

# Methodology Statement: Protect High Seas Tool

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## Methodology

This interactive web tool builds off of The Pew Charitable Trusts' [High Seas MPA Report](#) and the [peer-reviewed paper](#) that underpinned it.<sup>1</sup> This document first describes the methodology and data used in the interactive web tool and then clarifies how the methodology used in this web tool differs from that used in the original MPA report analysis.

Conservation plans were optimally generated from input scenarios with [prioritizr](#), a systematic conservation prioritization software package built in the R scientific programming language and using the Gurobi integer linear programming engine to identify protected area solutions that meet conservation objectives while minimizing the “cost” associated with conserving these regions.<sup>2</sup> The system has similar functionality to the Marxan conservation planning program, although [prioritizr](#) uses exact algorithms to find optimal conservation solutions.

For this analysis, areas of the ocean within any nation’s jurisdiction, typically those waters 200 nautical miles (nms) from shore and known as the exclusive economic zones (EEZ), were removed.<sup>3</sup> Although there are large portions of the Mediterranean Sea where countries have not claimed EEZs, because all of those areas are within 200 nms, they were excluded from this analysis to ensure consistency. The resulting areas were divided into approximately 42-kilometer-wide hexagonal planning units.<sup>4</sup> This analysis included a total of 31 different data layers grouped into four conservation feature layers and one human use layer (fishing opportunity), described in greater detail in the “Data” section below. A team of scientists (the co-authors of the [peer-reviewed paper](#)) identified key conservation features to be included in the analysis—including biodiversity, seamounts and hydrothermal vents, seafloor habitat diversity, and productivity. The fishing layer is the inverse of fishing effort, such that a higher priority reduces overlap with high fishing effort areas. The prioritization algorithm maximizes these target features while minimizing cost, which for this analysis is the total area of all planning units to be selected in the solution and further limited by overall ocean area to conserve, e.g., 30% or 50%, depending on the user’s selection.

These conservation layers can be given a relative weight, which sets the priority for how much of each layer is conserved in the solution. This web tool enables users to adjust these weights for each of the

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<sup>1</sup> M. Visalli et al., “Data-Driven Approach for Highlighting Priority Areas for Protection in Marine Areas Beyond National Jurisdiction,” *Marine Policy* 122 (2020): 103927, <https://doi.org/10.1016/j.marpol.2020.103927>.

<sup>2</sup> J.O. Hanson et al., [Prioritizr](#): “Systematic Conservation Prioritization in R—R Package Version 7.1.1, 2022,” accessed Aug. 5, 2022, <https://github.com/prioritizr/prioritizr>.

<sup>3</sup> EEZ boundary data was obtained from [MarineRegions.org](#), consistent with other studies focused on high seas areas. See N.C. Ban et al., “Systematic Conservation Planning: A Better Recipe for Managing the High Seas for Biodiversity Conservation and Sustainable Use,” *Conservation Letters* 7, no. 1 (2014): 41-54, <https://doi.org/10.1111/conl.12010>; C. White and C. Costello, “Close the High Seas to Fishing?” *PLOS Biology* 12, no. 3 (2014): 1-5, <http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=95435102&site=eds-live&authtype=sso&custid=s3229936>.

<sup>4</sup> The hexagons conformed with the h3 hexagonal hierarchical spatial index system by Uber: <https://eng.uber.com/h3/>.

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prioritization features as “low,” “medium,” or “high.”<sup>5</sup> The weights varied by orders of magnitude: 0.1 for “low,” 1 for “medium,” and 10 for “high.”

The results of this tool show high seas areas that would be priorities for protection based on a set number of conservation values; it also shows how those priority areas shift with different conservation values. This global-level analysis is intended to be a first step in identifying future high seas MPAs. However, this tool does not identify or propose specific boundaries for future high seas MPAs, nor is it intended to replace the important stakeholder engagement process that would be needed to develop specific site proposals.

## Data

### Biodiversity (48 data layers)

To capture the known organisms that exist, or are thought to exist, in specific areas, data from AquaMaps was used to determine species richness.<sup>6</sup> AquaMaps predicts the relative probability of a species occurring in a given half-degree pixel based on environmental data such as depth, temperature, salinity, and the habitat preferences of that species from literature and observations. In this analysis, 11,900 species from the AquaMaps data were considered and grouped into 23 major taxonomic groups—with each of the 23 taxonomic groups represented in a data layer.

To incorporate the projected impact of climate change, researchers used a similar method, examining data projections from the AquaMaps 2100 model. That model estimates where species are likely to occur in 2100, based on predictions of global climate change conditions.

In the end, 46 different species richness layers were analyzed by the prioritizr function: 23 taxonomic groups in current ocean conditions, and the same groups under the climate-changed scenario.

The analysis also considered the vulnerability of those species to extinction. To capture this, the team used the International Union for the Conservation of Nature (IUCN)’s extinction risk data, excluding data-deficient species. The IUCN Red List categories were given a value (Critically Endangered=4, Endangered=3, Vulnerable=2, Near Threatened=1 or Least Concern=0); the Red List score for each of the species present in a given planning unit was assessed and then the scores were added together. Researchers repeated this process for the AquaMaps 2100 distribution data, although this layer does not consider other drivers of extinction risk, such as ocean acidification. This resulted in two “species extinction risk” layers—one representing current species extinction risk, and another representing future risk under a climate-changed scenario.

### Seamounts and vents (four data layers)

Seamounts are large underwater mountains, and a great breadth of biodiversity—deep-sea corals, mollusks, crustaceans, and large schools of fish—live among them. The depth of the seamount influences the type of biodiversity it supports. The extent that light penetrates shallower seamounts, for example, dramatically affects the types of life that can survive and thrive there.<sup>7</sup> The analysis used global

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<sup>5</sup> Weights are implemented with the “Add feature weights” function of prioritizr. See J.O. Hanson et al., “Add Feature Weights,” accessed Aug. 5, 2022, [https://prioritizr.net/reference/add\\_feature\\_weights.html](https://prioritizr.net/reference/add_feature_weights.html).

<sup>6</sup> K. Kaschner et al., “AquaMaps: Predicted Range Maps for Aquatic Species,” accessed Aug. 5, 2022, [www.aquamaps.org](http://www.aquamaps.org).

<sup>7</sup> M.R. Clark et al., “A Global Seamount Classification to Aid the Scientific Design of Marine Protected Area Networks,” *Ocean and Coastal Management* 54, no. 1 (2011): 19-36,

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seamount distribution data measured by satellites and described by scientists Seung-Sep Kim and Paul Wessel in 2011.<sup>8</sup>

To capture the range of expected biodiversity associated with seamounts in areas beyond national jurisdiction, the team incorporated three seamount layers into the prioritizr tool, one for each of the representative seamount depth categories identified by Clark et al. (2011): 0-200 metres (the sunlight zone: seamount summits in shallower depths, still within the areas of the ocean penetrated by light); 201-800 metres (the twilight zone: seamount summits in the zone in which mesopelagic fish, and other animals that vertically migrate within the water column, can be found); and >800 metres (the midnight zone: the lower bathyal biogeographic zone).<sup>9</sup> The types of organisms found at each depth class can vary considerably. Deeper in the water column, light penetration and temperature decrease while pressure increases, resulting in uniquely evolved species at different seamount depths.

In addition to seamounts, this conservation feature also includes one data layer for hydrothermal vents. Hydrothermal vents are unusual seafloor formations in which superheated fluids from deep in the Earth have been or are being released into the water column. Despite the intense heat and lack of sunlight, marine organisms, including fish, shrimp, and mussels, can thrive in these waters. Scientists are discovering new species near hydrothermal vents at high rates, in large part because those found near the vents are often unique to that particular vent system.<sup>10</sup> To capture hydrothermal vents, researchers used vent distribution data from the InterRidge Vents Database managed by InterRidge, a nonprofit organization that promotes ocean floor research.<sup>11</sup>

### Seafloor diversity (one data layer)

The great diversity of habitat on the ocean floor supports correspondingly diverse ecosystems. To take this benthic biodiversity into account, the analysis used one data layer of seafloor characteristics that was developed by scientists Peter T. Harris and Tanya Whiteway. Harris and Whiteway (2009) incorporated global data on six biological and physical seafloor characteristics (depth, seabed slope, sediment thickness, primary production, bottom water dissolved oxygen, and bottom temperature) to identify areas with diverse habitat characteristics, and thus potentially diverse life.<sup>12</sup>

### Productivity (one data layer)

Tiny microscopic organisms known as phytoplankton are the basis of the food chain in the ocean and are responsible for most of the oceanic primary productivity. As such, these organisms play an important role in shaping the behavior of high seas species. This analysis uses a productivity data layer from Oregon State University that relies on a vertically generalized production model (VGPM), a common method for

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<http://search.ebscohost.com/login.aspx?direct=true&db=edselp&AN=S0964569110001560&site=eds-live&authtype=sso&custid=s3229936>.

<sup>8</sup> S.-S. Kim and P. Wessel, "New Global Seamount Census From Altimetry-Derived Gravity Data," *Geophysical Journal International* 186, no. 2 (2011): 615-31,

<http://search.ebscohost.com/login.aspx?direct=true&db=edsbas&AN=edsbas.C58A931B&site=eds-live&authtype=sso&custid=s3229936>.

<sup>9</sup> Clark et al., "A Global Seamount Classification."

<sup>10</sup> E. Ramirez-Llodra, T.M. Shank, and C.R. German, "Biodiversity and Biogeography of Hydrothermal Vent Species: Thirty Years of Discovery and Investigations," *Oceanography* 20, no. 1 (2007): 30,

<http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.24859973&site=eds-live&authtype=sso&custid=s3229936>.

<sup>11</sup> InterRidge, InterRidge Vents Database Ver. 3.4, accessed Nov. 27, 2019, <https://vents-data.interridge.org>.

<sup>12</sup> P.T. Harris and T. Whiteway, "High Seas Marine Protected Areas: Benthic Environmental Conservation Priorities From a GIS Analysis of Global Ocean Biophysical Data," *Ocean and Coastal Management* 52, no. 1 (2009): 22-38,

<http://search.ebscohost.com/login.aspx?direct=true&db=edselp&AN=S0964569108001130&site=eds-live&authtype=sso&custid=s3229936>.

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estimating primary productivity in the ocean. The VGPM models primary productivity in specific waters by examining chlorophyll concentrations detectable from satellites, depth of the seafloor, and photosynthetically available light.<sup>13</sup>

### Fisheries (one data layer)

Fish represent an integral component of ocean biodiversity, but fishing has become a major industry in the high seas. This feature data layer was inverted such that the higher the weight given, the more the conservation solution avoided areas with high fishing effort. Researchers used a data set describing the global distribution of high seas fishing effort (in kilowatt hours) published by Sala et al. in the journal *Science Advances* in 2018.

Researchers created this map of fishing effort using data from automatic identification systems (AIS) and vessel monitoring systems (VMS), which are GPS-like tracking systems on most large fishing vessels in the high seas. To minimize conflict with areas with the highest concentration of fishing effort, the conservation planning software sought to avoid including areas that contained the top quartile of fishing effort in the candidate marine protected areas solution.

### Other factors

Although shipping and seabed mining are current and emerging threats to high seas biodiversity, they were not considered in this analysis. Seabed mining claims in areas beyond national jurisdiction are still in the exploratory stage, and mining has yet to begin on a commercial scale. Conversely, the shipping industry has a global footprint that affects most of the high seas. Although this analysis could support decisions to adopt measures that would minimize the negative impact of shipping in important high seas areas, high levels of shipping traffic are so pervasive that those areas were not removed from consideration.

## How this tool differs from the MPA Report

Although this web tool uses the same data, the same prioritization software, and a similar algorithm to the original analysis, the methodology for the web tool differs from the original report in a few key areas: area objective; criteria weight; and criteria grouping.

### Area objective:

Whereas the prioritizr tool in the original report ensured that all conservation objectives were met in the high seas area, it also aimed to meet those conservation objectives while using the smallest amount of space required. So, although the conservation solution identified in the original report protected at least 30% of each conservation feature, because a number of conservation features were co-located (e.g., areas that were highly productive were often also species-rich), the total area included in the conservation solution equated to only 23.7% of the high seas. This web tool has made a key adjustment to the algorithm so that the prioritizr tool now protects as much of the weighted conservation features as possible while protecting a set area of the high seas (either 30% or 50% of the high seas, depending on the user's selection). Scientists tell us that we need to protect at least 30% of the ocean if we want it to

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<sup>13</sup> Oregon State University, Ocean Productivity: Online VGPM Data, accessed March 17, 2019, <http://orca.science.oregonstate.edu/2160.by.4320.monthly.xyz.vgpm.v.chl.v.sst.php>.

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support healthy, productive ecosystems,<sup>14</sup> and there is growing political support to protect 30% of the ocean by 2030.<sup>15</sup> Some scientists have called for an even more ambitious target: for half of the Earth to be protected.<sup>16</sup> So the total area included in the web tool's conservation solution (either 30% or 50%) is greater than the area included in the MPA report's conservation solution (23.7%).

Additionally, while the original analysis used 50.1-kilometer x 50.1-kilometer square planning units in the Mollweide projection, this web tool analysis used approximately 42-kilometer-wide hexagonal planning units in the unprojected geographic coordinate system.

### Criteria weight:

The original analysis weighted each of the criteria equally and the solution protected at least 30% of each conservation feature. The interactive web tool allows users to select their own criteria weight, so the relative weight of the criteria is variable, dependent upon the user's selection. Users could choose to equally weight all criteria (i.e., select all criteria as "high" priorities; all criteria as "medium" priorities; or all criteria as "low" priorities) and the conservation solution would be similar to the solution from the original analysis (although the overall area conserved would be greater in the web tool analysis, as it would protect at least 30% of the high seas, compared with the 23.7% protected in the original analysis). (See Figure 1.) However, the user could prioritize just certain conservation features (i.e., by identifying them as a "high" or "medium" priority) at the expense of other conservation features (i.e., by identifying them as "low" priority). The criteria are all weighted relative to each other, which means that the impact of selecting any one criterion as a "high" or "medium" or "low" priority depends on the prioritization selection of the other criteria. For example, if the "biodiversity" criterion is selected as a "high" priority and the remaining criteria are selected as "low" priorities, the algorithm will be heavily weighted to prioritize those areas that are high in "biodiversity." (See Figure 2.) However, if the "biodiversity," "productivity," "habitat diversity" and "seamounts and vents" are all selected as "high" priorities and only "fishing cost" is selected as a "low" priority, then the "biodiversity" feature will be less prioritized compared with the example in which it was the sole "high" priority feature—the four features selected as "high" priorities will be equally weighted, although they will be prioritized over the one feature identified as a "low" priority. (See Figure 3.)

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<sup>14</sup> B.C. O'Leary et al., "Effective Coverage Targets for Ocean Protection," *Conservation Letters* 9, no. 6 (2016): 398-404, <http://dx.doi.org/10.1111/conl.12247>; N.J. Gownaris et al., "Gaps in Protection of Important Ocean Areas: A Spatial Meta-Analysis of Ten Global Mapping Initiatives," *Frontiers in Marine Science* 6, no. 650 (2019), <https://doi.org/10.3389/fmars.2019.00650>.

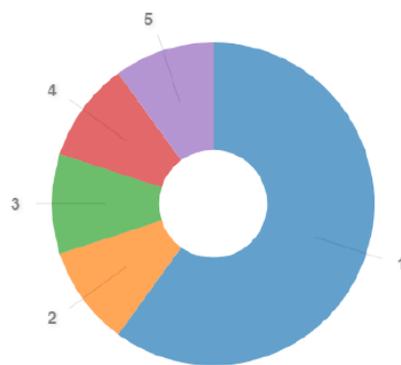
<sup>15</sup> Campaign for Nature, "More Than 100 Countries Commit to Protect at Least 30% of Land and Oceans by 2030," accessed Aug. 19, 2022, <https://www.campaignfornature.org/more-than-100-countries-commit-to-protect-at-least-30-of-land-and-oceans-by-2030>.

<sup>16</sup> E. O. Wilson, *Half-Earth: Our Planet's Fight for Life* (New York: Liveright, 2016).

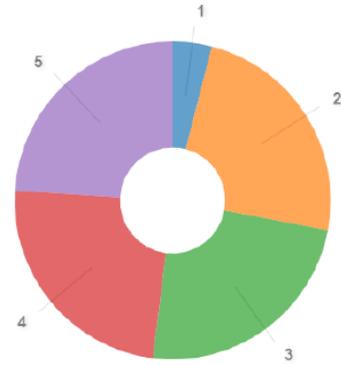
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**Figure 1.** A visual representation of the five criteria equally weighted.



**Figure 2.** A visual representation of one criterion weighted as "high" while the remaining criteria were equally weighted as "low."



**Figure 3.** A visual representation of four criteria weighted as "high" and one criterion weighted as "low."

### Criteria grouping:

Although the original analysis grouped the different data layers into six broad categories and one cost layer of fishing, the interactive web tool grouped the different layers into four broad categories, and the inverse of fishing effort is incorporated as another conservation feature while the selected planning unit area is the cost. The web tool grouped the data layers into fewer categories to simplify the user experience. There were two instances in which data layers that were divided into two categories in the original analysis were combined into one category for the updated web tool. In the first instance, data layers originally included in the "species richness" and "species extinction risk" categories were combined into one new category called "biodiversity." In the second instance, all of the data layers originally included in the "seamounts" and "hydrothermal vents" categories were combined into one new category called "seamounts and vents."

Rather than fishing effort being used as the cost as in the original analysis, the inverse of fishing effort was used as a target feature (similar to biodiversity) in the web tool. Applying a "high" prioritization of the inverted fishing effort layer, now dubbed "fishing opportunity," would then minimize overlap of the conservation solution with areas having high fishing effort, thus prioritizing fishing. A "low" prioritization of "fishing opportunity" simply diminishes the degree to which the impact on fisheries is taken into consideration.