A Global Market for Marine Conservation

Draft

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Abstract

Humanity depends on the ocean for livelihood, subsitance, and way of life. Yet, many of our activities continiously pose a threat to marine populations and ecosystems. The implementation of Marine Protected Areas (MPAs), where extractive activities are regulated or prohibited on the basis of spatial deliniations, are one of many ways to manage the oceans. Current intenrational agreements call to achieve a certain amount of within-country conservation. Here we explore the benefits from implementing a market for conservation in which nations trade conservation towards a global target. We find that such a market reduces the costs of conservation by 46%, relative to a BAU scenario without a market where each country protects a fixed portion of their waters. When creating 12 distinct markets based on biogeography regionalization, we find that costs are reduced by 34.8%.

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1 Main

More than three decades of conservation science have shown us that well-designed Marine Protected Areas (MPAs) can deliver large economic and ecological benefits[1,2,3]. Various international goals seek to protect anywhere between 10% and 30% of the global ocean with MPAs. Along with these commitments, the scientific roadmap on where to site them[4,5,6,7,8,9] should be enough to see these goals realized. Why, then, have some nations achieved (and even surpassed) the ambitious 30% target, while others lag behind even the modest 10% target? Partly, because under the current unilateral conservation framework some nations face higher costs of conservation than others. Here, we show how an environmental market can be designed to lower the costs of conservation and induce cooperation towards a more efficient and equitable protection of the marine environment.

Habitat suitability, and the costs of protecting it, are heterogeneously distributed across the globe and non-perfectly correlated[1,4,10]. As a result, different nations can attain the same amount of conservation for dramatically different costs, questioning the efficiency and equity of the current unilateral approach to marine conservation. But what if there were a way to maximize global conservation while lowering national costs of conserving? We propose a new institution where nations facing large costs of conserving in their Exclusive Economic Zones (EEZ) can purchase conservation credits from nations with a surplus of habitat worth protecting, and show that the costs of conservation can be dramatically reduced.

The latest findings on marine conservation prioritization show that a globally coordinated effort is more efficient than unilateral conservation efforts[9]. While these results can point out where protection is most warranted and highlight the importance of coordination, they do little to incentivize nations to engage in it. Instead, institutions are needed to align actions with the desired conservation outcomes. One way to induce this desired cooperation is by allowing nations to conserve *in situ* (*i.e.* within their EEZ) or pay to conserve *ex situ* (*i.e.* in another nation's EEZ) to meet an aggregate target.

A market for conservation credits would allow just that. However, in designing such a market, two main challenges arise. First, not all ecosystems are created equally. Protecting one hectare of coral reef is not the same as protecting one hectare of kelp forest. A conservation market that ignores this could inadvertently fail to protect important habitat. Secondly, we live in a highly dynamic and connected world, one in which the biodiversity and costs of a patch of ocean depend on what else has been (or will be) protected, as well as it's own protection status. We provide solutions to both of these problems, and then simulate the trade outcomes of a global market for marine conservation credits and compare them to the business-as-usual baseline of unilateral conservation. For a range MPA coverage targets (1% - 99%), we find that a market always reduces the cost of conservation, resulting in a more efficient and equitable outcome.

2 Designing a market for conservation credits

The first challenge in designing a market for conservation credits is to ensure that all ecosystems are properly protected. A coral reef can not be substituted for a kelp forest - they complement each other to produce our world's rich biodiversity. One way to avoid trading credits across different ecosystems is by using a "bubble policy"[11]. In air quality management, this approach enables polluting plants to flexibly manage their air emissions. By placing a "bubble" over a city with multiple polluting plants and applying a single emission cap to the "bubbled" city, each plant can decide how to internally manage production and trade emissions permits accordingly.

We use biogeographic regionalization (Realms and Provinces[12] Fig S1) to create ecologically-coherent "blue bubbles" where nations trade conservation credits for similar habitats. For example, for Realm-based bubbles, Mexico and the United States trade conservation credits under two blue bubbles (Temperate Eastern Pacific [TEP] and Tropcial Atlantic [TA]), using bubble-specific conservation credits (*e.g.* Kelp forest in the TEP and coral reefs in the TA).

The second challenge a market faces is in the deffinition of conservation targets. In the air pollution example, the target can be a fixed amount or ambient concentration of a pollutant, both of which are measurable quantities. Moreover, the amount of pollution in one bubble is not affected by the management status of the adjacent bubbles. However, biodiversity is an elusive variable, with multiple nuanced indices implicitly assigning weighs to different features (*e.g.* species richness does not weigh abundance, while biomass does not acount for richness). Moreover, the biodiversity for any pixel in the world will be influenced by the protection status of itself, but also the network of connected pixels.

Instead, we define the value of a pixel based on its surface area and the suitability of the habitat it contains for the species distributed there. Habitat suitability is defined as X. Conveniently, the habitat suitability of any pixel in the ocean can be defined independently of the habitat suitability and protection status of other pixels. Habitat suitability maps for 4,000 (exact number here) marine species, as indicated by the probability of occurrence which is a function of X, Y and Z[13]. The habitat suitability of any pixel in the world can be calculated as the average suitability across all species, conditional on the pixel being suitable (i.e. $p > 0.5$).

Marine Protected Areas are spatial conservation interventions that seek to directly protect habitat and, indirectly, the species that reside there. The siting of MPAs can therefore be guided by abiotic characteristics that are conducive to the persistence of species. Together, these abiotic characteristics define the habitat suitability of a patch for a given species.

3 Simulations

We combine habitat suitability and fisheries revenue to generate supply curves for each nation, as well as a global biodiversity supply curve. While in practice this approach can be used for any given biodiversity target, I produce an example using the 30% area-based target (*i.e.* We translate this area-based target into biodiversity units). We then find the trading price in the global supply curve and use the country-level supply curves to calculate in-situ and ex-situ conservation for every country. We can then calculate the differences in costs, and estimate the gains from trade.

The same approach can then be repeated for any level of spatial aggregation. As an example, I repeat the conservation excercise by subdividing the world into 12 Realms, and calculate realm-level supply curves to estimate the trading price for all countries that are part of that market.

The following sections go into more detail to describe my methods. The first section describes the data, and important caveats are mentioned at this stage. The second section describes how nation-level and aggregate supply curves were built. The third section dives into translating area-based targets into biodiversity benefit targets and the corresponding trading prices. Finally, we discuss how the analysis can be replicated by creating markets at different spatial scales.

3.1 Spatial considerations

When combining different data sources, we also include pixel-level information about the Hemisphere, Realm, Province, and Ecoregion in which they reside. This allows us to repeat the exercise of finding supply curves for any level of spatial division in order to simulate markets within them. This is better described in the results section, where I present detailed methods and results in parallel.

4 Results

The main purpose of this project is to identify the gains from trade. But in order to get there, there are other minor findings that are worth mentioning here. This sections presents some preliminary results. The first section shows findings for a global market, where I calculate the gains from trade for a given target and it's corresponding trading price. I then turn to the realm-level markets, and present the same information for each realm. Whenever relevant, I mention opportunities for improvements, and I later discuss them in the discussion section.

4.1 Global

By combining costs and benefits of conservation and anticipating the ways in which countries may conserve within their waters, we can translate the (percent) area-based targets into biodiversity benefit targets. We find that a 30% target yields a global biodiversity benefit of 3 to 106, depending on the approach taken (Figure 1; Table 1).

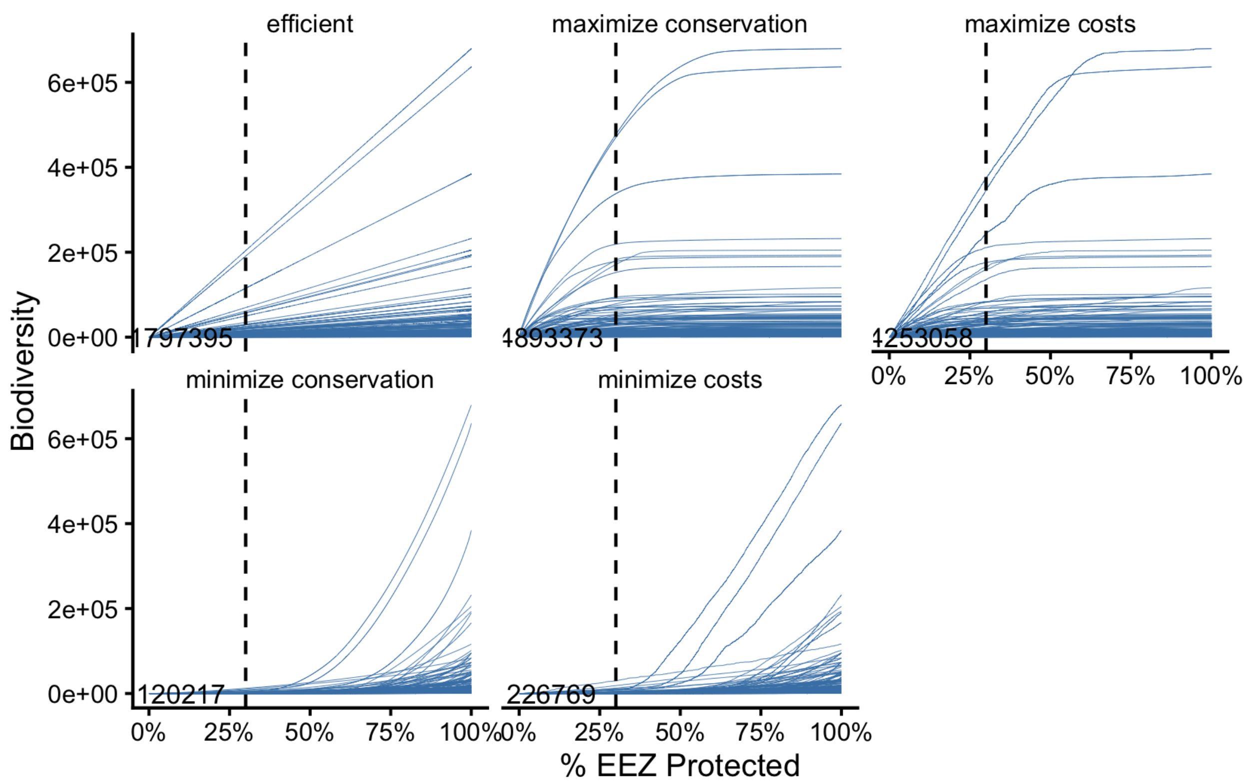


Figure 1: Five sequential conservation approaches. Each line represents one nation. The y-axis shows how much conservation is achieved by protecting a given percentage (x-axis) of a nation's EEZ. The numbers show the totl biodiversity, summing across all nations.

Table 1: Trading prices for each of the five biodiversity targets, depending on the approach taken.

Type	Biodiversity	Trading price
Efficient	1797394.9	778.94
Maximize conservation	4893372.9	10948.09
Minimize conservation	120216.5	32.79
Maximize costs	4253058.2	7174.91
Minimize costs	226769.5	54.38

Our global supply curve allows us to take any biodiversity target and find its corresponding costs. In doing so, we can identify the trading price for any possible target. We find that the trading price for conservation lies between 0.08 and 483,528[1]. Figure 2 shows the corresponding trading prices for each of the targets outlined above. Table 1 shows the five targets and their trading prices. While these figures and table show only the values for the five approaches mentioned above, the same can be done for any given biodiversity target.

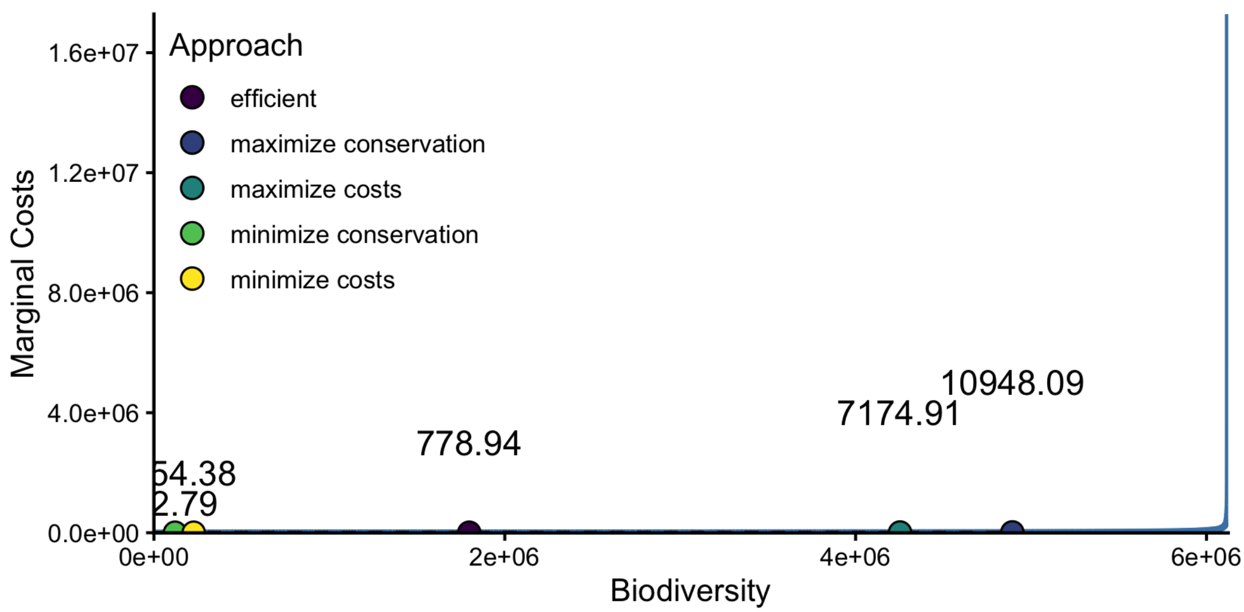


Figure 2: The global conservation supply curve, showing the costs for each of the biodiversity benefit targets.

[1] I must stress that these figures represent losses in fisheries landings, not dollars, and that more work needs to be done.

In translating the area-based target into a biodiversity benefit target we identified the global conservation benefits, but also the costs to each nation (Figure 3 left). We can use the nation-level supply curves and trading price to find the market's equilibrium for conservation (Figure 3 right). Under a market-based approach, in-situ conservation will decrease for some nations (those for which costs are higher than the trading price), while some may see increased in-situ conservation (those under the trading price). The additional conservation in some nations (red lines in Figure 3) can only be achieved through a market, where nations whose in-situ conservation would exceed the trading price are willing to pay to conserve elsewhere.

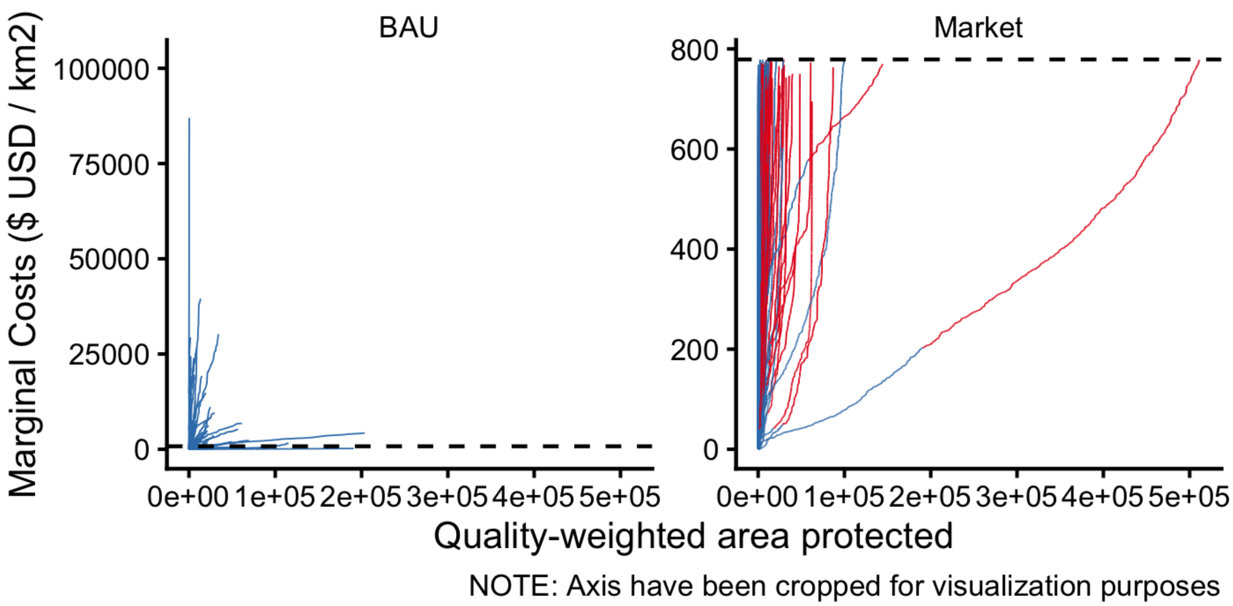


Figure 3: Supply curves for a case where nations efficiently conserve 30% in-situ (left) or with a market-based approach (right). The horizontal dashed line shows the trading price (131,241.92). Red lines in the right-side panel show the portion of additional conservation that is incentiviez by trade.

By knowing the equilibrium under each approach we can compare the total costs and calculate the gains from trade. We find that a market-based approach can produce the same biodiversity benefit of 71.56 units for just 54% of the costs (Table 2). Of course, gains from trade are heterogeneously distributed among nations. The map below (Figure 4) shows which countries would rather pay to conserve elsewhere, and which countries get paid to conserve in-place. Figure 5 shows the outcome of each approach.

Table 2: Gains from trade from protecting 71.56 units of biodiversity. Difference shows BAU - Market, ratio shows Market / BAU.

Variable	BAU	Market	Difference	Ratio
Area	47372500	37825000	9.54750e+06	0.8
Biodiversity benefits	1800046	1796932	3.11392e+03	1.0
Total costs	4349368353	883798096	3.46557e+09	0.2

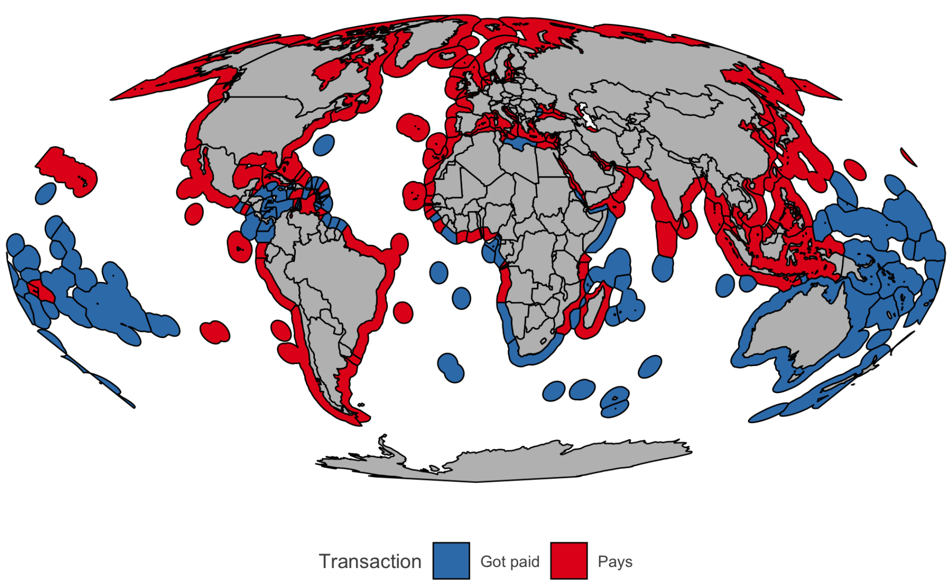


Figure 4: Map of trade. Blue indicates nations that reach the trading price before meeting their target, and therefore chose to pay to conserve elsewhere. Red nations get paid to conserve in their waters, due to the low costs relative to blue nations.

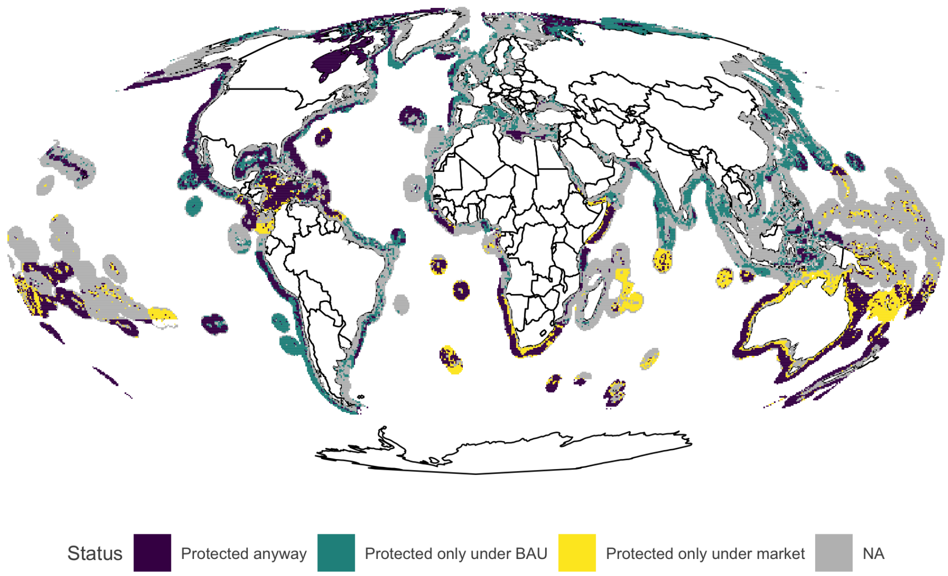


Figure 5: Map of two possible conservation outcomes.

4.2 Realms

The results presented so far assume that a unit of biodiversity is worth the same anywhere around the world. However, we might want to ensure that no single type of habitat or region is left out. To overcome this, markets can be established at different spatial scales. Here, we use different scales of zoning in the marine environment (*i.e.* Biogeographic zoning).[12] divided the oceans using a hierarchical approach with Realms (n = 12) containing Provinces (n = 60), which in turn contain Ecoregions (n = 219).

The same approach as above can be repeated for any level of spatial aggregation that allows for more than one country. For example, this can be done for each of the 12 realms (Figure 11). Each Realm contains more than one nation, which would allow for trade to occur (Figure 6). For example, the Tropical Atlantic contains more than 60 nations, while Temperate Australasia contains just three. Any given country may also be part of more than one realm (Figure 7). For example, Mexico is present across four realms (Tropical Eastern Pacific, Temperate Northern Pacific, Temperate Northern Atlantic, and Tropical Atlantic).

As done before for the global analysis, we can generate the biodiversity supply curves of each country-realm combination, and calculate the realm-level supply curve for biodiversity benefit. Then, for any desired level of biodiversity benefit, we can estimate the realm-specific trading price, and derive the market equilibrium. From there, we can estimate the gains from trade, and identify who gains from this approach.

We first must find the target amount of biodiversity. We do this by finding how much biodiversity would be protected if every country were to protect 30% of each realm present within their Exclusive Economic Zone [2]. We then sum the realm-level biodiversity to obtain the aggregate biodiversity (Table 3). Using the realm-level supply curves (Figure 8 bottom) we can identify the trading prices. When the market is segmented by realms, a market approach produces the same amount of conservation for just 65.2% of the costs in the BAU scenario. The realm-level gains from trade for such a market are shown in Table 4, and Figure 9 shows the realm-level transactions. Note how for the Temperate Northern Pacific Mexico gets paid to conserve, while in the Tropical Atlantic it pays to conserve elsewhere.

So far, I have performed preliminary analyses for a global market and outlined how it would be done for 12 realms. I believe there is room (and need) to try a few more approaches. The first approach would involve "zooming out" to create four markets, one for each hemisphere. The second approach would then increase the scale by repeating the exercise for each ocean basin. Then, I would further increase the scale by taking the market at the province-level (Figure 10). Doing it at the ecoregion-level (the next biogeographical scale) would yield less benefits from trade, since many Ecoregions contain only one nation. I expect gains from trade to decrease as spatial resolution (or segmentation of the markets) increases. In the end I will have six levels of spatial aggregation: global, hemisphere, ocean, realm, province, and EEZ (BAU).

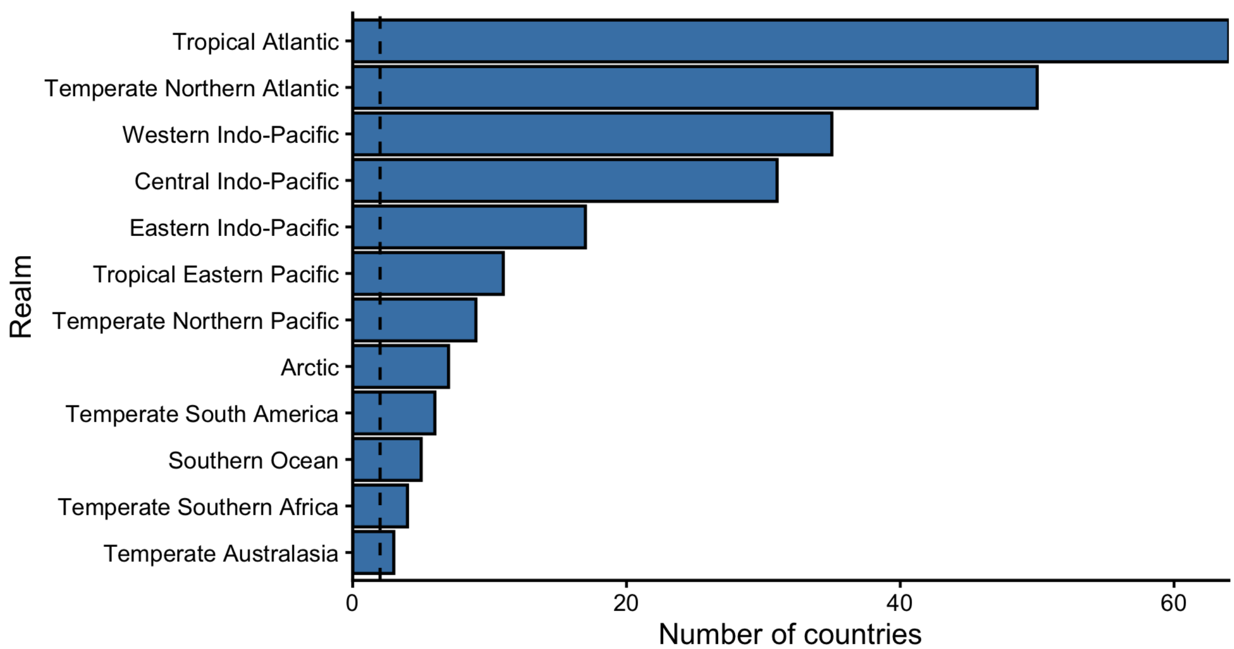


Figure 6: Number of nations contained within each of the realms described by [12]. The vertical dashed line lies at 2, the minimum number of nations required for trade to occur.

[2] This is more closely aligned with what the IUCN 30% target is: the International Union for the Conservation of Nature (IUCN) has suggested that at least 30% of each marine habitat should be protected in areas with no extractive activities.

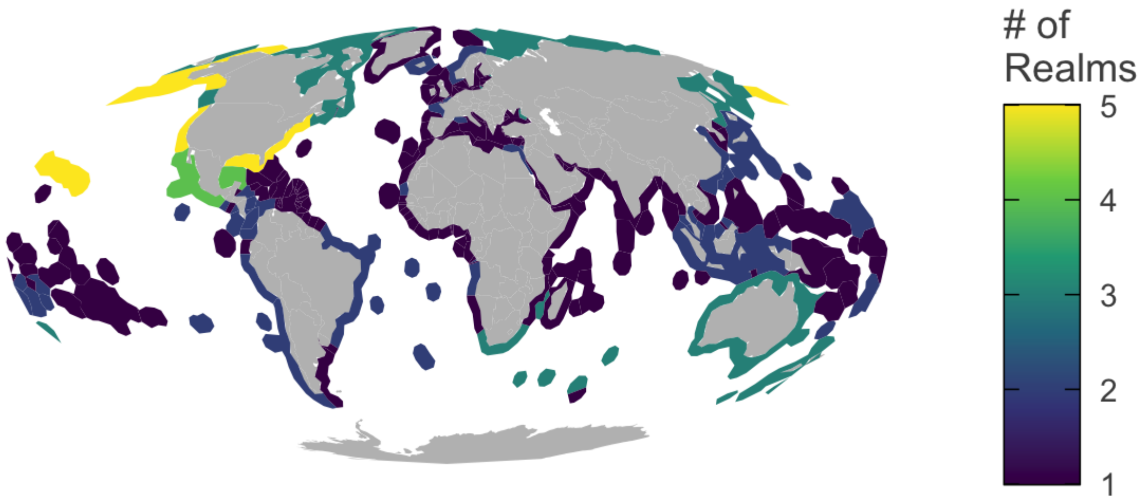


Figure 7: Number of realms in each Exclusive Economic Zone

Table 3: Biodiversity targets and trading prices for 12 realms. The Last row shows total biodiversity and weighted mean of trading price

Realm	Biodiversity	Trading Price
Temperate South America	21.84	33342.43
Tropical Eastern Pacific	9.99	6759.42
Arctic	1.67	17985.21
Western Indo-Pacific	69.28	19051.10
Temperate Northern Pacific	50.76	46030.94
Temperate Northern Atlantic	32.47	43250.04
Central Indo-Pacific	191.98	19030.74
Eastern Indo-Pacific	24.88	16505.23
Temperate Australasia	27.04	8107.10
Tropical Atlantic	54.17	13811.61
Southern Ocean	3.30	220.50
Temperate Southern Africa	7.39	34480.71
Summary	494.76	22583.68

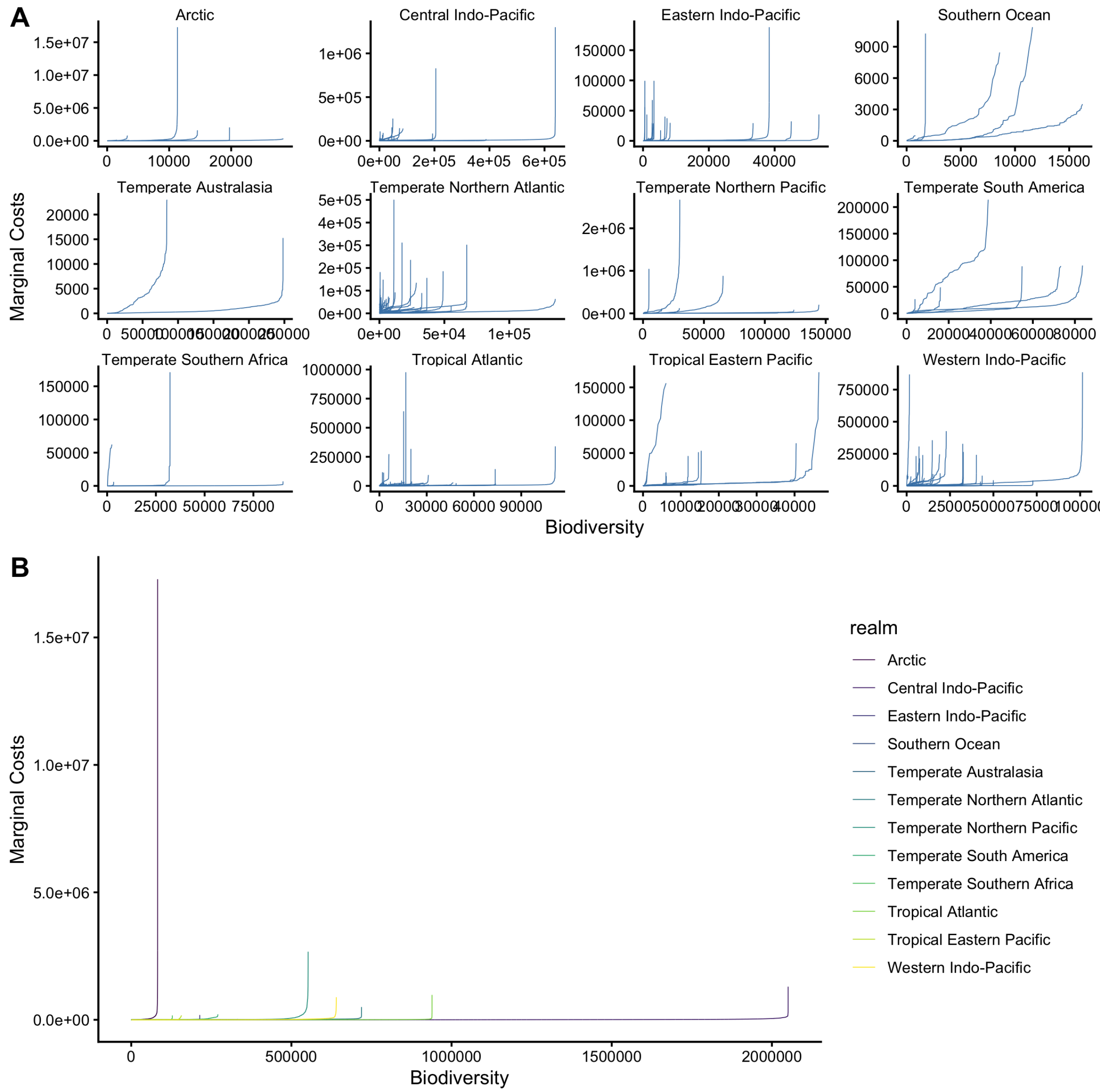


Figure 8: Biodiversity supply curves for all nations within each realm (top panels), and realm-level biodiversity supply curves (bottom). For the small panels, each line represents a country. In the large bottom panel, each line represents the horizontally-summed supply curve for each realm (color coded).

Table 4: Gains from trade from protecting 73.65 units of biodiversity. Difference shows BAU - Market, ratio shows Market / BAU.

Realm	Variable	BAU	Market	Difference	Ratio
Arctic	Area	1146.00	1648.00	-502.00	1.44
Arctic	Biodiversity	1.67	1.66	0.00	1.00
Arctic	Costs	55581.25	9978.38	45602.86	0.18
Central Indo-Pacific	Area	3241.00	2722.00	519.00	0.84
Central Indo-Pacific	Biodiversity	191.98	191.95	0.03	1.00
Central Indo-Pacific	Costs	2109138.56	1947633.78	161504.79	0.92
Eastern Indo-Pacific	Area	2258.00	1601.00	657.00	0.71
Eastern Indo-Pacific	Biodiversity	24.88	24.87	0.01	1.00
Eastern Indo-Pacific	Costs	171536.41	135951.27	35585.14	0.79
Southern Ocean	Area	257.00	317.00	-60.00	1.23
Southern Ocean	Biodiversity	3.30	3.27	0.03	0.99
Southern Ocean	Costs	740.33	311.27	429.06	0.42
Temperate Australasia	Area	540.00	546.00	-6.00	1.01
Temperate Australasia	Biodiversity	27.04	27.04	0.00	1.00
Temperate Australasia	Costs	100907.95	100882.85	25.09	1.00
Temperate Northern Atlantic	Area	1322.00	1580.00	-258.00	1.20
Temperate Northern Atlantic	Biodiversity	32.47	32.42	0.05	1.00
Temperate Northern Atlantic	Costs	1240462.79	782522.08	457940.71	0.63
Temperate Northern Pacific	Area	1124.00	1057.00	67.00	0.94
Temperate Northern Pacific	Biodiversity	50.76	50.76	0.01	1.00
Temperate Northern Pacific	Costs	1309299.95	798762.77	510537.18	0.61
Temperate South America	Area	672.00	938.00	-266.00	1.40
Temperate South America	Biodiversity	21.84	21.82	0.01	1.00
Temperate South America	Costs	281533.17	197839.23	83693.94	0.70
Temperate Southern Africa	Area	231.00	223.00	8.00	0.97
Temperate Southern Africa	Biodiversity	7.39	7.27	0.12	0.98
Temperate Southern Africa	Costs	102163.69	96264.39	5899.30	0.94
Tropical Atlantic	Area	1566.00	1981.00	-415.00	1.27
Tropical Atlantic	Biodiversity	54.17	54.16	0.00	1.00
Tropical Atlantic	Costs	560984.52	485755.18	75229.33	0.87
Tropical Eastern Pacific	Area	515.00	637.00	-122.00	1.24
Tropical Eastern Pacific	Biodiversity	9.99	9.98	0.01	1.00
Tropical Eastern Pacific	Costs	33937.37	17614.01	16323.36	0.52
Western Indo-Pacific	Area	1653.00	1512.00	141.00	0.91
Western Indo-Pacific	Biodiversity	69.28	69.21	0.07	1.00
Western Indo-Pacific	Costs	768162.06	599325.81	168836.25	0.78

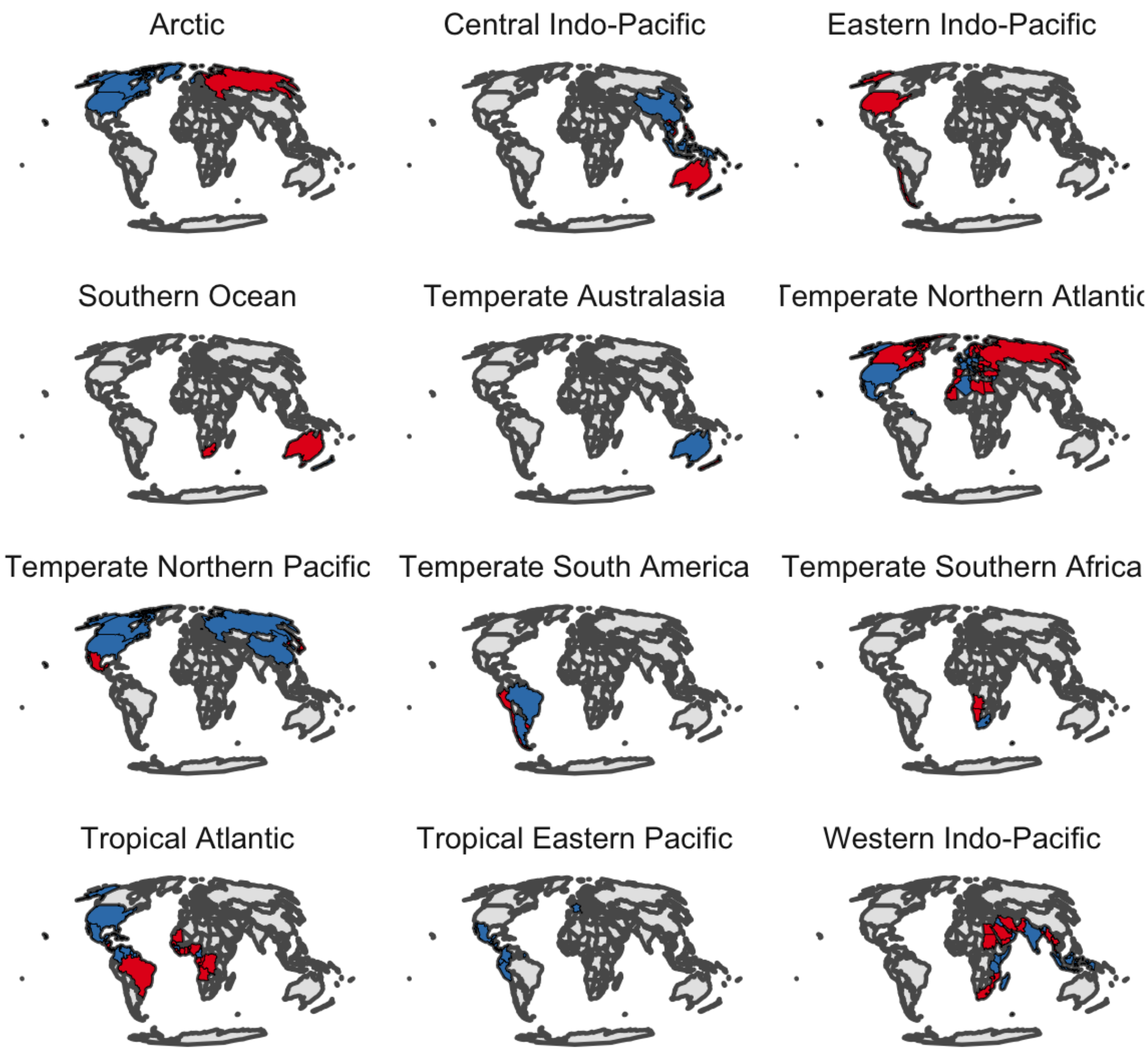
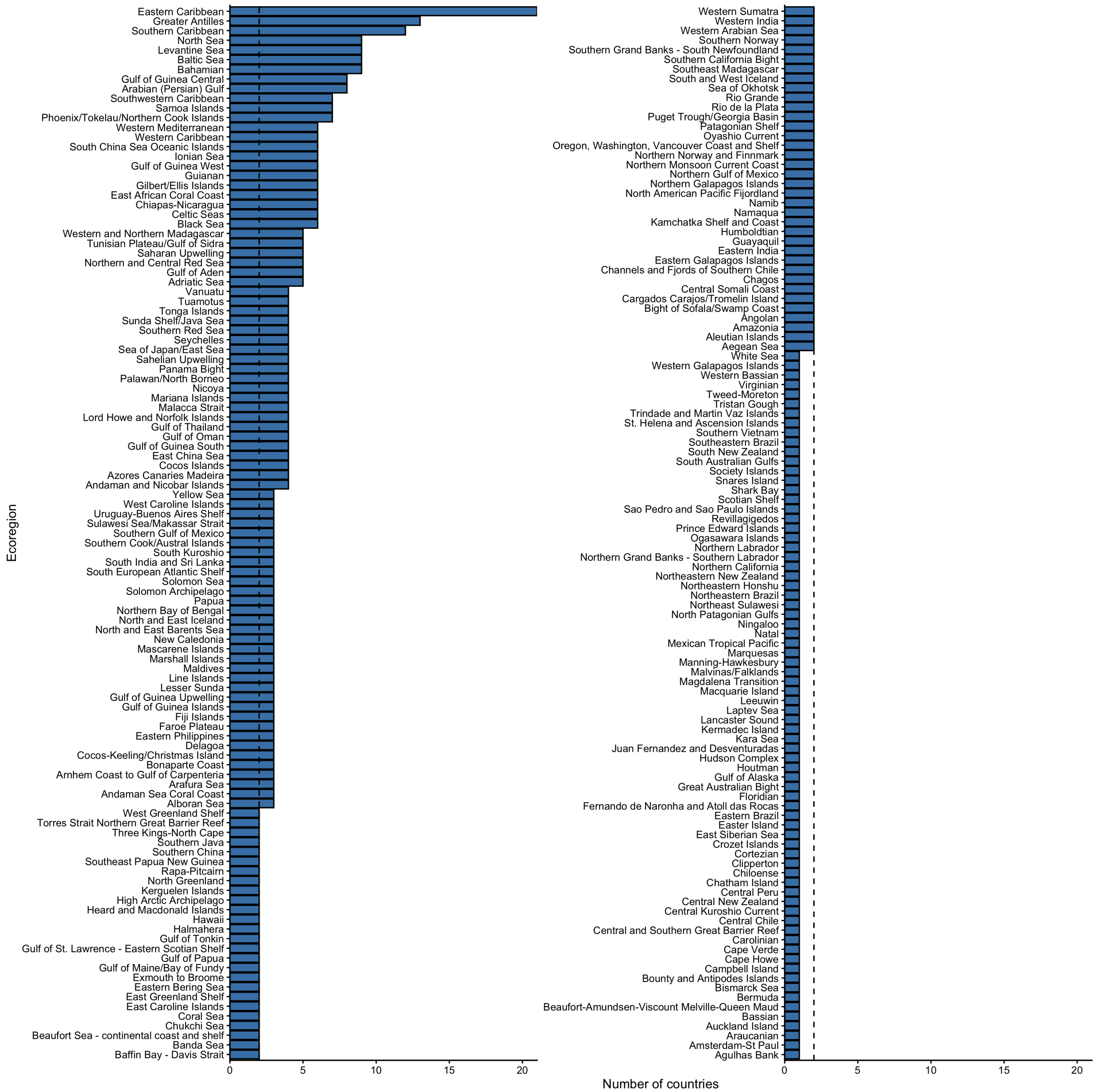


Figure 9: Map of trade for each realm. Blue indicates nations that reach the trading price before meeting their target, and therefore chose to pay to conerve elsewhere. Red nations get paid to conserve in their waters, due to the low costs relative to blue nations.

5 Other figures and tables



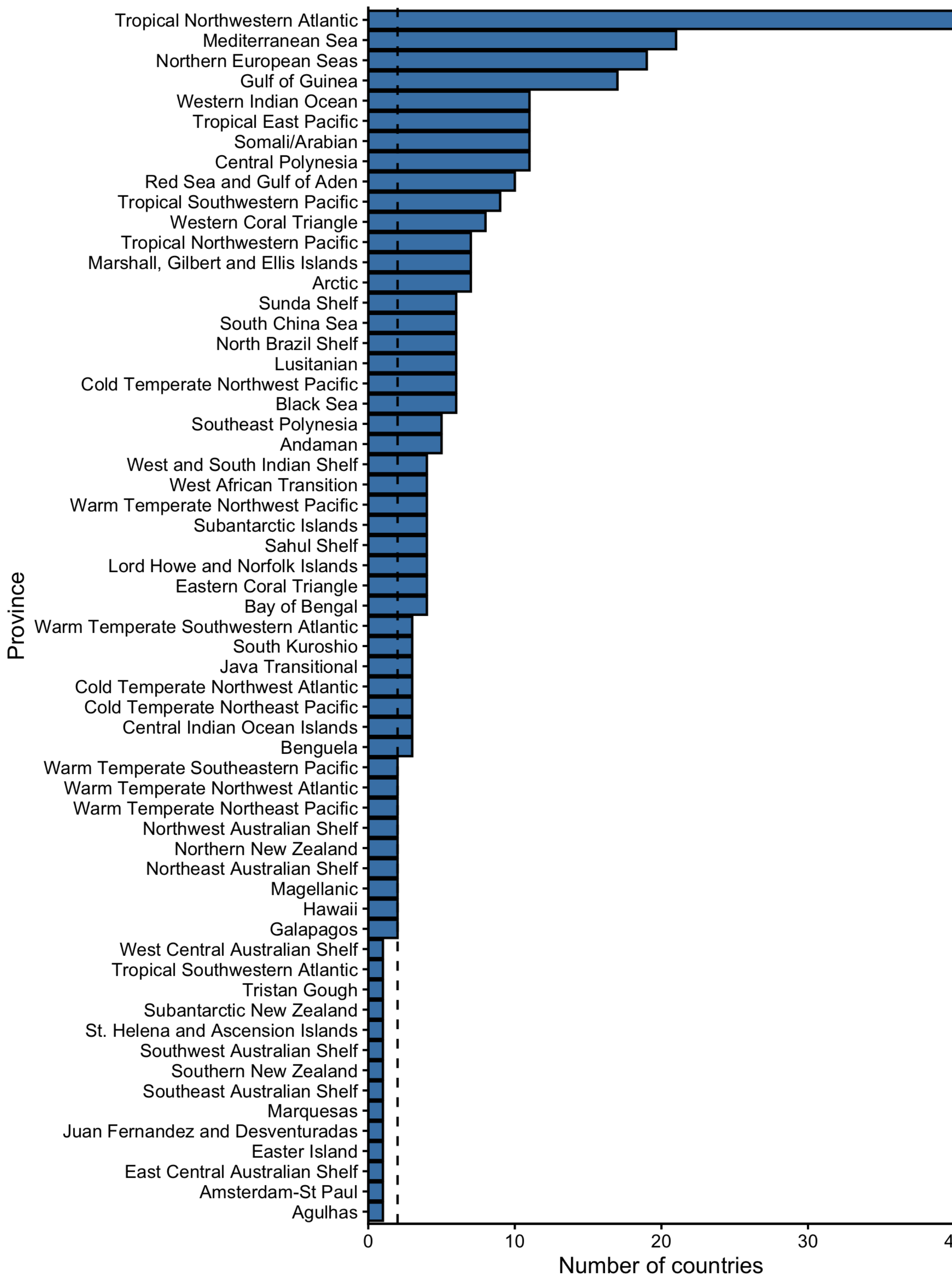


Figure 10: Number of Exclusive Economic Zones in each province

6 Supplementary Information

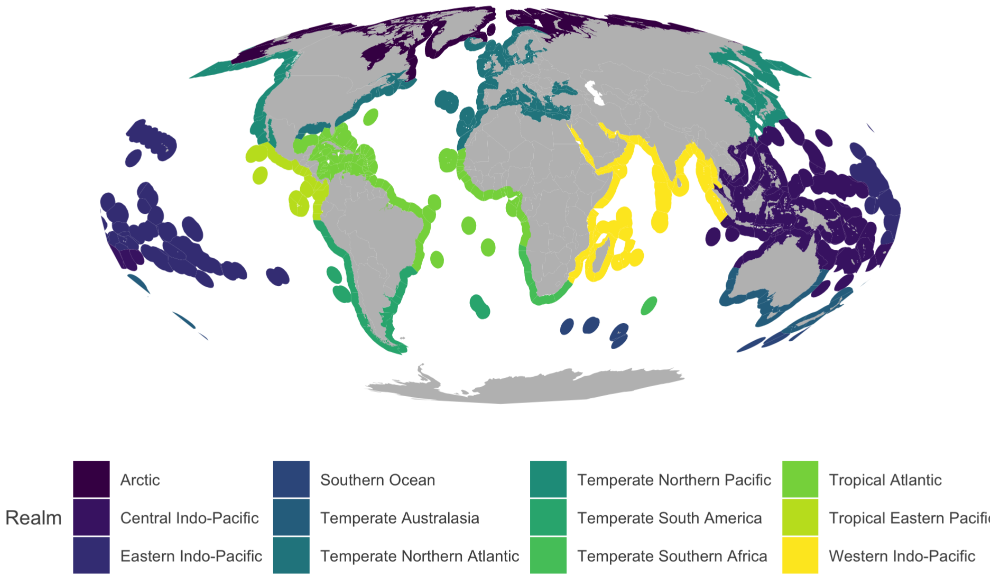


Figure 11: Map of the 12 realms, as defined by[12].

Map of provinces

6.1 Data description

We must first identify the costs and benefits of conservation. Conserving biodiversity may provide benefits to society. For example, areas with higher species richness and biomass are more attractive to tourism[14]. Species richness also leads to increased stability of ecosystems[15], and may reduce exposure to pathogens[16]. The quantification is not straightforward, but we can assume that biodiversity indices are positively correlated with their benefits they provide (although saturation may occur past a given point).

I use spatially-explicit data on biodiversity benefit for each 50 X 50 km grid in the ocean. The score was derived to account for species richness and evolutionary distinctiveness, but also presence of topographic features (*e.g.* sea mounts). Figure 12 shows a global map of these values. The value of a given pixel (termed Δv) depends on previously protected pixels. As such, the value of a randomly chosen pixel is more or less meaningless. However, the configuration represented in Figure 12 was derived to maximize biodiversity. Therefore, protecting the best n pixels and summing their values does represent the total amount of biodiversity protected. The same exercise has been done at the country-level (This is an important consideration for target calculations mentioned below. While I will use this global data for the purposes of motivating my approach, I do plan on using the appropriate data in my final work.)

On the other hand, we need to quantify the costs associated to each pixel. An often-cited

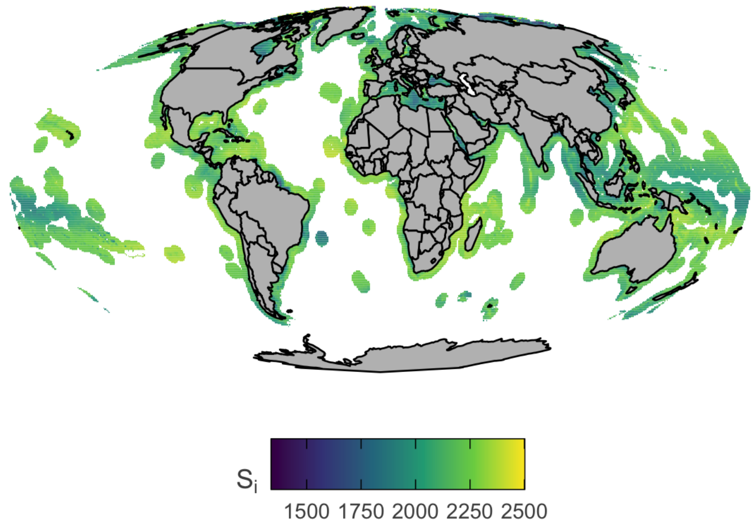


Figure 12: Global map of biodiversity ranking priorities. Higher values indicate higher priority to conserve.

cost of implementing MPAs is that of losses in fisheries revenues[17]. In this case, we define costs as losses in fisheries landings [3]. Since protection of some areas may lead to rebuilding fisheries, parts of the ocean might have negative costs. This means that there are gains to be made in conserving them. A map of global costs of conservation is shown in Figure 13. As before, these data do not consider the transient dynamics, and represent the equilibrium state of protecting any given pixel.

[3] I intend to use losses in fisheries revenues in the future. This will involve species-level changes in landings, as well as species-level price data. Essentially, the global losses in landings used here will be weighed by species price data.

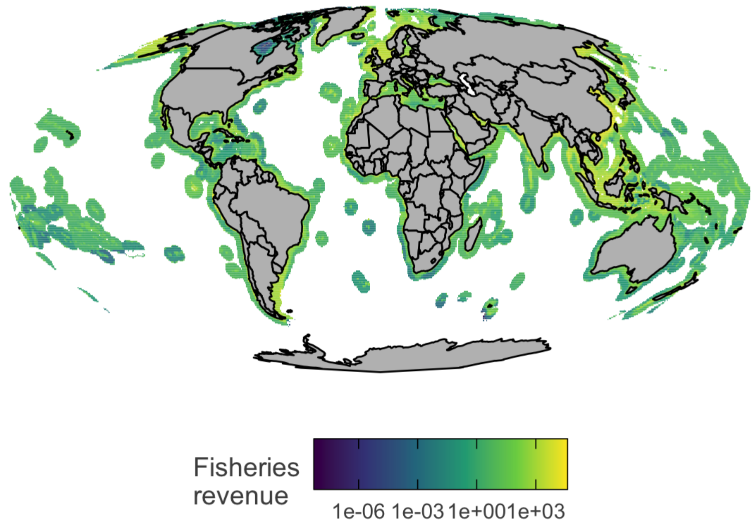


Figure 13: Global map showing the costs (losses in landings) from closing portions of the ocean. Negative values imply that there are gains to be made.

6.2 Building supply curves

Although there are important caveats, these data provide us with a way of calculating the costs and benefits of protecting any place under a nation's jurisdiction. While protecting the high seas may provide many benefits[18,19], our market-based approach requires enforceable property rights, such as those offered by Exclusive Economic Zones. Moreover, biodiversity benefit is higher within Exclusive Economic Zones, where most of the species live[9]. Therefore, we will ignore areas beyond national jurisdiction.

The next step is to identify which areas to protect. For two grid cells that provide equal biodiversity benefit, which one should be prioritized? This prioritization exercise need not be too complicated. We can assume that even if a country is seriously committed to conservation, costs must still be minimized. The most efficient thing to do is to protect the one that minimizes costs while maximizing biodiversity benefits. Therefore, we must calculate the benefit-cost ratio of each gridcell:

$$BCR_i = \frac{B_i}{C_i}$$

Where B_i corresponds to the biodiversity benefit associated with protecting cell i, and C_i corresponds to the costs of protecting cell i. We can do this calculation globally, and produce a map of BCR (Figure 14). Due to the possibility of negative costs, the BCR may be negative. We must therefore differentiate the BCR of cells with negative and positive costs, and rank them in this nested way.

For each country, we can rank the grid cells by their BCR and calculate the total biodiversity

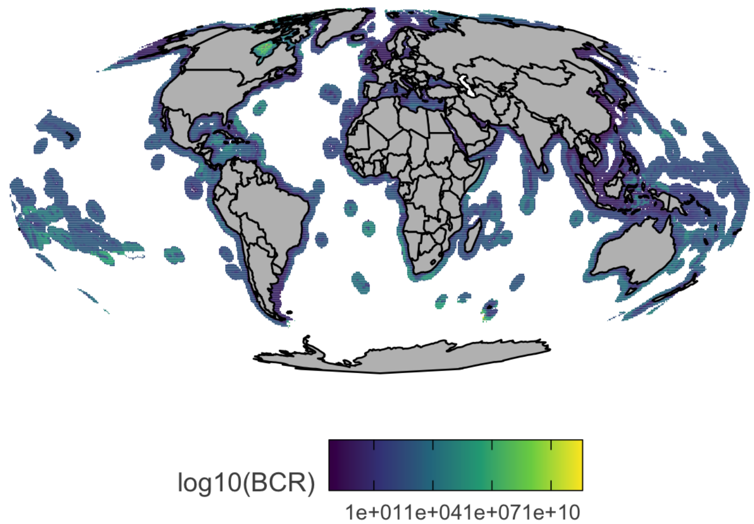


Figure 14: Map of Benefit-Cost Ratio (BCR) within nation's Exclusive Economic Zones.

benefit and total costs of achieving that benefit. But more importantly, we can calculate the marginal costs (defined as the cost of protecting an extra unit of biodiversity: tonnes of fish lost / benefit unit), and produce a supply curve of conservation for each country. Their shape suggests that the first few units of conservation can be achieved at relatively low costs, but that it becomes increasingly costly to obtain more and more biodiversity benefits. Figure 15 shows the biodiversity supply curves of each country, and the horizontally-summed global supply curve.

6.3 Finding targets and trading price

The supply curves above will tell us the per-unit-costs of achieving a given amount of biodiversity benefit. But what is this "desired" amount of biodiversity benefit? All conservation targets are area-based, and do not explicitly call for an amount of conservation such as "protect 20 species", or "protect 3 habitats". However, we know the costs and benefits of each grid cell. This allows us to anticipate how rational nations may translate their area-based requirements into conservation interventions.

Figure 1 shows five possible ways in which nations may reach an area-based target. Each panel shows the amount of biodiversity benefit produced by protecting a given percentage (x-axis) of a nation's EEZ. The only difference between panels is the strategy taken by nations, which leads to different curvatures. In the first panel, labeled as "efficient", nations conserve area in decreasing BCR values. The second panel maximizes conservation, and nations protect based on the biodiversity benefit rankings and completely ignore the costs. Similarly, the third panel seeks to maximize costs only, without accounting for how much conservation is achieved. The last two panels do the opposite, and try to minimize conservation or costs, without accounting for the other. The scenarios where costs are maximized or biodiversity

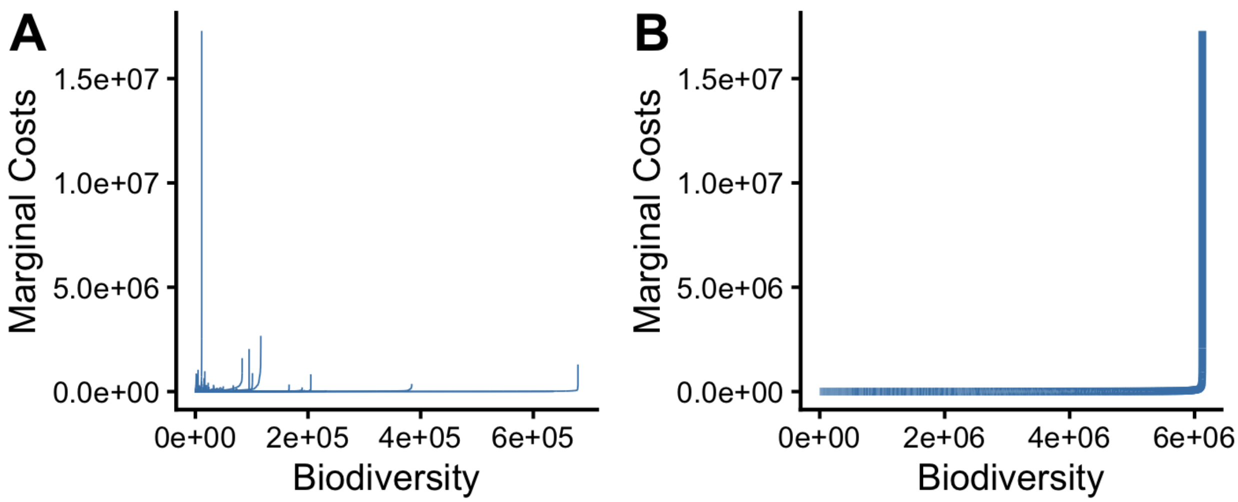


Figure 15: Supply curve for each country

benefits minimized are of course unlikely, however they provide bounds for where the true target lies. From now on, we will move forward with he efficient target of achieving 72 units of biodiversity benefit.

The most efficient way to achieve this level of conservation is by prioritizing places with a higher BCR. We can take the horizontally-summed global supply curve of biodiversity and find the corresponding costs for each of the benefit targets identified above (Figure 2). This values are also known as the trading price. A nation will continue to conserve in-situ up until the cost of an additional unit of conservation is equal to this value. Instead, it is more cost-effective to conserve elsewhere in the world where the costs are lower.

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