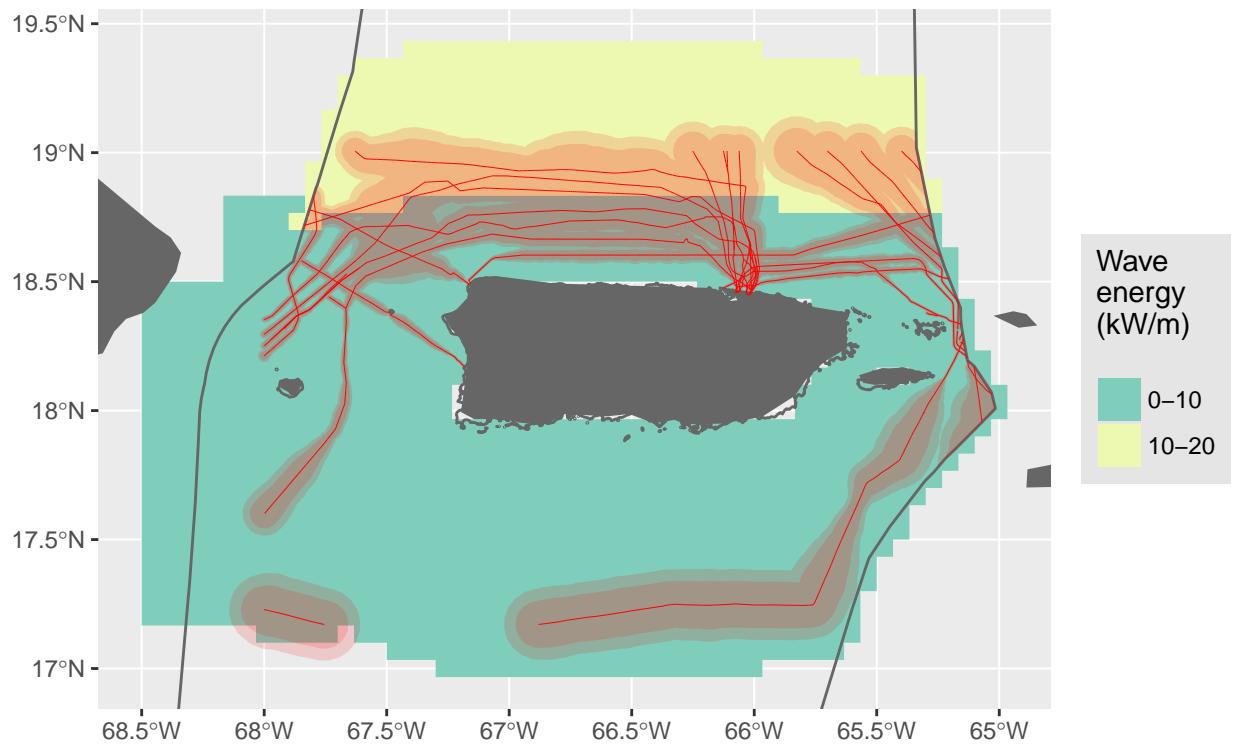


Figure 27: Wave energy for Puerto Rico.

## **3.3.10 US Virgin Islands**

See Figure 28.

### **3.3.10.1 Tidal**

See Figure 29.

### **3.3.10.2 Wave**

See Figure 30.

## **3.3.11 Wake Island**

See Figure 31.

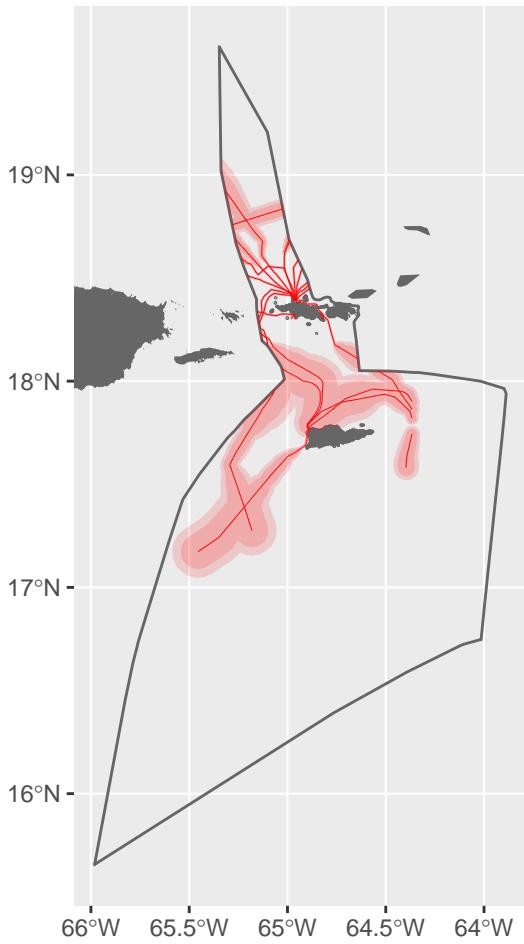


Figure 28: Cable buffers for US Virgin Islands.

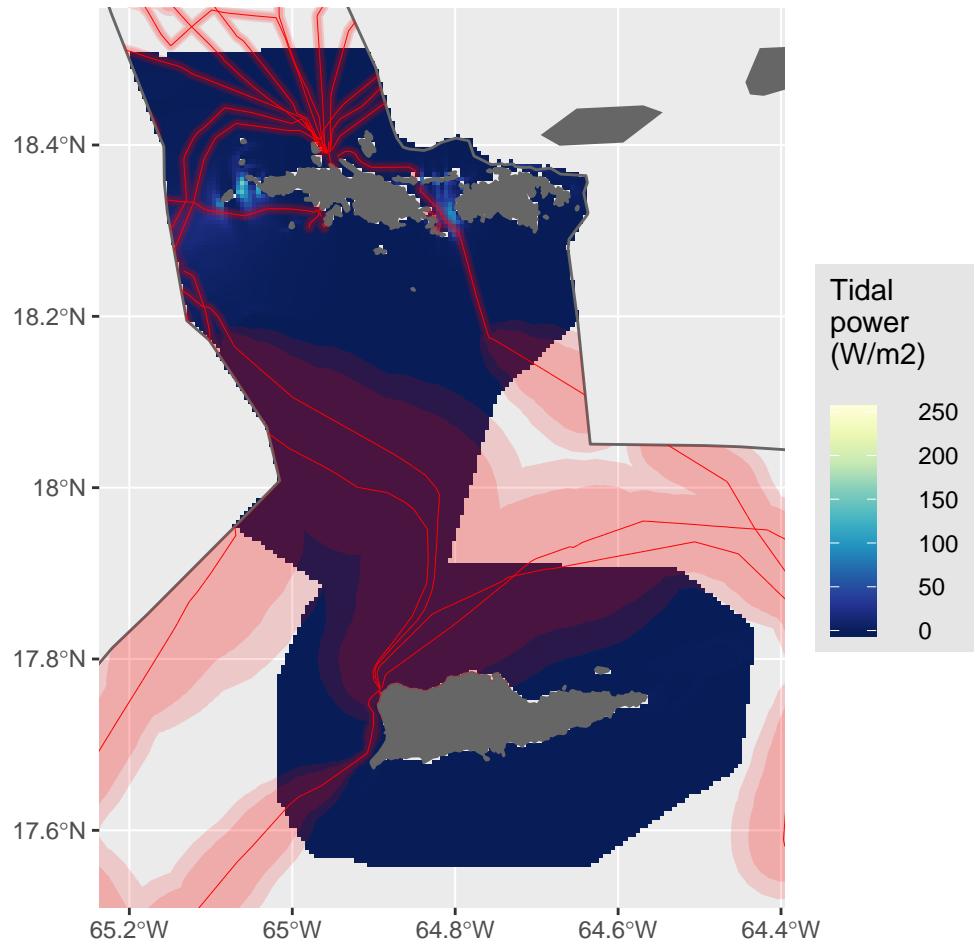


Figure 29: Tidal energy for US Virgin Islands.

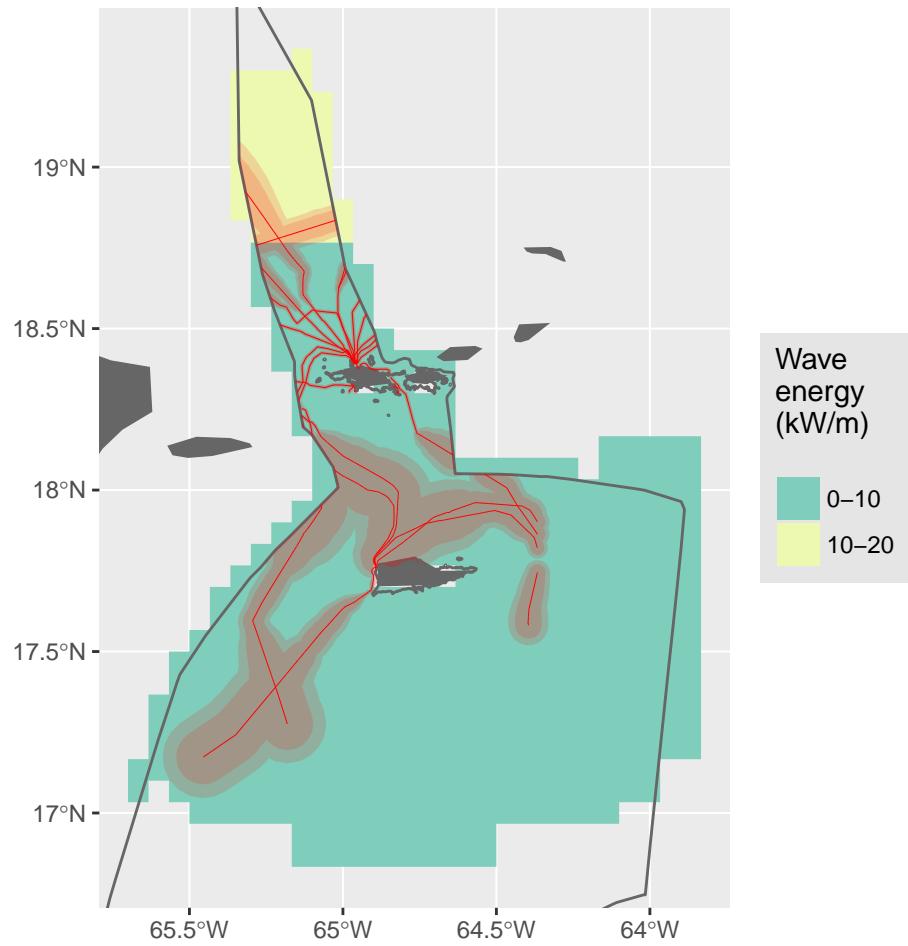


Figure 30: Wave energy for US Virgin Islands.

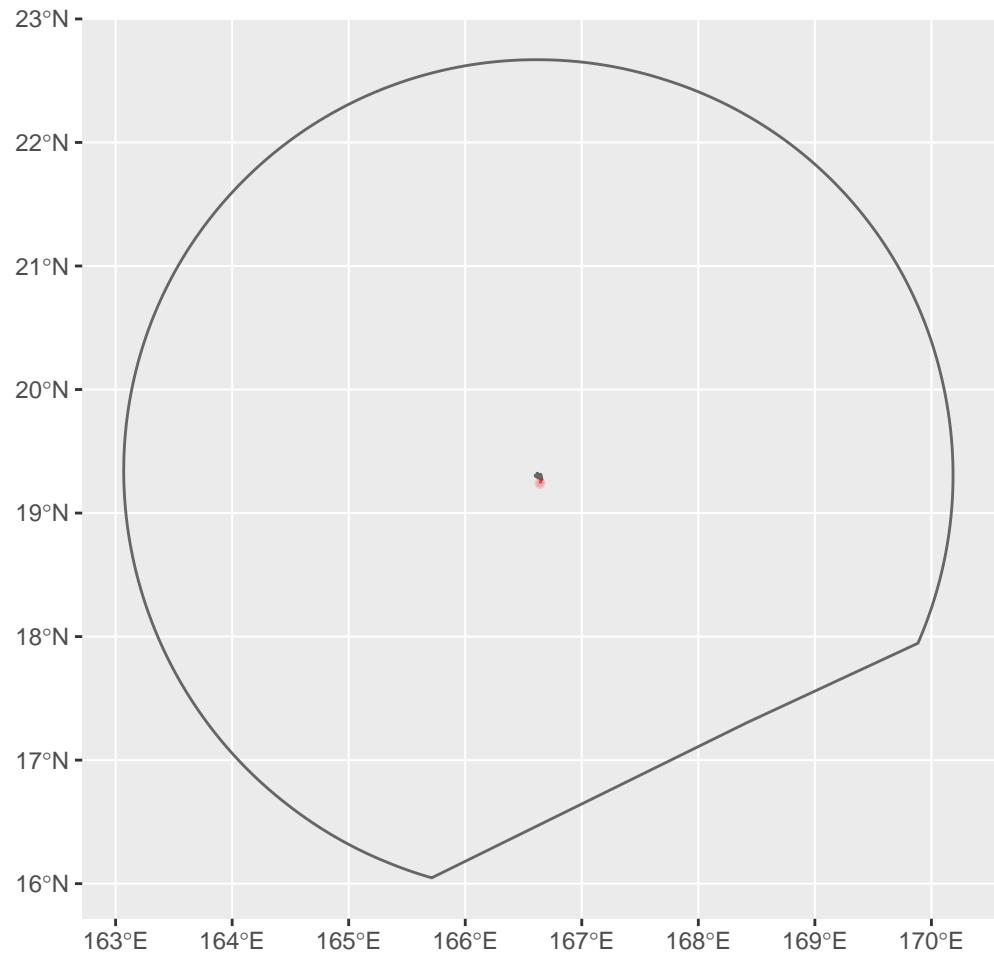


Figure 31: Cable buffers for Wake Island.

### **3.3.12 West**

See Figure 32.

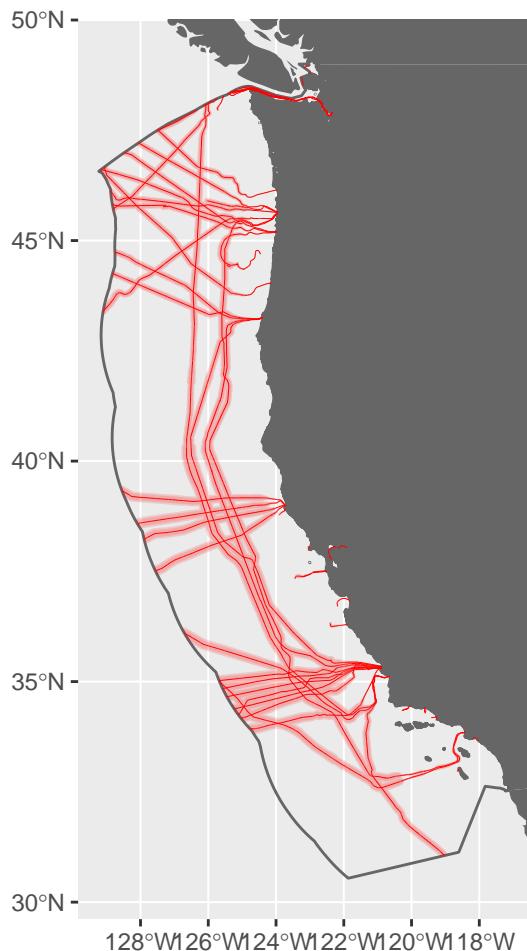


Figure 32: Cable buffers for West.

#### **3.3.12.1 Tidal**

See Figure 33.

#### **3.3.12.2 Wave**

See Figure 34.

#### **3.3.12.3 Wind**

See Figure 35.

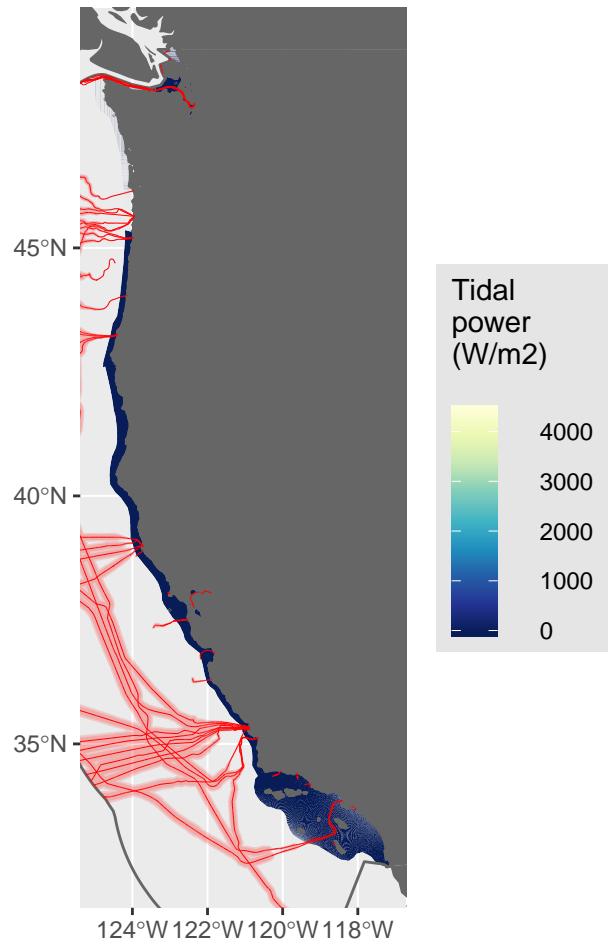


Figure 33: Tidal energy for West.

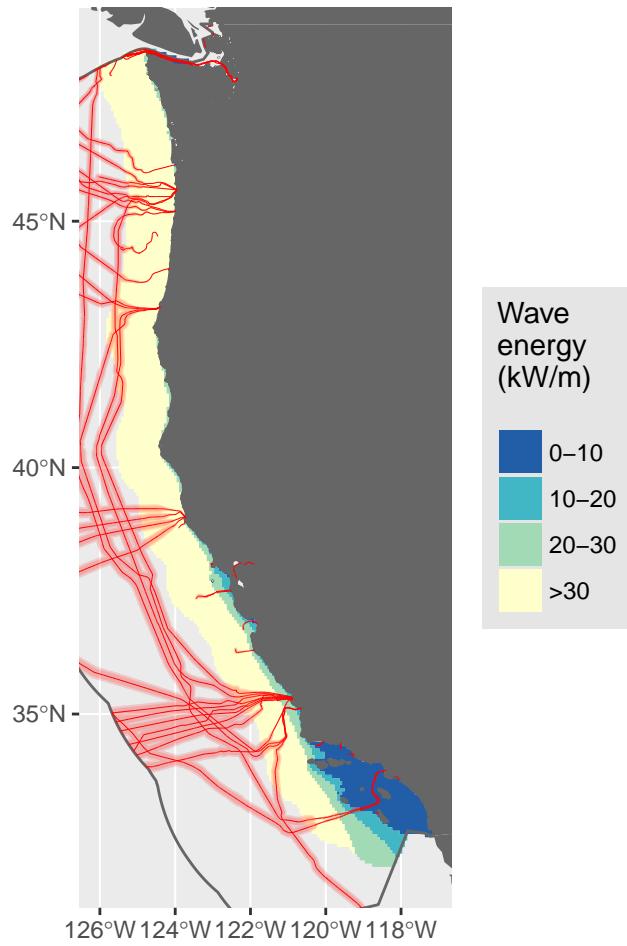


Figure 34: Wave energy for West.

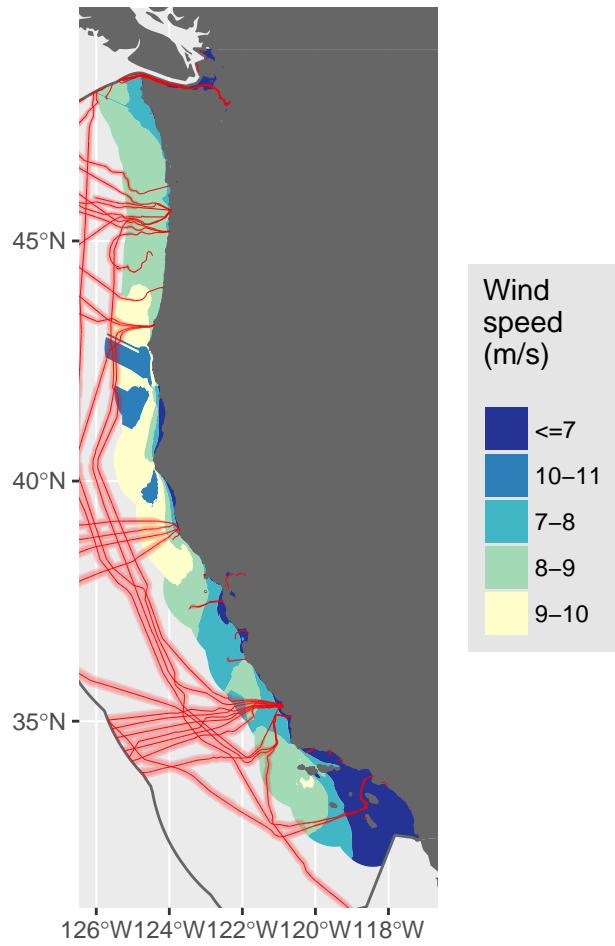


Figure 35: Wind energy for West.

## 4 Conclusions

### 4.1 Next Steps

- stacked histogram by cbl2/(cbl3-cbl2)/other; hist(wind\$Speed\_90)
- simplify as native geojson

Musial et al (2016):

- wind speed (m/s) – Table A-3 (p. 48): <7, 7-8, 8-9, 9-10, 10-11, total
- depth classes (m) – Table B-1 (p. 49): <30, 30-60, 60-700, 700-1000, >1000, total
- distance to shore (nm) – Table B-2 (p. 50): <3, 3-12, 12-50, 50-200, total
- by states

### 4.2 Communication with Stakeholders

Products will be online and readily digestable by stakeholders.

## References

- Amante, C., Kilcher, L., Roberts, B., & Draxl, C. (2016). *Offshore Cable Analysis: Pilot Study*.
- Communications Security, Reliability and Interoperability Council IV. (2014). *Protection of Submarine Cables Through Spatial Separation*.
- Communications Security, Reliability and Interoperability Council IV. (2016). *Clustering of Cables and Cable Landings*.