Appendix B: Spatial Analysis


Photo Credit: Principle Power

Region of Interest (ROI)

The CalWind Region of Interest (ROI) is focused on San Luis Obispo, Santa Barbara, and Ventura Counties. If you were to extend county boundaries out to sea, the offshore environment studied as part of the spatial analysis includes areas that are north and south of county lines.

We limited our offshore ROI to the extent of available NREL wind data (see Figure 2). Next, we converted our offshore ROI to a 10km x 10km cell fishnet for our multi-criteria decision analysis (MCDA) (ROI Fishnet, below). We then erased our exclusion area (represented by the cross-hatched area) to arrive at a final offshore ROI. The exclusion area was created by combining all 10km x 10km cells that intersected the channel shipping lanes or national marine sanctuaries (obtained from marinecadastre.gov). All remaining cells in the ROI Fishnet polygon were considered developable cells for the MCDA and Marxan analyses. We then calculated individual cell values for each variable considered in those analyses, reclassified them into quantiles, and assigned them a score of 1-5. These reclassified scores were then used for the weighted sum of the MCDA and the weighted cost file for Marxan.

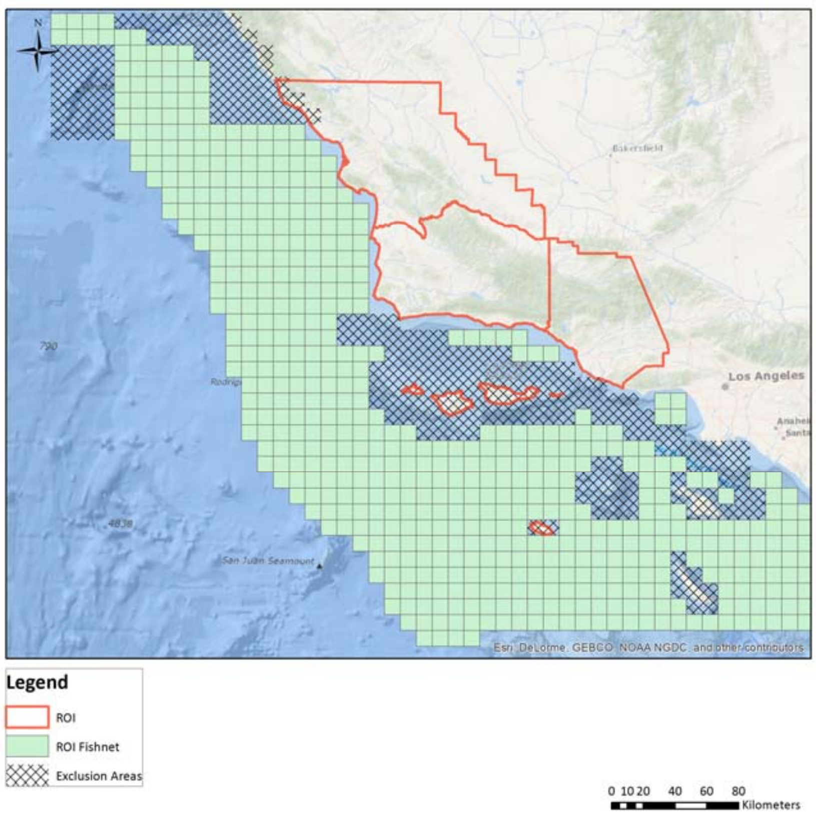

Figure 1: Fishnet Grid Cells for CalWind Region of Interest

Wind Speeds and Interconnection Points

The wind speed data was obtained from the National Renewable Energy Laboratory (NREL). NREL developed this data set by extrapolating onshore 50m wind recordings 50nm into the offshore environment.[40] Therefore, the accuracy of this data should be considered when interpreting the results of our MCDA and Marxan analyses.

Once wind speeds were calculated for each developable grid cell in our ROI, we reclassified them. Whereas the other MCDA variables were reclassified into 5 quantiles, the wind value reclassification differed slightly to reflect the inability of developers to utilize wind speeds below ~4 m/s for commercial energy generation (see Figure 3 and power curve in Figure 12).

We obtained the interconnection points from Platts Electric Transmission System Map dataset.[14] Using the ‘near’ tool in ArcGIS, we determined the distance of every developable cell to the nearest interconnection point and then reclassified these scores into five quantiles. Using this tool assumes that developable cells can connect to the closest interconnection point on shore by following a straight line. Clearly, this is not accurate, as many obstructions (e.g., the Channel Islands) would impede those straight paths. We then created a weighted a wind development score to be 75 percent wind reclassification value and 25 percent distance to shore. This wind development score became the “developer” value for the MCDA.

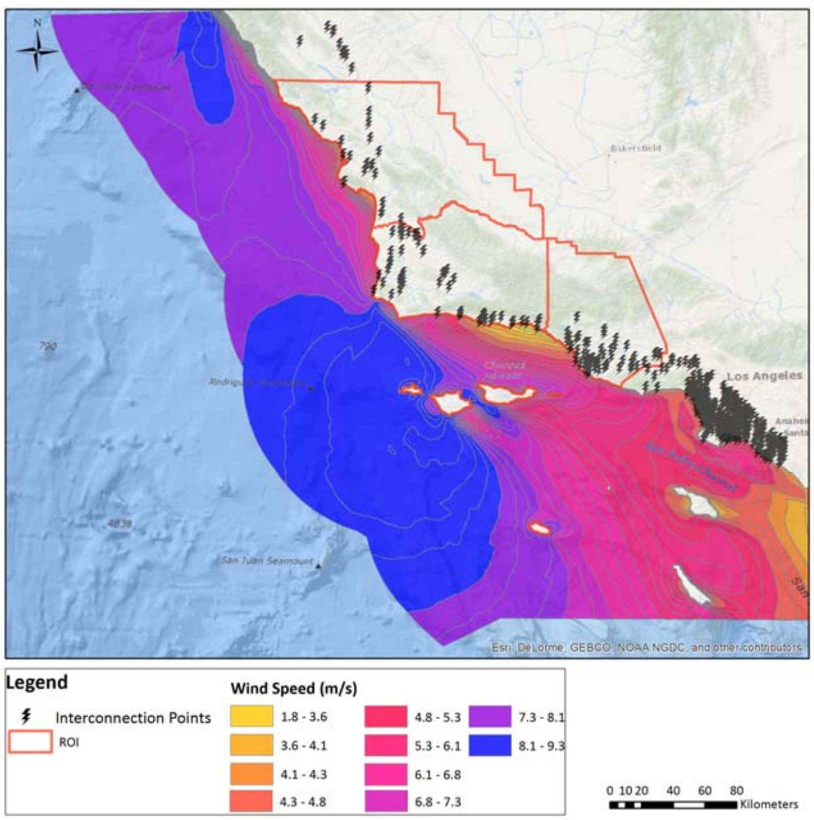

Figure 2: Wind Speeds (m/s) and Interconnection Points

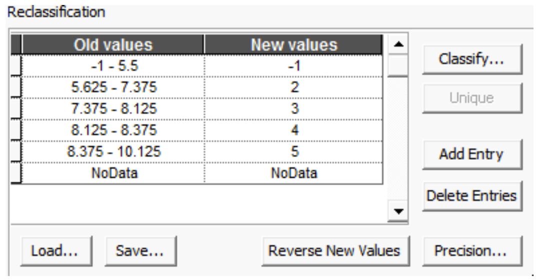

Figure 3: ArcGIS reclassification for wind speed scores

Benthic Substrate

Hard bottom substrate (primarily rocks and reefs) covers far less area than soft bottom (typically sand or mud) in the ROI (see Figure 4). Given its importance as habitat for a wide range of species, permitting agencies typically prioritize its conservation. An informal conversation with the Pacific OCS Region office of BOEM relayed the opinion that offshore wind project proposals would be considered over hard bottom substrate, but, for the purposes of our simplified spatial analysis, we could consider a site's feasibility as inversely proportional to the area of hard bottom coverage.

Substrate coverage was estimated from data gathered for "A Biogeographic Assessment of the Channel Islands National Marine Sanctuary" (November 2005).[15] We calculated the amount (m^2) of hard bottom coverage in each developable grid cell and then reclassified those values 1-5 (5 being 100 percent soft bottom; 1 being 100 percent hard bottom).

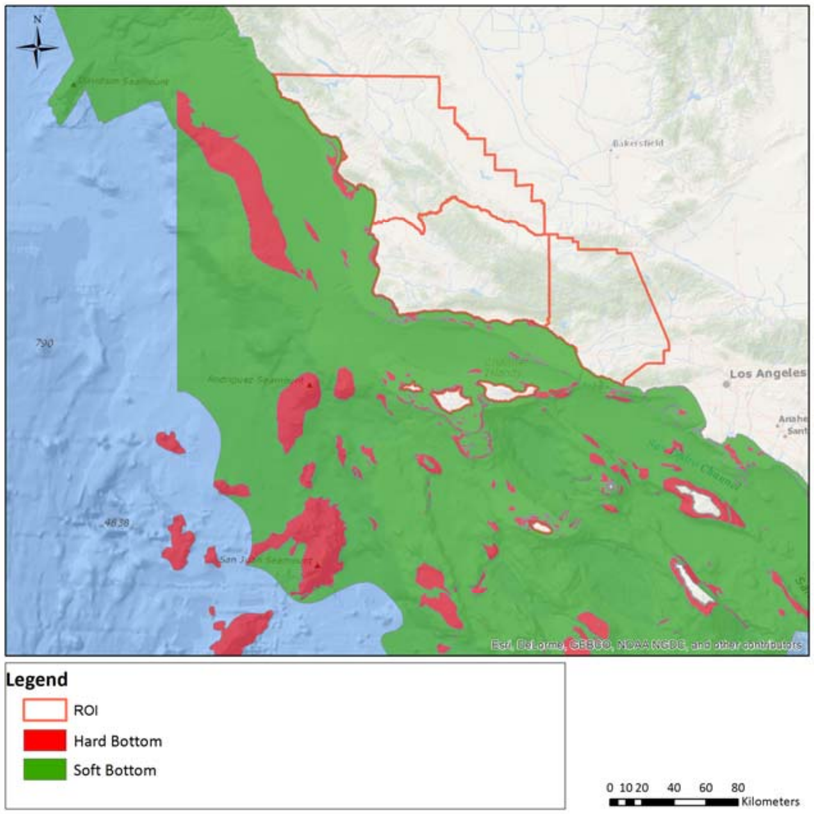

Figure 4: Hard and Soft Bottom Substrate Coverage

Department of Defense Sea Range

The 'Sea Range' constitutes an area of extreme value to the Department of Defense (DoD)(see Figure 5). The Range is the only place in the United States where the military has a controlled laboratory setting to test weaponry and defense equipment.

Horizontal axis wind turbines cause a Doppler effect on land and air-based radar equipment for up to 200 nautical miles. Essentially, radar noise (which can appear with signal strength larger than a Boeing 747) created by spinning turbine blades can cause a loss of radar detection in the air space above a wind farm. This problem extends to weather detection equipment, as blade motion may result in the appearance of storm activity.[12,13]

Interviews with DoD indicate the existence of the Range does not mean that there is no future for offshore wind development in the ROI, but consultation and possibly curtailment would be necessary. To capture this conflicting use in the spatial analysis, the team included the Range extent shapefile provided by the U.S. Naval Air Systems Command (NAVAIR). We used binary scoring for developable cells; inside or outside of the Sea Range. Cells outside the Range were reclassified to a score of 5, and cells inside the Range were reclassified to 1.

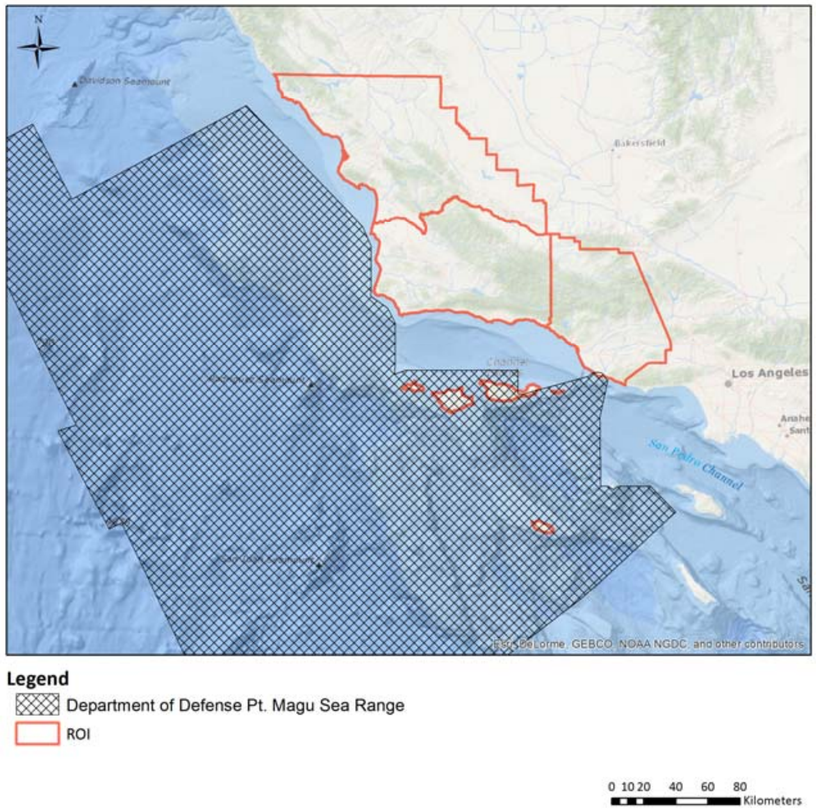

Figure 5: Department of Defense Sea Range

Marine Bird Biodiversity

Our CalWind stakeholder analysis indicate that avian impacts are of high concern for offshore wind development; however no clear metric exists to measure expected impacts to avian life from offshore turbines. The best marine bird data we could find for our analyses were generated from 6 sea surveys (1975-1997), which produced transect measures of diversity measured by the Shannon Index (balance of the number of species and distribution of individual species). These data were interpolated for “A Biogeographic Assessment of the Channel Islands National Marine Sanctuary” (November 2005).[15] These interpolated data were downloaded and employed for our spatial analyses. Measures of biodiversity are not a substitute for abundance data, but we felt it was better to include the data than ignore a large stakeholder concern. Developable cells containing areas with the highest interpolated Shannon Index received a 1, and those with the lowest Shannon Index score received a 5.

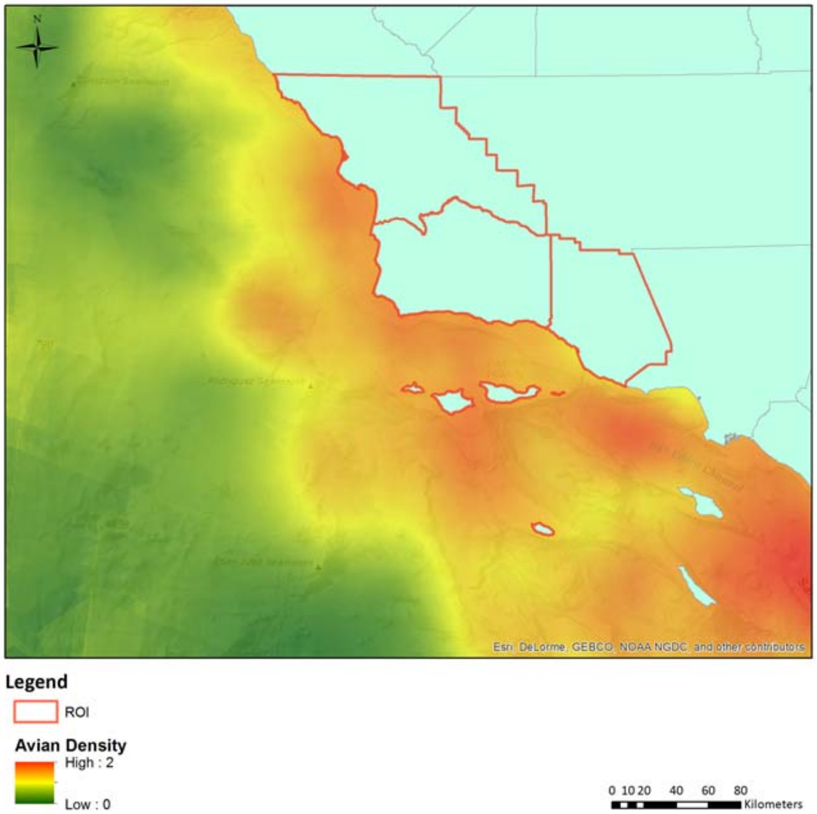

Figure 6: Interpolated Marine Bird Biodiversity (scored using Shannon Index)

Marine Mammal Presence

Potential impacts of an offshore wind farm are numerous, ranging from disturbance during construction to entanglement during operation. Similar to the marine bird data, we employed transect survey data (USGS and Humboldt State University) for marine mammal presence (see Figure 7).[41] The data relay the percent of time that marine mammals (20 species in all) were observed in a transect area (5 minute of latitude by 5 minute of longitude) across all surveys (102 days of flights). Transect data were provided for all species across three different months (May, June, and September). To come up with a relative measure of overall mammal presence value for each transect area, we summed the presence of all mammals for every transect cell and then averaged those values across the months. We then interpolated the data using ArcGIS's Empirical Bayesian Kriging tool to cover the ROI (see Figure 8). The density value portrayed in Figure 8 is unitless, and just represents relative differences in estimated mammal presence scores.

After running a 'union' tool to translate transect scores to our fishnet cells, developable cells containing areas with the highest interpolated values received a 1, and those with the lowest mammal presence score received a 5.

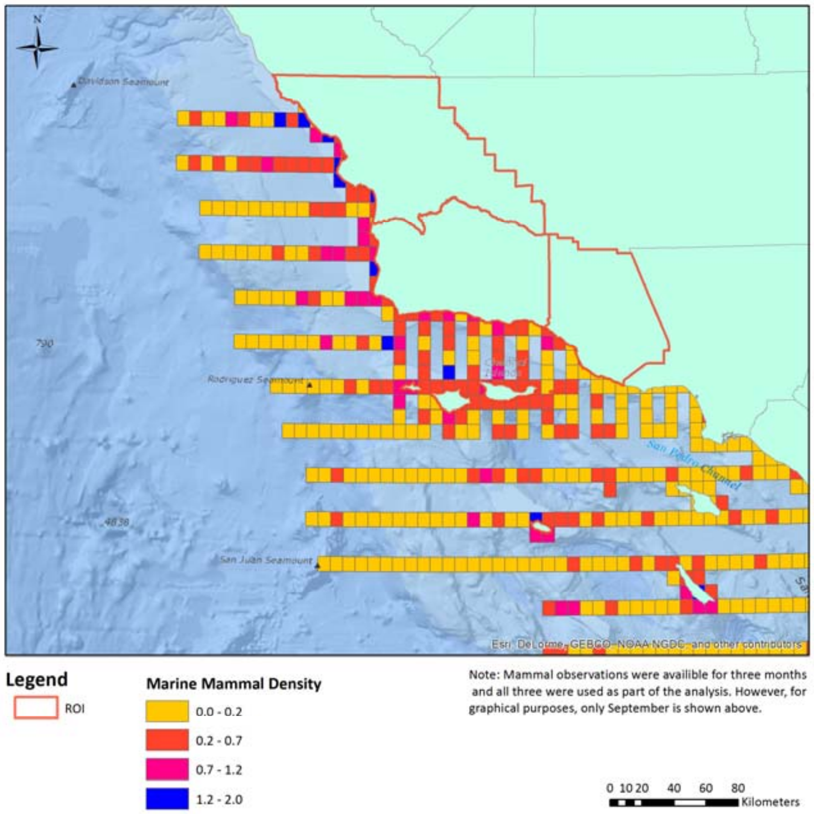

Figure 7: Marine Mammal Presence Observations

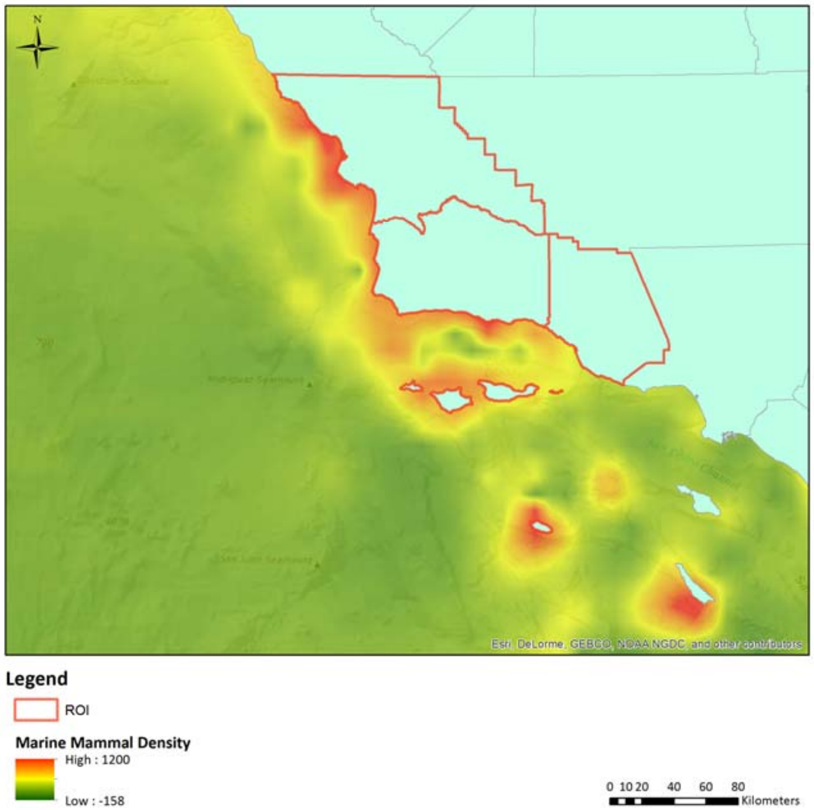

Figure 8: Marine Mammal Presence Interpolation

Dragging and Salmon Fishing Grounds

To present the interests of commercial fisheries in our analyses, we relied upon spatial survey data produced by Impact Assessment, Inc. and Ecotrust (Open Ocean Map) as part of the Central Coast MPA Baseline Program. Based on available spatial layers, the team focused on dragging (rockfish, halibut, sole, sablefish, and crustaceans) and gillnet (salmon) fishery data, as these gear types would likely be restricted within an offshore wind farm (see Figure 9).[17] The logic behind this gear exclusion is the risk of entanglement of dragging nets with anchor lines of turbine platforms. Dragging fisheries and salmon layers are areas designated as important fishing grounds by fishermen who participated in the survey, and do not incorporate values based on landings. Separate dragging and salmon ground scores were calculated for all developable cells. Cells with the longest measured distance (m) of dragging grounds and largest area of salmon fishing area (m^2) received a score of 1, while cells not containing fishing grounds received a score of 5.

We recognize that the inclusion of these fishing ground layers in our analyses do not remotely capture the interests of commercial fishermen in our ROI. Instead, the application of these fishing grounds in the MCDA and Marxan demonstrate the importance of incorporating fishery considerations into wind development site selection.

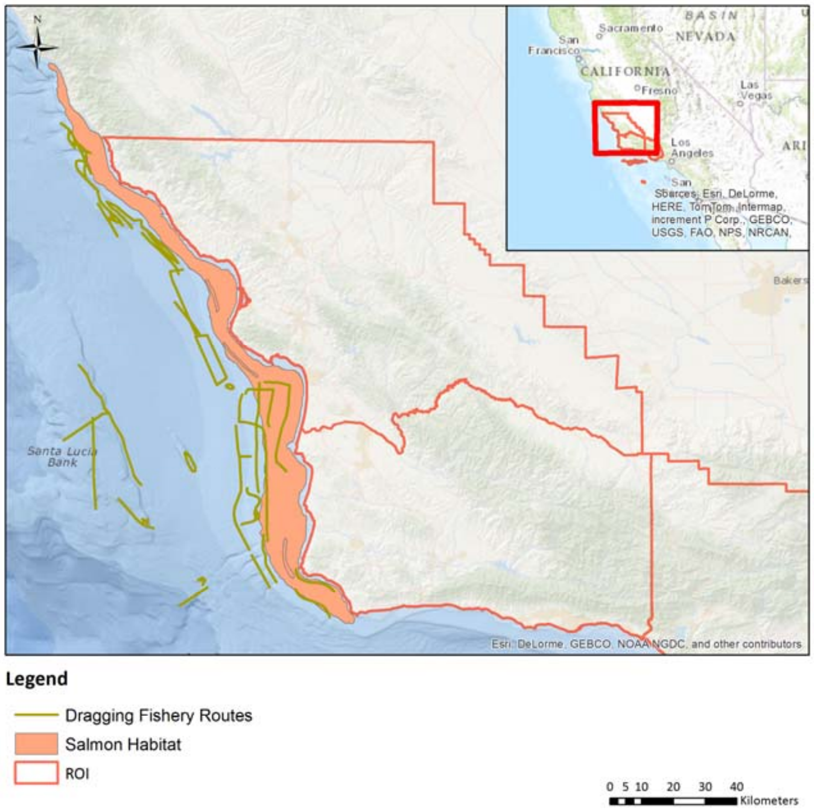

Figure 9: Important Dragging and Salmon Fishing Grounds

MCDA Analysis

For each variable included in the MCDA, we reclassified the scores to values 1-5 for every developable cell, and then calculated a comprehensive weighted sum score (1-5) (see **Error! Reference source not found.** and **Error! Reference source not found.**). Weighted values used to produce different 'stakeholder scenarios' (where the estimated preferences of different stakeholder groups were weighted more heavily) were chosen somewhat arbitrarily (40 percent weighting for single variable prioritization; 50 percent combined weighting for two variable prioritization). The weightings are simply a way to demonstrate how development scenarios vary when decisionmakers prioritize the interests of different stakeholders groups.

An example of the MCDA weighting calculation is included below for Scenario 1 (DoD):

Development Score = $(0.1^* \beta_1) + (0.1^* \beta_2) + (0.1^* \beta_3) + (0.4^* \beta_4) + (0.1^* \beta_5) + (0.1^* \beta_6) + (0.1^* \beta_7)$

Where:

- β_1 = Reclassified Substrate Score
- β_2 = Reclassified Dragging Score
- β_3 = Reclassified Salmon Score
- β_4 = Reclassified DoD Score

- β_5 = Reclassified Marine Bird Score
- β_6 = Reclassified Marine Mammal Score
- β_7 = Reclassified Wind Score (75 percent wind, 25 percent distance to interconnection)

We isolated five cells (shown in pink in Figure 10) that scored the highest across the four weighting scenarios. Given the limitations of our approach, these cells represent the areas with the highest development potential (commercially viable wind speeds and least conflict).

Table 1: Multi-Criteria Decision Analysis Variables and Scores

Variable	Score Description	Score
Benthic Substrate	Area (m^2) of hard bottom substrate	1 (100 percent hard bottom) – 5 (0 percent hard bottom)
Commercial Dragging Fishing Grounds	Area (m^2) of fishing grounds	1 (100 percent fishing grounds) – 5 (0 percent fishing grounds)
Commercial Salmon Fishing Grounds	Area (m^2) of fishing grounds	1 (100 percent fishing grounds) – 5 (0 percent fishing grounds)
Department of Defense Sea Range	Binary (in or out)	1 (in the Range) or 5 (outside the Range)
Marine Birds	Shannon Index score of species richness and evenness	1 (highest measured biodiversity) – 5 (lowest measured biodiversity)
Marine Mammals	Average observed presence of all species across survey months	1 (highest measured presence) – 5 (lowest measured presence)
Wind Development Potential	Weighted Sum: 75 percent of score = average wind speed (ms^{-1}); 25 percent of score = distance (m) to nearest transmission substation	1 (low wind and long distance to substation) – 5 (high wind and short distance to substation)

Table 2: Weighting Scenarios for MCDA

Scenario	Substrate Weight	Dragging Weight	Salmon Weight	DoD Weight	Bird Weight	Mammal Weight	Wind Weight
1: DoD	10 percent	10 percent	10 percent	**40 percent**	10 percent	10 percent	10 percent
2: Developer	10 percent	10 percent	10 percent	10 percent	10 percent	10 percent	**40 percent**
3: Fishermen	10 percent	**30 percent**	**20 percent**	10 percent	10 percent	10 percent	10 percent
4: Bird & Mammal	10 percent	10 percent	10 percent	10 percent	**25 percent**	**25 percent**	10 percent

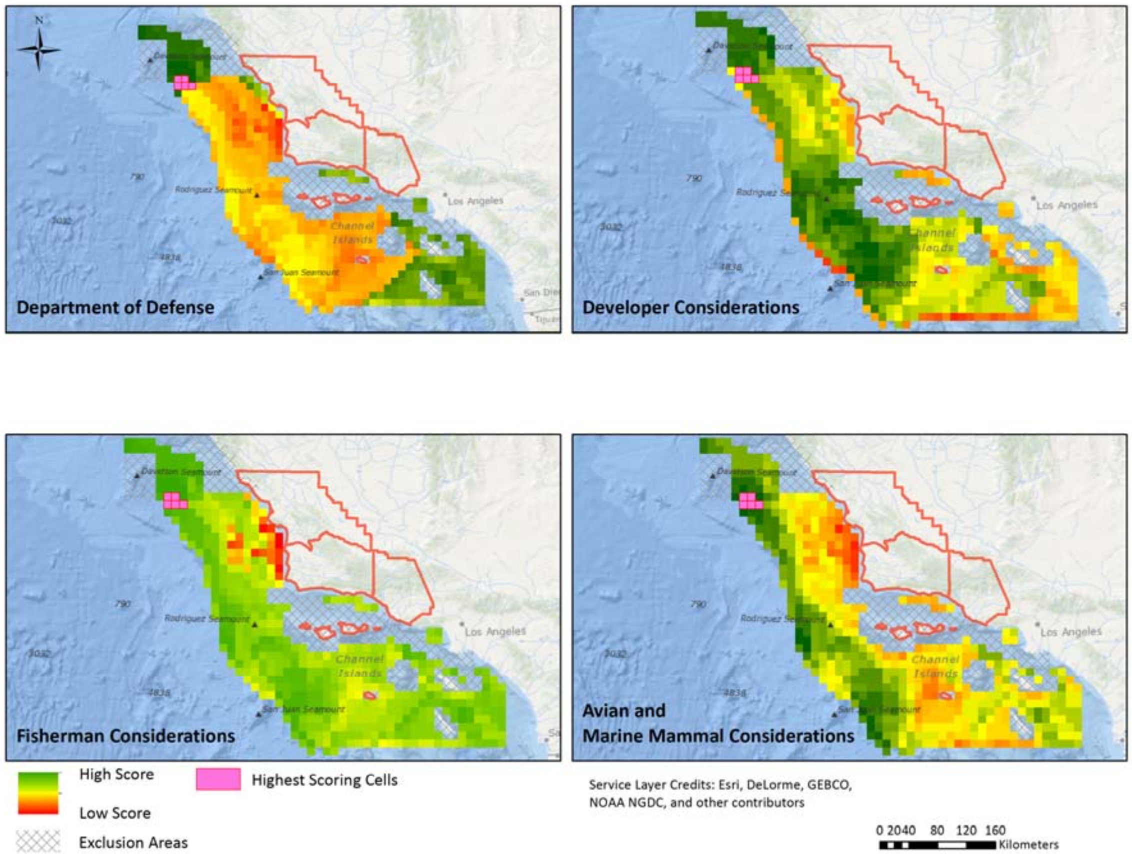

Figure 10: MCDA Output for Different Weighting Scenarios

Marxan Analysis

Practically all of the assumptions from the GIS-MCDA were carried over to the Marxan analysis. To use Marxan input file terminology, developable cells became planning units, all stakeholder/environmental variables except wind speed became development costs, and the number of turbines per cell (33) remained constant. We derived wind generation per cell by fitting an equation to the NREL power curve for a 5MW turbine (includes capacity factor, and average wind speed (see Figure 12).[42] Using this equation, any grid cell that generated 239.7kW (the y-intercept value) of electricity was reclassified as producing 0kW of electricity (otherwise, the y-intercept term from the fitted equation would superficially inflate the wind generation potential of these cells). Turbine efficiency data are often considered proprietary information, so the team was unable to secure a power curve for a 6MW turbine (the size modeled in the spatial analysis footprint).

CalWind assigned a 200MW annual wind generation target. While the rated capacity of our modeled wind farm is 198MW, turbines do not operate at 100 percent capacity. Instead, a 39.7 percent capacity factor was assigned.[33] With that assumption, it would take at least three planning units with high wind speeds (~8-9m/s) to produce 200MW. The team tested several cost weighting scenarios, and found results to be particularly sensitive to the distance to interconnection. Ultimately, the following cost weighting structure was included in this report:

hard bottom substrate (30 percent); DoD Sea Range (20 percent); distance to interconnection (10 percent); marine mammal presence (10 percent); marine bird biodiversity (10 percent); dragging fishing grounds (10 percent); and salmon fishing grounds (10 percent). Lastly, a boundary length modifier of 0.0001 was used. Boundary length is the, "the sum of the planning units that share a boundary with planning units outside the reserve system," or in this case, the wind farm.[34] Marxan's boundary length modifier setting penalizes boundary length (adds it to the planning unit cost) to encourage 'clustering' of planning unit selections. Clustering is desirable in the wind development context, as farms spaced far apart would increase construction and operation costs. We created the boundary file using ABPmer's tool for ArcGIS.[43]

Table 3: Marxan Input Files

Marxan File	Marxan Description	CalWind Usage
1:	Species file *(typically population or habitat area of species in every planning unit)*	Potential annual wind generation per planning unit *(function of the turbine power curve as it relates to average wind speed, multiplied by the number of turbines in each cell)*
2:	Target file *(percentage of the population or habitat of the species you want to try to protect)*	Total desired annual generation of wind power
3:	Cost file *(costs associated with conserving each planning unit)*	Weighted sum calculated as development cost per planning unit (Consists of all variables described in **Error! Reference source not found.**, as well as distance to a onshore transmission interconnection point)

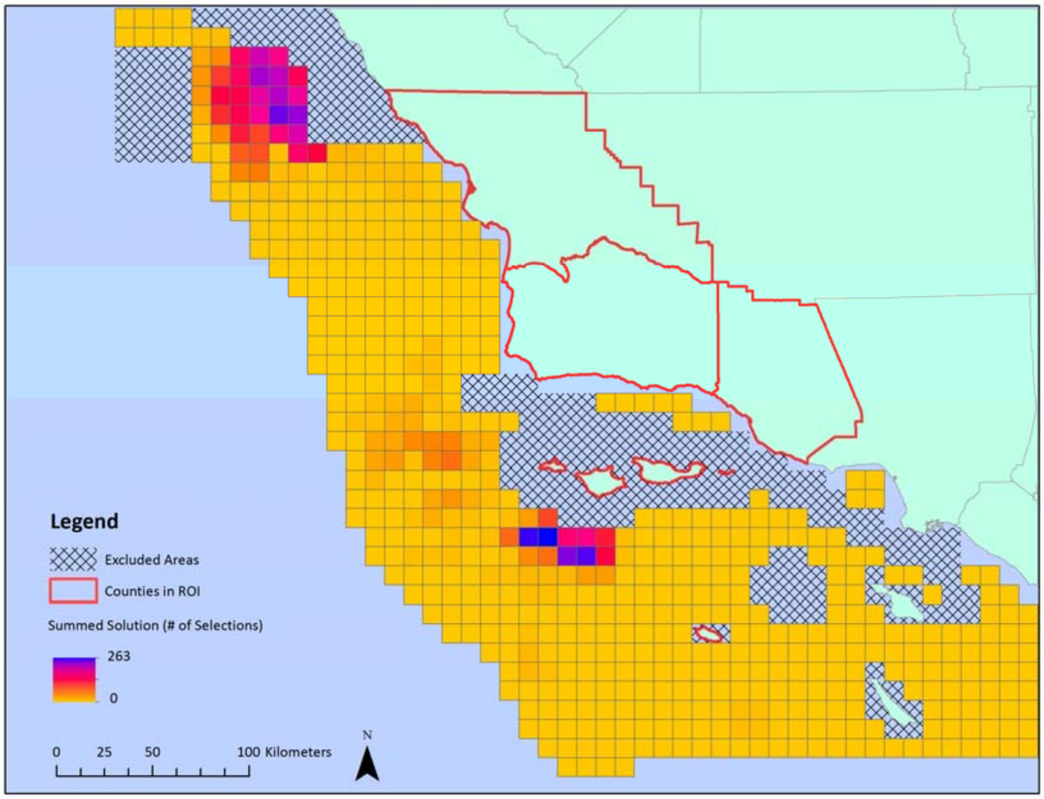

Figure 11: Marxan Summed Solutions

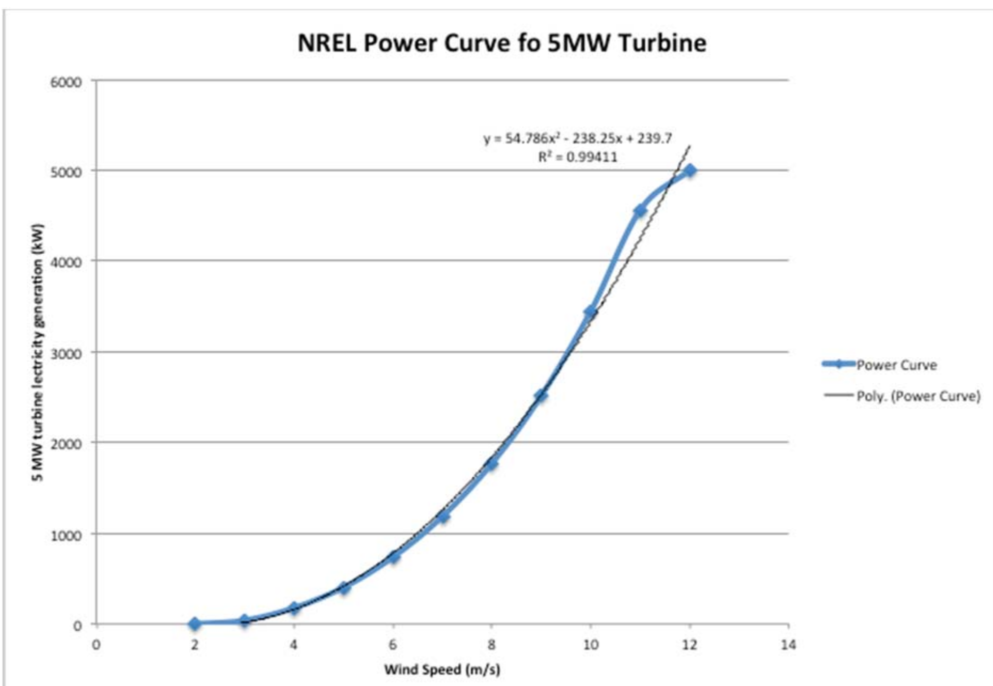

Figure 12: NREL Power Curve for 5MW Turbine[42]

References

1. Cape Wind: America's First Offshore Wind Farm on Nantucket Sound. at <http://www.capewind.org/FAQ-Category4-Cape+Wind+Basics-Parent0-myfaq-yes.htm>
2. *National Ocean Policy Implementation Plan*. (National Ocean Council, 2013). at <http://www.whitehouse.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf>
3. The Nature Conservancy. Marine Planning Policy - USA Regions. *Marine Planning* (2012). at <http://www.marineplanning.org/Policy/USA_Regions.html>
4. MLPA Summary. at <http://www.dfg.ca.gov/marine/mpa/background.asp>
5. MarineMap Consortium. at <http://marinemap.org/>
6. Lester, S. *et al.* Biological effects within no-take marine reserves: a global synthesis. *Marine Ecology Progress Series* **384,** 33–46 (2009).
7. Botsford, L. W. *et al.* Connectivity, sustainability, and yield: bridging the gap between conventional fisheries management and marine protected areas. *Reviews in Fish Biology and Fisheries* **19,** 69–95 (2008).
8. Gell, F. R. & Roberts, C. M. Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology & Evolution* **18,** 448–455 (2003).
9. Sutinen, J. G. & Kuperan, K. A socio-economic theory of regulatory compliance. *International journal of social economics* **26,** 174–193 (1999).
10. Reed, M. S. Stakeholder participation for environmental management: A literature review. *Biological Conservation* **141,** 2417–2431 (2008).
11. Freeman, E. R. *Strategic Management: A Stakeholder Approach*. (Cambridge University Press, 1984).
12. FAA. Testimony – Statement of Nancy Kalinowski. (2010). at <https://www.faa.gov/news/testimony/news_story.cfm?newsId=11562&print=go>
13. *Report to the Congressional Defense Committees: The Effect of Windmill Farms on Military Readiness*. (Office of the Director of Defense Research and Engineering, 2006). at <http://www.defense.gov/pubs/pdfs/windfarmreport.pdf>
14. Platts Electric. North American Electric Transmission System Map: Americas Maps and Geospatial. at <http://www.platts.com/products/us-transmission-system-map>
15. *A Biogeographic Assessment of the Channel Islands National Marine Sanctuary*. (NOAA National Centers for Coastal Ocean Science, 2005). at <http://ccma.nos.noaa.gov/products/biogeography/cinms/>
16. Bibi, F. & Ali, Z. Measurement of Diversity Indices of Avian Communities at Taunsa Barrage Wildlife Sanctuary, Pakistan. *JAPS, Journal of Animal and Plant Sciences* **23,** 469–474 (2013).
17. Impact Assessment Inc. Spatial distribution of fisheries. at <http://oceanspaces.org/data/spatial-distribution-fisheries-dataset-impact-assessment>
18. Goodnough, A. For Controversial Wind Farm Off Cape Cod, Latest Hurdle Is Spiritual. *New York Times* A11 (2010).
19. Myers, K. C. Wampanoag tribe preparing Cape Wind lawsuit | CapeCodOnline.com. *Cape Cod Online* (2011). at <http://www.capecodonline.com/apps/pbcs.dll/article?AID=/20110709/NEWS/107090326/0/special18>
20. Malczewski, J. GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science* **20,** 703–726 (2006).

21. Musial, W., Elliot, D., Fields, J. & Parker, Z. *Assessment of Offshore Wind Energy Leasing Areas for the BOEM New Jersey Wind Energy Area*. (Natioanl Renewable Energy Laboratory, 2013). at <http://www.nrel.gov/docs/fy13osti/60403.pdf>
22. Schlez, W., Neubert, A. & Smith, G. *New Developments in Precision Wind Farm Modelling*. (Garrad Hassan and Partners Ltd, 2006). at <http://www.gl-garradhassan.com/assets/downloads/New_Developments_in_Precision_Wind_Farm_Modelling.pdf>
23. Archer, C. L., Mirzaeisefat, S. & Lee, S. Quantifying the sensitivity of wind farm performance to array layout options using large-eddy simulation: WIND FARM LAYOUT AND PERFORMANCE. *Geophysical Research Letters* n/a–n/a (2013). doi:10.1002/grl.50911
24. Meyers, J. & Meneveau, C. Optimal turbine spacing in fully developed wind farm boundary layers: Optimal turbine spacing in wind farm boundary layers. *Wind Energy* **15,** 305–317 (2012).
25. Green, J., Bowen, A., Fingersh, L. J. & Wan, Y. Electrical collection and transmission systems for offshore wind power. in *Offshore technology conference* **30,** (Offshore Technology Conference, 2007).
26. Snyder, B. & Kaiser, M. J. Ecological and economic cost-benefit analysis of offshore wind energy. *Renewable Energy* **34,** 1567–1578 (2009).
27. NASA: Earth Observatory. California's Channel Islands: From Shore to Sea (Jason Project). *Channel Islands* at <http://earthobservatory.nasa.gov/Experiments/ICE/Channel_Islands/>
28. USGS. The National Map: Elevation. (2014). at <http://nationalmap.gov/elevation.html>
29. Ladenburg, J. & Lutzeyer, S. The economics of visual disamenity reductions of offshore wind farms—Review and suggestions from an emerging field. *Renewable and Sustainable Energy Reviews* **16,** 6793–6802 (2012).
30. BOEM. Offshore North Carolina Visualization Study. *Renewable Energy Programs* (2012). at <http://www.boem.gov/Renewable-Energy-Program/State-Activities/NC/Offshore-North-Carolina-Visualization-Study.aspx>
31. Ball, I. R., Possingham, H. P. & Watts, M. Marxan and relatives: software for spatial conservation prioritisation. *Spatial conservation prioritisation: quantitative methods and computational tools. Oxford University Press, Oxford* 185–195 (2009).
32. Göke, C. & Lamp, J. *Case Study: Systematic site selection for offshore wind power with Marxan in the pilot area Pomeranian Bight*. (Baltic Sea Region Programme, 2012).
33. Capacity factors at Danish offshore wind farms. (2014). at <http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms>
34. University of Queensland. Module 2: Theory Behind Marxan. (2008). at <http://www.uq.edu.au/marxan/tutorial/module2.html>
35. Triantaphyllou, E. & Baig, K. The Impact of Aggregating Benefit and Cost Criteria in Four MCDA Methods. *IEEE Transactions on Engineering Management* **52,** 213–226 (2005).
36. BOEM. MarineCadastre.gov. (2014). at <http://marinecadastre.gov/default.aspx>
37. USGS. Pacific Coast Fisheries GIS Resource Database (Fisheries Data). *USGS Western Ecological Research Center* at <http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=2&ProjectID=203&List=SubWebPages&Web=Project_203&Title=Pacific%20Coast%20Fisheries%20GIS%20Resou>
38. White, C., Halpern, B. S. & Kappel, C. V. Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. *Proceedings of the National Academy of Sciences* **109,** 4696–4701 (2012).

39. McLeod, K. L., Lubchenco, J., Palumbi, S. R. & Rosenberg, A. A. Scientific Consensus Statement on Marine Ecosystem-Based Management. *Communication Partnership for Science and the Sea* (2005). at <http://nicholasinstitute.duke.edu/sites/default/files/publications/pathway-to-ocean-ecosystem-based-management-design-principles-for-regional-ocean-governance-in-the-united-states-paper.pdf>
40. NREL. California Offshore 90-Meter Wind Map and Wind Resource Potential. *Stakeholder Engagement & Outreach* (2010). at <http://www.windpoweringamerica.gov/windmaps/offshore_states.asp?stateab=ca>
41. USGS; Humboldt State University. Southern California Bight Seabird and Marine Mammal Distribution Data (1999-2002). *Pacific Coast Fisheries GIS Resource Database* (2004). at <http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=4&ProjectID=203&List=SubWebPages&Web=Project_203&Title=Pacific%20Coast%20Fisheries%20GIS%20Resource%20Database>
42. Jonkman, J. Forum: NREL 5-MW reference turbine. *National Wind Technology Center (NWTC)* (2010). at <https://wind.nrel.gov/forum/wind/viewtopic.php?f=2&t=363>
43. ABPmer. ABPmer provides GIS tool for marine conservation zone planning. (2011). at <http://www.abpmer.co.uk/newsarticle/38/>