Supplementary Material of Marine biodiversity in a changing world: present status and future management

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Contents

1 Preface

This supplementary was was built with 3.6.2 programming language and was written using R-studio IDE (v.1.2.5033) by a R-markdown file. Data and R code scripts to replicate figures and analysis can be downloaded from **here**, as well as a R-markdown version of this supplementary.

In this supplementary, we assume some knowledge of the R programming language. If instructions in the Readme file are followed, this should be fully reproducible using R studio. Please find **the contacts informations** at the end of this supplementary to get in touch with the authors to report bugs or problems.

Beware that while all data used are open source (except for kelp which source has been removed until the dataset is published), specific permission to reuse and publish them are needed from data providers. Credit for the use of those data should also go to the proper source listed in Table SI and SII.

2 The distribution of habitats

2.1 Habitat area

We obtained the polygons of 6 habitats closely associated with the coast, and 6 more closely associated with open ocean, for a total of 12 majour habitats (Table SI). We then calculated the area for each habitat by dissolving the resulting layer by Country and projecting it into the World Cylindrical Equal Area projection, and then using the "Calculate Geometry" tool in ArcGIS v.10.5 Desktop software. Losses and gains in habitat extension that occurred the data aquisition dates were not accounted for.

Table SI: habitat data type, date of creation, and detailed references

Habitat	Date of Data	Data Type	Source
Estuaries	2003	Polygon	Alder (2003)
Mangroves	1997 - 2000	Polygon	Giri, et al. (2011)
Saltmarsh	1973 - 2015	Points	McOwen, et al. (2017)
Seagrasses	1934 - 2015	Polygon	UNEP-WCMC, Short FT (2017)
Coral Reefs	1954 - 2018	Polygon	UNEP-WCMC, WorldFish Centre, WRI, TNC (2018)
Kelp	NA	Point	Jorge Assis (submitted for publication)
Cold Corals	1915 - 2014	Point	Freiwald A (2017)
Sills	1950 - 2009	Polygon	Harris et al. (2014)
Seamounts/Guyots	1950 - 2009	Polygon	Harris et al. (2014)
Bridges	1950 - 2009	Polygon	Harris et al. (2014)
Rift Valleys	1950 - 2009	Polygon	Harris et al. (2014)
Hydrothermal Vents	1994 - 2019	Point	Beaulieu, S.E., Szafranski, K. (2019)

3 Anthropogenic impacts on marine biodiversity

(**GABRIEL**)

4 The decline of marine species and habitats

4.1 Analysis of IUCN Red List for Levels of Extinction Risk

For marine invertebrates and vertebrates, data were extracted from the IUCN online Summary Statistics (https://www.iucnredlist.org/search). The assessment was restricted to taxa with more than 10 species assessed, to reduce bias. Whilst these taxa represent a relatively small proportion of those living in marine environments, they are the best studied to date; therefore, they present a good (if taxonomically biased) dataset on which to assess extinction threat and its causes across a range of marine ecosystems (Webb & Mindel, 2015). Only around 3% of the ~ 240,000 described marine species have been assessed for the Red List (Sullivan et al., 2019).

We note that a controversy began in the 1990s regarding the use of the IUCN extinction threat categories for commercially fished species (Rice & Legacè, 2007). The main policy instruments used for fisheries management (e.g. United Nations Convention on the Law of the Sea; the UN Fish Stocks Agreement and the FAO Code of Conduct for Responsible Fishing - see below) all highlight Bmsy (Biomass at Maximum Sustainable Yield), as a target for sustainable fisheries management. Under a sustainable management regime, it is possible to reduce a stock size to below levels which would trigger categorisation of a species or stock as threatened with extinction under the IUCN Red List criterion of decline in population size, while other fisheries management reference points indicate the stock can still be exploited (Rice & Legacè, 2007). Whilst this has been a subject of debate (see Rice & Legacè, 2007), more recent studies have demonstrated that conservation metrics as assessed by Red List criteria align well with fisheries assessments of stock status (e.g. Davies & Baum, 2012; Fernandes et al., 2017). Thus, it can be concluded that threat categories identified through the Red List criteria do not exaggerate extinction or extirpation risk and occurrences of disagreement between the two approaches are rare (Davies & Baum, 2012; Fernandes et al., 2017). IUCN have specifically identified this issue in the guidelines for applying extinction risk criteria (IUCN, 2017).

4.2 Analysis of IUCN Red List for Drivers of Extinction

In this analysis the drivers of decline of threatened species (IUCN Red List categories Critically Endangered, Endangered and Vulnerable) in the 12 taxa for which extinction risk was assessed were summarized. Drivers of decline included: Residential and Commercial Development; Biological Resource Use; Pollution; Transport and Service Corridors; Invasive Species, Genes and Diseases; Climate Change and Severe Weather; Human Intrusions and Disturbance; Agriculture and Aquaculture; Energy Production and Mining; Natural System Modifications. Whilst many of the IUCN drivers of biodiversity decline are relatively straightforward to interpret, the category "Biological Resource Use" requires some explanation. This refers to the effects of targeted catch for commercial and artisanal fisheries, but also bycatch and/or bykill, as a cause of extinction risk; as well as a range of other harvesting activities including for the aquarium trade, marine curio trade, shell collecting and traditional medicine. It should be noted that for many taxa there are multiple drivers of decline and we have counted each threat for each species.

5 Habitat loss

6 Drivers of biodiversity loss in the ocean

[**EMPTY**]

7 Current conservation efforts

We calculated the protected habitat area by intersecting the dissolved MPA layer per each country EEZ for each of the habitat listed in Table SI. It needs to be clarified that being inside a MPA does not mean the habitat is protected, since the MPA objective and regulamentation might not involve the habitat at all. However, we consider that being inside an environmentally managed area should provide at least some indirect benefits to the habitat conservation.

Table SII: additional variables used in this section

Variable	Variable name	Description	Source
Exclusive Economic Zone	eez_area	Area of the EEZ for each country in squared kilometers	Sala *et al.,* 2018
Marine Protected Area	mpa	MPA extension in squared kilometers in each country. The dataset was filtered by MPAs whose status was either designated, inscribed, adopted or established, thus removing not reported and proposed categories	We obtained MPA extension from the World Database of Protected Areas (UNEP-WCMC accessed in February 2019)
Species Biodiversity	biodiversity_points	Extracted value of estimated species diversity	Reygondeau and Dunn (2018)
Gross Domestic Product per capita	gdp_total	total GDP per country (current USD)	World Bank Open data: https://data.worldbank.org/
Protected habitat area	protected	Overlap between protected area and the target habitat in squared kilometers	This paper
Marine Wilderness	wilderness	Areas identified from Jones et al. 2018 that have very little anthropogenic impact (lowest 10% from 15 stressors) and very low combined cumulative impact from these stressors.	Jones et al., 2018

Datasets are three `.csv` text files:

- `habitat_data`: which contains all the habitat extensions in squared kilometers for each country, as well as the area of each country Exclusive Economic Zone (EEZ) and total MPA area both in squared kilometers;
- `habitat_protected`: which contains how much of each habitat within each country is protected (protected);
- `pressures_gdp_biodiversity`: which contains the environmental pressures, the total GDP (Gross Domestic Product in USD) and the estimated biodiversity for each of the country;

Download an .Rmd version of this file from **here**.

7.1 Figure 4: Relationship among conservation efforts, world economy and natural biodiversity.

In Figure 4, we calculated the percentage of EEZ covered by an MPA (%MPA/EEZ) and plot it against the % of world GDP of each country. Data were transformed using the base 10 logarithm. The relationship resulted significant (Table SII). In Figure XXb, we plotted biodiversity *vs* the percentage of EEZ covered by an MPA (%MPA/EEZ). This comparison resulted not significant. The grey box represent an ideal 30% of EEZ area protected target.

```r
# Loading pressure data
pressures <- read.csv(text = getURL("https://raw.githubusercontent.com/Fabbiologia/BlueF
toplot <- pressures %>%
        select(country, eez_area,
               mpa, gdp_tot, biodiversity_points) %>%
        na.omit() %>%
        mutate(percent_GDP = (gdp_tot/max(gdp_tot))*100) %>%
        mutate(percent_MPA = (mpa/eez_area)*100)

# Panel a

pa <- ggplot(toplot, aes(x=log10(percent_GDP), y=log10(percent_MPA))) +
        geom_point(col="white", fill= "#32aeff",
                   shape=21, size=5,
                   show.legend = F, alpha=0.6)+
        geom_smooth(method='lm',formula=y~x, fill="gray70") +
        theme_light() +
        labs(x="log10(World GDP %)", y="log10(MPA/EEZ %)") +
        theme(legend.position = "",
              panel.grid = element_blank(),
              strip.background = element_blank(),
              strip.text.x = element_blank())

# Panel b

pb <- ggplot(toplot, aes(x=percent_MPA, y=biodiversity_points)) +
        geom_rect(xmin=0, xmax=30,
                  ymin=-Inf, ymax=Inf,
                  fill="gray90", col="black",
                  alpha=0.6, linetype="dotted")+
        geom_point(col="white", fill= "#F8692F",
                   shape=21, size=5,
                   show.legend = F, alpha=0.6)+
        theme_light() +
        labs(x="MPA/EEZ %", y="Species Biodiversity")+
        theme(legend.position = "",
```

```
                panel.grid = element_blank(),
                strip.background = element_blank(),
                strip.text.x = element_blank())


# this function creates a panel with all the plots created above
plot_grid(pa, pb, labels="auto", nrow = 1)
```

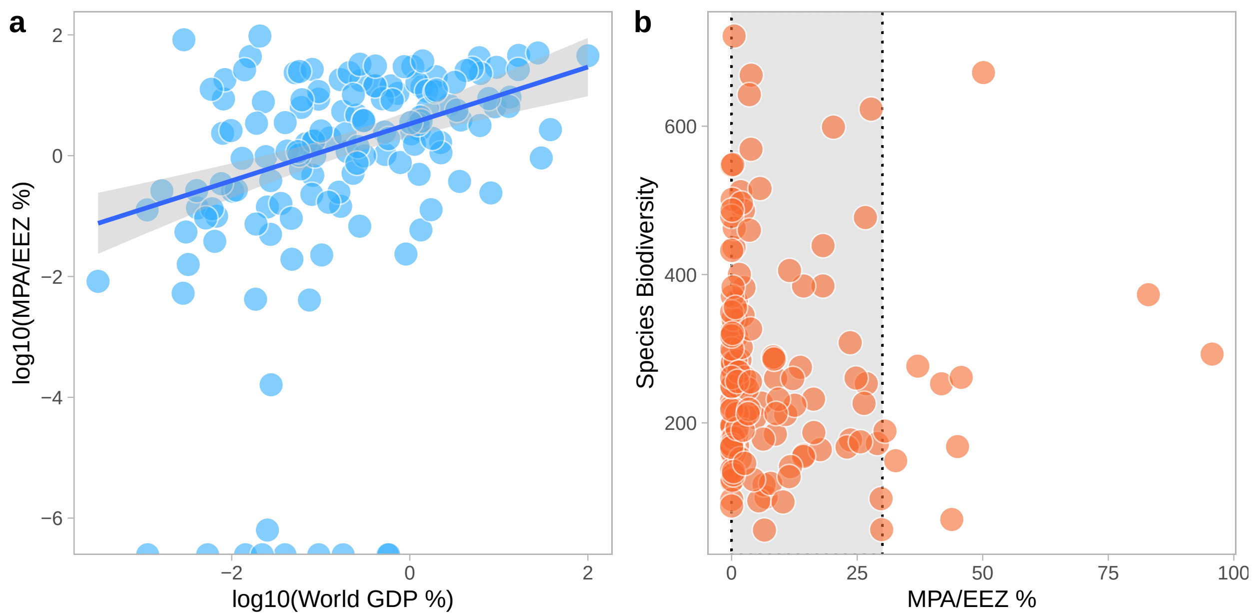

Figure 4: Relationship among conservation efforts, world economy and natural biodiversity (more detail in main text)

7.1.1 Linear models

Below we calculate and report the linear model statistics of the two scatterplots in Figure 4:

Table SIV: % MPA/EEZ vs % of World GDP regression

term	estimate	std.error	statistic	p.value
(Intercept)	9.5595649	1.6668579	5.735081	0.0000000
percent_GDP	0.3746134	0.1741082	2.151613	0.0329567

Table SV: Species Biodiversity vs % MPA/EEZ regression

term	estimate	std.error	statistic	p.value
(Intercept)	272.2317201	13.4290483	20.2718550	0.0000000
percent_MPA	0.0068833	0.7806563	0.0088173	0.9929772

7.2 Figure 5. Current conservation efforts over key selected habitats.

7.2.1 Percent protected and percent in wilderness for each habitat globally calculations

The amount of each habitat within marine protected areas or wilderness was calculated in ArcGIS Pro 2.4 using the data in table SI and SII. The marine protected area polygons were first projected into the same projection and rasterized at the same resolution (~1km) as the global wilderness data (World Behrman). Next, each habitat was converted rasterized at the same resolution, using "Point to Raster" or "Polygon to Raster" tools depending on the data type. The number of pixels for each habitat were counted. Next, the habitat pixels within either marine protected area were counted using the "Extract by Mask" tool. This was repeated for the wilderness areas. These pixel counts were then used to calculate the percent of each habitat within marine protected areas or within wilderness displayed in Table SX. Seagrasses spatial data in the United States had several geometry problems that were solved by first dicing the features with a maximum vertex of 1000 before geoprocessing this file.

Table SVI: The percent of each habitat within Marine Wilderness as defined by Jones et al. 2018 and within marine protected areas (MPAs).

Habitats	Within wilderness (%)	Within MPAs (%)
Cold Corals	5.04	28.98
Coral Reefs	1.96	40.66
Estuaries	4.27	20.88
Hydrothermal Vents	7.52	14.75
Kelp	0.90	40.01
Mangroves	0.08	34.85
Ridges	9.74	12.54
Saltmarsh	1.08	41.99
Seagrasses	0.54	25.57
Seamounts and Guyots	5.91	25.67
Shelf and Canyons	26.88	11.24
Trenches	1.60	21.02

7.2.2 *Effort gap* calculations

We created Figure 5b by filtering all the habitats with a higher than 0 cover in each country and we calculated how much habitat is protected in % in each country. Then, we calculated the mean percent protected of each habitat in all the countries, and the median percent protected of each habitat in all the countries. In the plot, black circles represent countries hosting one of the key habitat in the x-axis. The y-axis represents how the percentage of area each country is protecting of that habitat within its EEZ. Most of the countries are below the 30% target (white line), which has been identified as a threshold to ensure the maintenance of habitat's ecosystems services. The blue circles represent the mean % of all the countries protection efforts to that habitat, whereas the red circles are the median % of all the countries protection efforts.

Now with the following code we can recreate figure 5 in the main text:

```
protected_areas <- read.csv(text = getURL("https://raw.githubusercontent.com/Fabbiologia

toplot <- protected_areas %>%
        filter(habitat_area > 0) %>% # first we filter absent habitat for each country
        mutate(pp = (protected/habitat_area)*100) %>% # Then we calculate the % protect
        group_by(habitat) %>% # we group the data for each habitat
        mutate(mean_pp = mean(pp),
               median_pp = median(pp)) %>% # here we calculate the mean percent protect
        ungroup() %>% # the code section below is for graphic purposes
        mutate(habitat = factor(.$habitat,
                                labels=c("Cold Corals",
                                         "Coral Reefs",
                                         "Estuaries",
                                         "Hydrothermal vents",
                                         "Kelp",
                                         "Mangroves",
                                         "Ridges",
                                         "Saltmarshes",
                                         "Seagrasses",
                                         "Seamounts guyots",
                                         "Shelf valley canyons",
                                         "Trenches")))
toplot$habitat <-
        factor(toplot$habitat, levels = c(
                "Estuaries",
                "Mangroves",
                "Saltmarshes",
                "Seagrasses",
                "Coral Reefs",
                "Kelp",
                "Shelf valley canyons",
                "Cold Corals",
                "Seamounts guyots",
                "Trenches",
                "Hydrothermal vents",
                "Ridges"
        ))

toplot2 <- read.csv("data/wilderness_protected.csv") %>%
        clean_names() %>%
        pivot_longer(-habitat, names_to = "type", values_to = "percent")
```

```r
toplot2$habitat <-factor(toplot2$habitat,
                         levels = c("Estuaries","Mangroves",
                                    "Saltmarsh","Seagrasses",
                                    "Coral Reefs","Kelp",
                                    "Shelf and Canyons","Cold Corals",
                                    "Seamounts and Guyots","Trenches",
                                    "Hydrothermal Vents",
                                    "Ridges"))



# day/night colours
night_colour <- c("aquamarine")
day_colour <- c("darkblue")

# generate data for a one-hour sunrise gradient
sunrise_pd <- GenerateGradientData(start_hour = 0,
                                   stop_hour = 13,
                                   start_colour = night_colour,
                                   stop_colour = day_colour,
                                   x_resolution = 1000)




pa <- ggplot(toplot, aes(x = habitat, y = pp, col=as.integer(habitat), group=habitat)) +
        geom_rect(xmin=0, xmax=13, ymin=-Inf, ymax=Inf, fill=day_colour)+
        # gradient backgrounds for sunrise and sunset
        geom_rect(data = sunrise_pd,
                  mapping = aes(xmax = xmax,
                                xmin = xmin,
                                ymax = ymax,
                                ymin = ymin),
                  fill = sunrise_pd$grad_colours,
                  inherit.aes = FALSE) +
        geom_jitter(size = 2, alpha = 0.5, width = 0.2, col="black", fill="white")+
        geom_hline(yintercept = 30, col="white", size=0.9)+
        geom_segment(aes(x = habitat, xend = habitat,
                         y = median_pp, yend = mean_pp), size = 0.1, col="white")+
        geom_point(aes(y= mean_pp), size = 3, pch=21, fill="blue") +
        geom_point(aes(y= median_pp), size = 3, pch=21, fill="red") +
        labs(x = NULL, y = "Area %") +
        ylim(0,100)+
        theme(legend.position = "none",
              panel.background = element_blank(),
              panel.grid = element_blank(),
```

```
             axis.text.x = element_text(angle=90))




pb <- ggplot(toplot2, aes(x=habitat, y=percent))+
        geom_rect(xmin=0, xmax=13, ymin=-Inf, ymax=Inf, fill=day_colour)+
        # gradient backgrounds for sunrise and sunset
        geom_rect(data = sunrise_pd,
                  mapping = aes(xmax = xmax,
                                xmin = xmin,
                                ymax = ymax,
                                ymin = ymin),
                  fill = sunrise_pd$grad_colours,
                  inherit.aes = FALSE) +
        geom_col(aes(fill=type), position = "dodge", col="black" , alpha=0.3)+
        scale_fill_manual(values=c("white", "gray10"), labels = c("Protected (MPA)", "%
        labs(x="", y="Area %")+
        theme(legend.position = "top",
              legend.title = element_blank(),
              panel.grid = element_blank(),
              strip.background = element_blank(),
              axis.text.x = element_blank(),
              strip.text.x = element_blank())


plot_grid(pb, pa, labels = "auto", ncol=1, align = "v")
```

Figure 5. Current conservation efforts over key selected habitats.

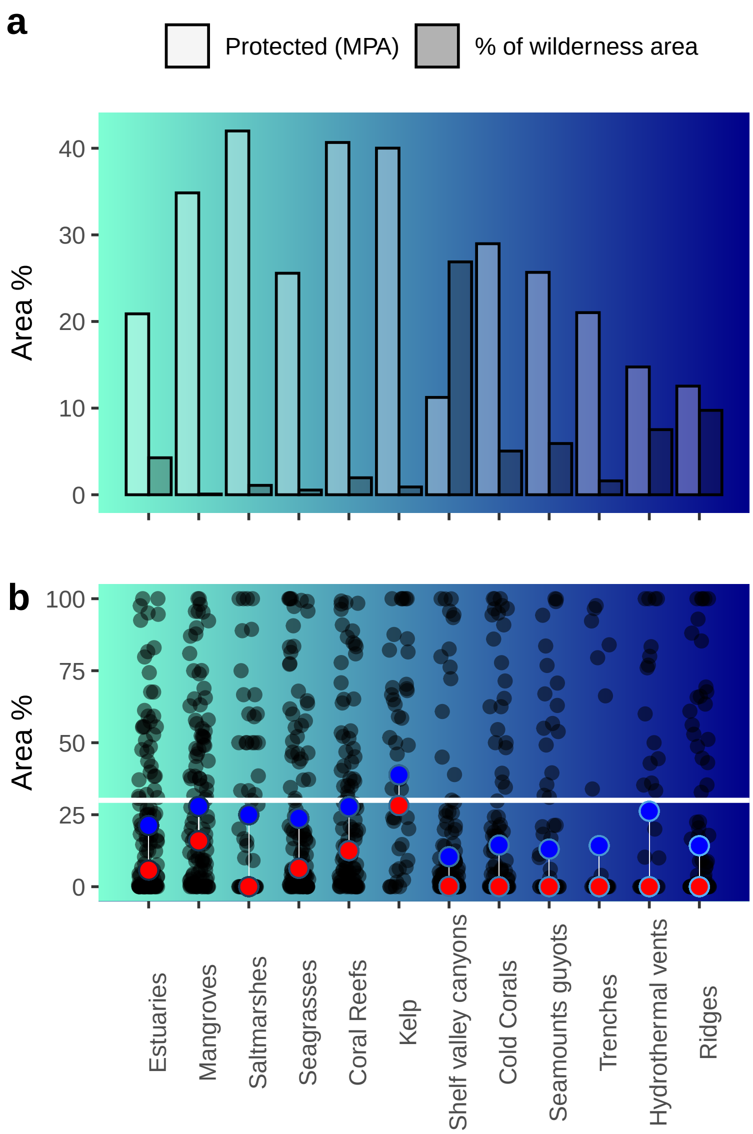

Figure 1: Figure 5. Current conservation efforts over key selected habitats.

8 The future of marine biodiversity

In this paragraph, we have been using a compiled information about conventions and agreements related to marine regulations. The table used is available here.

The datatable has 1-0 values to whether a particular convention (rows of the data) apply to a conservation topic (columns of the data). We calculated an euclidean distance followed by a Ward hierarchical clusterization technique to explore the similarities in the conventions or agreements topics.

We used the code below to compute the cluster and create Figure 6.

```
# Reading the International convention and angreements dataset (ida)
ica <- read.csv(text = getURL("https://raw.githubusercontent.com/Fabbiologia/BluePaper-1
        clean_names()


# Changing row names
rownames(ica) <- ica$convention_agreement

# Calculating distance matrix
res.dist <- dist(ica[4:ncol(ica)], method = "euclidean")

# Cluster calculation
res.hc <- hclust(d = res.dist, method = "ward.D2")

# Cutting the cluster tree
grp <- cutree(res.hc, k = 3)

# Cluster visualization
pa <- fviz_dend(res.hc, k = 3, # Cut in four groups
          palette = c("#c50000", "#408d78", "#007cba"),
          type = "phylogenic", repel = T,
          phylo_layout = "layout.gem", cex = .7,
          rect=TRUE)

# Converting the database in a long version for the plot of panel b and c
ica2 <- ica %>%
        pivot_longer(-c(long_name, convention_agreement, year),names_to="class", values_

# Panel b

pb <- ica2 %>%
        select(class, convention_agreement, year, value) %>%
        filter(value>0) %>%
        mutate(class = toTitleCase(gsub("\\_", " ", .$class))) %>%
        arrange(class) %>%
```

```r
        group_by(class) %>%
        count(value) %>%
        arrange(-n) %>%
        ggplot(aes(x=reorder(class, n), y=n, fill=class))+
        geom_col(col="black", alpha=0.5)+
        labs(x="", y="N° of conventions / agreements")+
        scale_fill_manual(values =  PAL)+
        coord_flip()+
        theme_hc()+
        theme(legend.position = "")

# Panel c

pc <- ica2 %>%
        select(class, convention_agreement, year, value) %>%
        filter(value>0) %>%
        arrange(class) %>%
        group_by(class, year) %>%
        count(value) %>%
        group_by(class) %>%
        mutate(cumsum=cumsum(n)) %>%
        ggplot(aes(x=year, y=cumsum, col=class))+
        geom_line(size=1)+
        labs(x="", y="N°")+
        scale_color_manual(values =  PAL)+
        theme_hc()+
        theme(legend.position = "")


# Plotting the grid

cowplot::plot_grid(pa, pb, pc,  labels = "auto", nrow = 3)
```

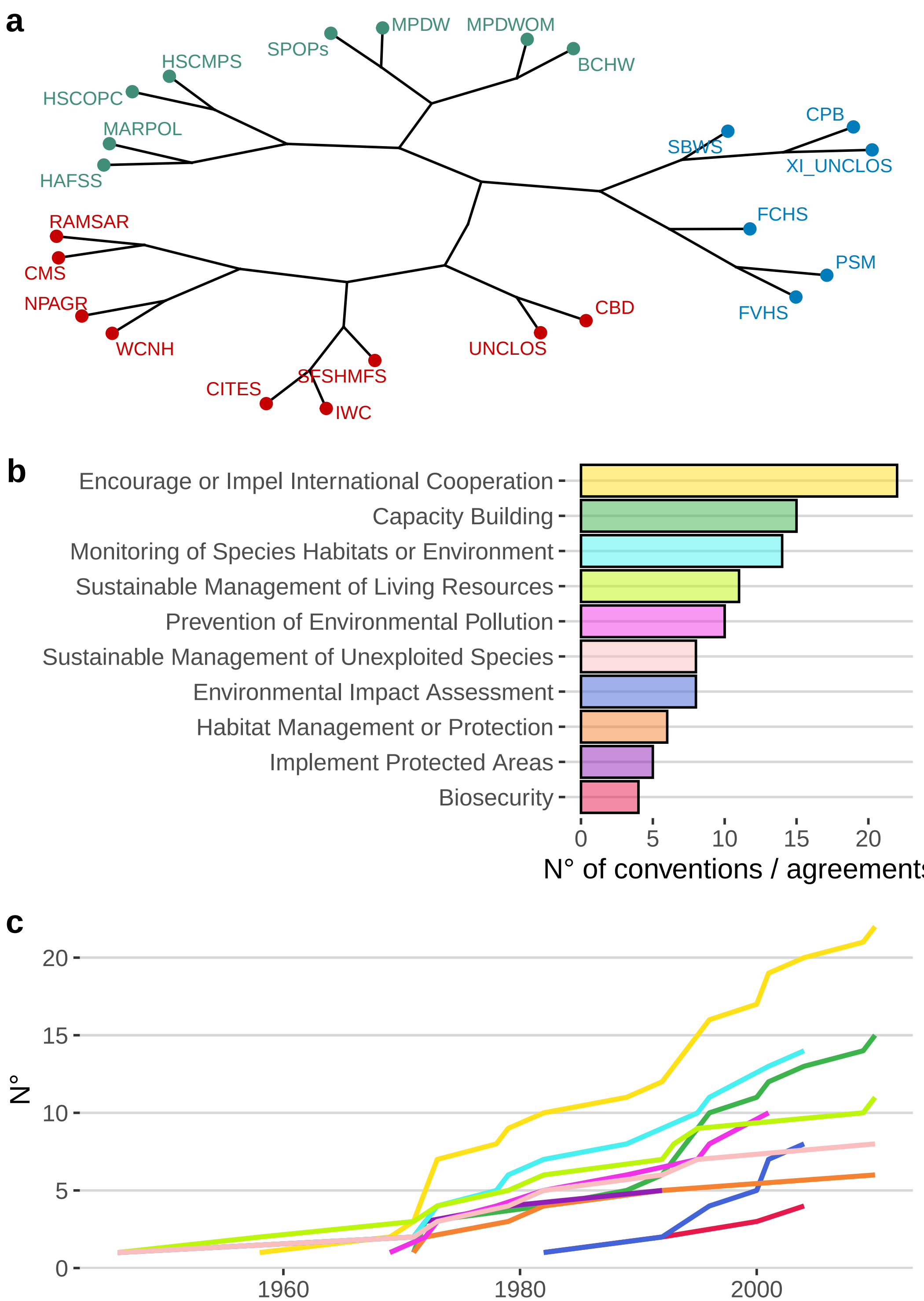

Figure 6: international conservation / agreements (more details in text).

9 Data references

- **Biodiversity data reference**: Reygondeau, Gabriel, and Daniel Dunn. "Pelagic Biogeography ." (2018).
- **Cold corals**: Freiwald A, Rogers A, Hall-Spencer J, Guinotte JM, Davies AJ, Yesson C, Martin CS, Weatherdon LV (2017). Global distribution of cold-water corals (version 5.0). Fifth update to the dataset in Freiwald et al. (2004) by UNEP-WCMC, in collaboration with Andre Freiwald and John Guinotte. Cambridge (UK): UN Environment World Conservation Monitoring Centre. URL: http://data.unep-wcmc.org/datasets/3
- **Coral Reefs**: UNEP-WCMC, WorldFish Centre, WRI, TNC (2018). Global distribution of warm-water coral reefs, compiled from multiple sources including the Millennium Coral Reef Mapping Project. Version 4.0. Includes contributions from IMaRS-USF and IRD (2005), IMaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UN Environment World Conservation Monitoring Centre. URL: http://data.unep-wcmc.org/datasets/1
- **EEZ data reference**: Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L. D., Pauly, D., [...] Zeller, D. (2018). The economics of fishing the high seas. Science Advances, 4(6), eaat2504. https://doi.org/10.1126/sciadv.aat2504
- **Estuaries**: Alder J (2003). Putting the coast in the "Sea Around Us". The Sea Around Us Newsletter 15: 1-2. URL: http://seaaroundus.org/newsletter/Issue15.pdf; http://data.unep-wcmc.org/datasets/23 (version 2.0)
- **Kelp**: Jorge Assis (submitted for publication)
- **Mangroves**: Giri, C., E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek, and N. Duke. (2011). "Status and Distribution of Mangrove Forests of the World Using Earth Observation Satellite Data: Status and Distributions of Global Mangroves." Global Ecology and Biogeography 20 (1): 154–59. https://doi.org/10.1111/j.1466-8238.2010.00584.x.
- **Saltmarsh**: Mcowen C, Weatherdon LV, Bochove J, Sullivan E, Blyth S, Zockler C, Stanwell-Smith D, Kingston N, Martin CS, Spalding M, Fletcher S (2017). A global map of saltmarshes. Biodiversity Data Journal 5: e11764. Paper DOI: https://doi.org/10.3897/BDJ.5.e11764; Data URL: http://data.unep-wcmc.org/datasets/43 (v.6)
- **Seagrasses**: UNEP-WCMC, Short FT (2018). Global distribution of seagrasses (version 6.0). Sixth update to the data layer used in Green and Short (2003). Cambridge (UK): UN Environment World Conservation Monitoring Centre. URL: http://data.unep-wcmc.org/datasets/7
- **Sills-Rift Valleys**: Harris, P. T., Macmillan-Lawler, M., Rupp, J., & Baker, E. K. (2014). Geomorphology of the oceans. Marine Geology, 352, 4–24. https://doi.org/10.1016/j.margeo.2014.01.011 Hydrothermal vents: Beaulieu, S.E., Szafranski, K.

(2018) InterRidge Global Database of Active Submarine Hydrothermal Vent Fields, Version 3.4. World Wide Web electronic publication available from http://vents-data.interridge.org Accessed 2019-02-20.

- **Wilderness** Jones, K. R., Klein, C. J., Halpern, B. S., Venter, O., Grantham, H., Kuempel, C. D., … & Watson, J. E. (2018). The location and protection status of Earth's diminishing marine wilderness. Current Biology, 28(15), 2506-2512.

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