

# Supplementary Information

## Assessing countries' social-ecological resilience to shifting marine commercial species

Elena Ojea<sup>\*,1</sup>, Elena Fontán<sup>1</sup>, Isabel Fuentes-Santos<sup>2</sup> and Juan Bueno-Pardo<sup>1</sup>

<sup>1</sup> Future Oceans Lab, CIM-Universidade de Vigo (Spain)

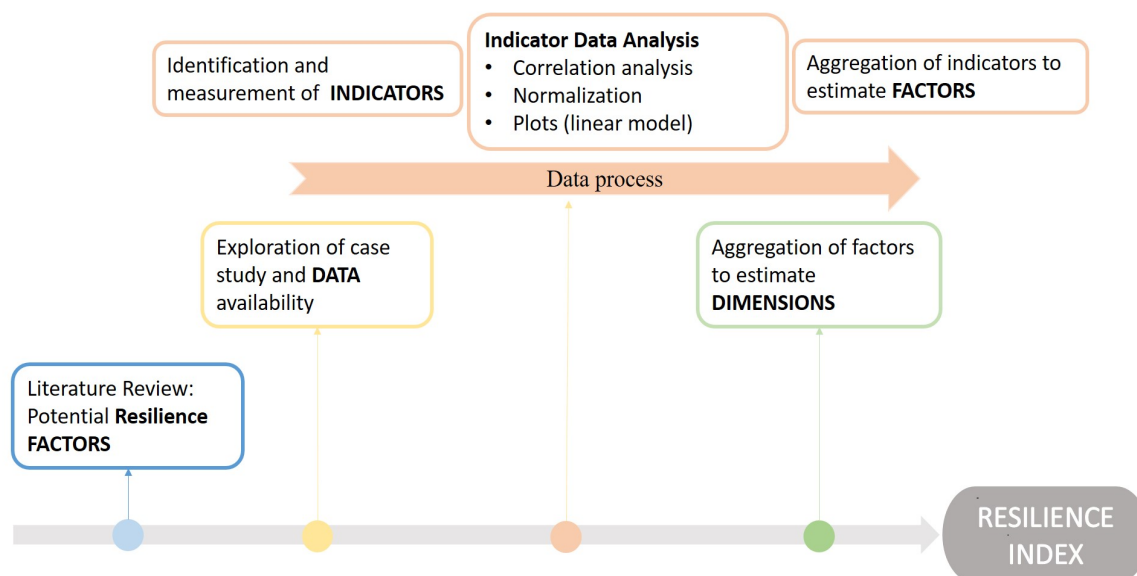
<sup>2</sup> Instituto Español de Oceanografía-Vigo (Vigo, Spain)

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## 1 Approach

Figure SI.1 shows the steps of the methodology that are followed to build the Fisheries Resilience Index. We review the literature to identify potential resilience factors and we classify these into the three dimensions of the index: ecological, socioeconomic, and institutional. Then, we explore the data available for measuring these factors per stock, per species and per country. We identify several indicators to quantitatively measure the potential resilience factors. The work with the indicators starts with data analysis to measure the indicators, by means of plots and linear models. Then we perform a correlation analysis to exclude duplicated information from our indicators (section 1.2), we normalize the indicators, and we aggregate the indicators into factors. Finally, factors are aggregated into dimensions and are averaged in the final Fisheries Resilience Index. What follows is a more detailed explanation on each step of the methodology. A detailed description of the data used and results from the construction of the indicators is available in the section 3: “Calculation of index values”.



**Figure SI.1.** Steps in the methodological approach and data process for the construction of the fisheries resilience index.

### 1.1 Potential resilience factors

A literature review was conducted to identify specific settings and conditions on a fishery that enhances resilience. We refer to these settings and conditions as “resilience factors”. Previous work has identified a set of resilience factors for fisheries and discuss the role of fisheries regulatory regimes in promoting or not these factors [1]. This effort has been expanded by looking at a broader set of resilience factors from the literature [2, 3, 4, 5], and classifying these factors into three resilience dimensions: ecological, socioeconomic, and institutional. Table SI.1 summarizes the collected evidence together with the description of each indicator (see Table 2 of the main text for a correspondence between the factors and indicators used), the sources in the literature for the statement, and an explanation of why the indicator may increase resilience.

**Table SI.1. Methods, measurement, units, and sources for the indicators selected.**

|               | INDICATORS                                | METHODS                                                                                                                                                  | MEASURE                                                                                  | UNITS             | SOURCE                                                                                                                                                                                                                   |
|---------------|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ECOLOGICAL    | Area2006<br>Area2100                      | Relative change of the species potential distribution area in 2100 relative to 2006 (Area2100-Area2006)/Area2006                                         | Global projections for 2006 and 2100 based on climate envelop models and scenario RCP8.5 | proportion        | García-Molinos et al., 2016                                                                                                                                                                                              |
|               | SSB (Spawning Stock Biomass) historic     | Coefficient of the linear model for the historic trend of SSB (1950-2018, varies per stock assessment)                                                   | Slope for the linear regression of SSB divided by average SSB of stock                   | dimensionless     | RAM Legacy Stock Assessment Database. (2020). RAM Legacy Stock Assessment Database v4.491 (Version v4.491) [Data set]. Zenodo. <a href="http://doi.org/10.5281/zenodo.3676088">http://doi.org/10.5281/zenodo.3676088</a> |
|               | SSB (Spawning Stock Biomass) 1980-present | Coefficient of the linear model for the SSB in the last 38 years (1980-2018, varies per stock assessment)                                                | Slope for the linear regression of SSB (1980-2018), divided by average SSB of stock      | dimensionless     |                                                                                                                                                                                                                          |
|               | Ftrend (mortality per fishing) *          | Coefficient of the linear model of F for the historic trend (1950-2018, varies per stock assessment)                                                     | Slope for the linear regression of catches (1950-2018), divided by average F of stock    | dimensionless     |                                                                                                                                                                                                                          |
|               | Rtrend (recruitment)                      | Coefficient of the linear model of R for the historic trend (1950-2018, varies per stock assessment)                                                     | Slope for the linear regression of catches (1950-2018), divided by average R of stock    | dimensionless     |                                                                                                                                                                                                                          |
|               | Trange                                    | Preferred temperature range for the species at the 25 and 75 percentiles                                                                                 | T <sup>a</sup> (q75)- T <sup>a</sup> (q25)                                               | °C                | Cheung et al., 2013                                                                                                                                                                                                      |
|               | T50                                       | Medium preferred temperature of occurrence for species (50 percentile)                                                                                   | T <sup>a</sup> (q50)                                                                     | °C                |                                                                                                                                                                                                                          |
|               | OverMSY*                                  | Relation of B/Bmsy and F/Fmsy from RAM Legacy, last 10 years of stock data                                                                               | (B/Bmsy)/(F/Fmsy)                                                                        | proportion        | RAM Legacy Stock Assessment Database. (2020). RAM Legacy Stock Assessment Database v4.491 (Version v4.491) [Data set]. Zenodo. <a href="http://doi.org/10.5281/zenodo.3676088">http://doi.org/10.5281/zenodo.3676088</a> |
|               | Status                                    | Most recent position in Kobe plot using SSB/SSBlimit and F/Flimit from RAM legacy data on stock                                                          | 0: upper left, 1: upper right, 2: down left, 3:down right (sustainable)                  | dimensionless     |                                                                                                                                                                                                                          |
|               | Recovery*                                 | The number of years the stock needs to go from SSBlimit to 1.5*SSBlimit                                                                                  | Year (stock > 1.5*SSBlimit) - Year(stock < SSBlimit)                                     | years             | Neubauer et al. 2013                                                                                                                                                                                                     |
|               | INDICATOR                                 | METHODS                                                                                                                                                  | MEASURE                                                                                  | UNITS             | SOURCE                                                                                                                                                                                                                   |
| SOCIOECONOMIC | SPgear                                    | Number of different gears used to fish the species per country (1950-2018)                                                                               | Number of gears used per species and by country                                          | number            | Sea around Us Pauly D., Zeller D., Palomares M.L.D. (Editors), 2020. Sea Around Us Concepts, Design and Data (searoundus.org).                                                                                           |
|               | ICESAreas5                                | Number of ICES areas where a country fishes a stock across a 5 year period                                                                               | Average number of ICES areas per country, from 2006 to 2010                              | number            | Historical Nominal Catches 1950-2010 in the Major Fishing Area 27                                                                                                                                                        |
|               | ICESAreasEU                               | The change in the number of areas a country has quota over a stock before and after the EU fisheries policy                                              | Average ICES areas before 1993 - Average ICES areas after 1993 per country               | number            | Historical Nominal Catches 1950-2010 in the Major Fishing Area 27                                                                                                                                                        |
|               | Stock dependency per species*             | Proportion of the annual catches of a species coming from a specific stock relative to all species catch in the country. Averaged across 5 years         | Catch stock/Catch species per country in the period 2006-2010                            | proportion        | Historical Nominal Catches 1950-2010 in the Major Fishing Area 27<br>RAM legacy (Ricard et al., 2012)                                                                                                                    |
|               | Stock dependency total*                   | Proportion of the annual catches of a species coming from a specific stock relative to total country catches. Averaged across 5 years                    | Catch stock/Catch totals per country in the period 2006-2010                             | proportion        |                                                                                                                                                                                                                          |
|               | Catch trends                              | Historic trend of catches per specie and country. The linear model slope is normalized by the average of the total catches of the period of each specie. | Slope for the linear regression of catches (1950-2010)                                   | million tonnes/yr | Historical Nominal Catches 1950-2010 in the Major Fishing Area 27                                                                                                                                                        |
|               | Research                                  | Data from <i>SeaAroundUs</i> webpage. They include investment in research and management (“good subsidies”)                                              | Subsides per country                                                                     | million euro      | Sumaila UR, Khan A, Dyck A, Watson R, Munro R, Tydemers P and Pauly D (2010) A bottom-up re-estimation of global fisheries                                                                                               |
|               | Management                                |                                                                                                                                                          |                                                                                          |                   |                                                                                                                                                                                                                          |

|                      |                  |                                                                        |                                                                                                                                                                                               |                         |                                                                                                                                                                                                                |
|----------------------|------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      |                  |                                                                        |                                                                                                                                                                                               |                         | subsidies. Journal of Bioeconomics 12: 201-225.                                                                                                                                                                |
|                      | <b>INDICATOR</b> | <b>METHODS</b>                                                         | <b>MEASURE</b>                                                                                                                                                                                | <b>UNITS</b>            | <b>SOURCE</b>                                                                                                                                                                                                  |
| <b>INSTITUTIONAL</b> | N.organizations  | Number of Producer Organizations per country in 2017                   | Producer organizations per country 2017                                                                                                                                                       | Number of organizations | Producer organizations in fisheries as listed by the EU CFP ( <a href="#">List of recognised producer organisations and associations of producer organisations</a> )                                           |
|                      | Swaps            | Total value of quota swaps per country 2000-2006                       | Money earned by country from quota exchanges from 2000 to 2006, as obtained from Andersen et al., 2009 Table 8. Net quota exchanges at member state level measured in value. Total 2000-2006. | million euro            | Andersen et al., 2009 (Andersen, J. L., Nielsen, M., & Lindebo, E. (2009). Economic gains of liberalising access to fishing quotas within the European Union. <i>Marine Policy</i> , 33(3), 497-503.)          |
|                      | AboveTAC*        | Catches of a stock over the established Total Allowable catches (2015) | (TAC – ICES advice)                                                                                                                                                                           | tones                   | Carpenter et. al. (2016) SSMM (Carpenter, G., Kleinjans, R., Villasante, S., & O'Leary, B. C. (2016). Landing the blame: The influence of EU Member States on quota setting. <i>Marine Policy</i> , 64, 9-15.) |
|                      | Compliance*      | IUU Fishing Index (2018)                                               | Level of compliance with fishing regulations and effort against Illegal Unreported unregulated Fishing.                                                                                       | dimensionless           | Macfadyen, G., Hosch, G., Kaysser, N. and Tagzira, L., 2019. The IUU Fishing Index, 2019. Poseidon Aquatic Resource Management Limited and the Global Initiative Against Transnational Organized Crime.        |

\*Negative relation to resilience

## 1.2. Resilience factors measurement

In order to operationalize the framework, we consider hake and cod stocks in European Atlantic waters under the Total Allowable Catches (TAC) system. We only include European Union countries with at least one year catch records of at least one of the stocks in the period of 1950 – 2015 (Historical Nominal Catches 1950-2010 <https://www.ices.dk/data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx>). These countries are Belgium, Denmark, Germany, Estonia, Ireland, Spain, France, Latvia, Lithuania, Netherlands, Poland, Portugal, Finland, and Sweden. We exclude those countries called “third part”, that are outside of the EU, named Norway, Iceland, or UK. The stocks of the two species are identified and information was obtained from the RAM legacy database [6]. Table SI.2 shows the list of stocks used for the analysis. For each factor, the selection of indicators and how to measure them is based on previous studies employing indices for fisheries management [7], vulnerability assessments [8] and fisheries socio-ecological systems [9]. We also rely on previous resilience approaches that looked at one specific component such as recovery time [4] or economic resilience [3]. Once the list of potential indicators and the methodology is defined, we collect the data from existing databases and reports, mainly at the European level. Ecological data was mainly obtained from the RAM Legacy database [6], the ICES Historical Nominal Catches (<http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx>) was downloaded for the last time on November 2020, and other databases and references were available in the Eurostat portal [12] and in Fishbase [13]. Social and institutional data was obtained from Sea Around Us [14], Eurostat (<https://ec.europa.eu/eurostat/data/database>), the United Nations Development Program (UNDP, <https://www.undp.org/>) and the Food and Agriculture Organization of the United Nations (FAO, <http://www.fao.org/home/en/>), among others (see Table SI.1 for data sources). These indicators could be further developed upon data availability in the specific stock, species, or country in future applications.

**Table SI.2. List of Stocks used to operationalize resilience (RAM Legacy database)**

| <b>Assessment ID</b>                           | <b>Assessor ID</b> | <b>Stock ID</b>   | <b>Stock area</b>                                         | <b>Recorder</b> |
|------------------------------------------------|--------------------|-------------------|-----------------------------------------------------------|-----------------|
| AFWG-CODNEAR-1943-2018-ICESIMP2018             | AFWG               | CODNEAR           | Atlantic cod North-East Arctic                            | ICESIMP2018     |
| AFWG-CODNEARNCW-1984-2017-ICESIMP2018          | AFWG               | CODNEARNCW        | Atlantic cod North-East Arctic (Norwegian coastal waters) | ICESIMP2018     |
| NWWG-CODFAPL-1958-2018-ICESIMP2018             | NWWG               | CODFAPL           | Atlantic cod Faroe Plateau                                | ICESIMP2018     |
| NWWG-CODICE-1952-2018-ICESIMP2018              | NWWG               | CODICE            | Atlantic cod Iceland Grounds                              | ICESIMP2018     |
| WGBFAS-CODBA2532-1965-2017-ICESIMP2018         | WGBFAS             | CODBA2532         | Atlantic cod Eastern Baltic                               | ICESIMP2018     |
| WGBFAS-CODKAT-1996-2018-ICESIMP2018            | WGBFAS             | CODKAT            | Atlantic cod Kattegat                                     | ICESIMP2018     |
| WGCSE-CODIS-1968-2017-ICESIMP2018              | WGCSE              | CODIS             | Atlantic cod Irish Sea                                    | ICESIMP2018     |
| WGCSE-CODVIa-1980-2017-ICESIMP2018             | WGCSE              | CODVIa            | Atlantic cod West of Scotland                             | ICESIMP2018     |
| WGNSSK-CODIIIaW-IV-VIIId-1962-2018-ICESIMP2018 | WGNSSK             | CODIIIaW-IV-VIIId | Atlantic cod ICES 3a(west)-4-7d                           | ICESIMP2018     |
| WGBIE-HAKENRTN-1978-2018-ICESIMP2018           | WGBIE              | HAKENRTN          | Hake ICES 3a-4-6-7-8abd                                   | ICESIMP2018     |
| WGBIE-HAKESOTH-1982-2018-ICESIMP2018           | WGBIE              | HAKESOTH          | Hake ICES 8c-9a                                           | ICESIMP2018     |

### 1.3 Data analysis

The R Statistical software [21] was used to analyze data and produce the figures of the manuscript, including the maps and graphics. We also perform random forest [12] over the final index values to explore what factors have greater impact on the index values and generalized additive models (GAM) [22] to explore latitudinal effects on the resilience index. The code used for the analysis is available in a Github repository: <https://github.com/future-oceanslab/Fisheries-Resilience-Index>.

## 2. Standardization of indicators

### 2.1 Normalization

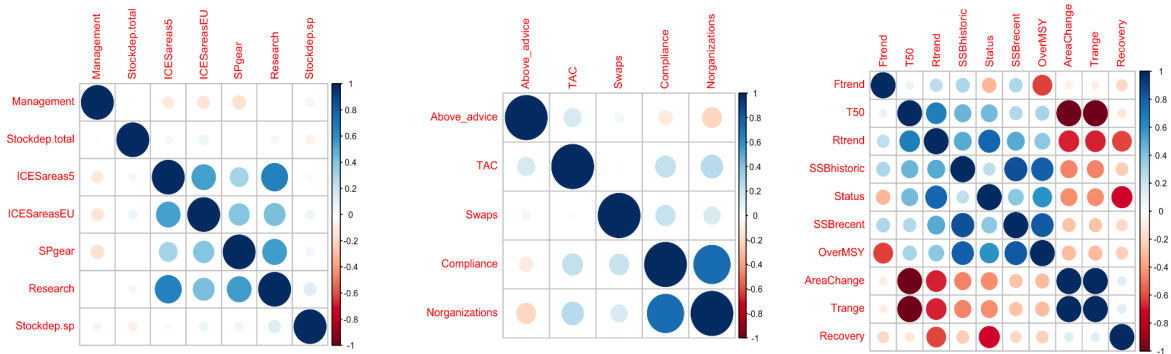
All the indicators in this document ( $x$ ) were standardized ( $x'$ ) between 0 and 1 following the general formula:

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \quad \text{Eq. 1}$$

where  $\min(x)$  represents the minimum theoretical value of  $x$ , and  $\max(x)$  its maximum theoretical value. When an indicator is referred to be standardized within the sample, it means that the minimum and maximum values  $\min(x)$  and  $\max(x)$  are taken from the observed values.

### 2.2. Correlation analysis

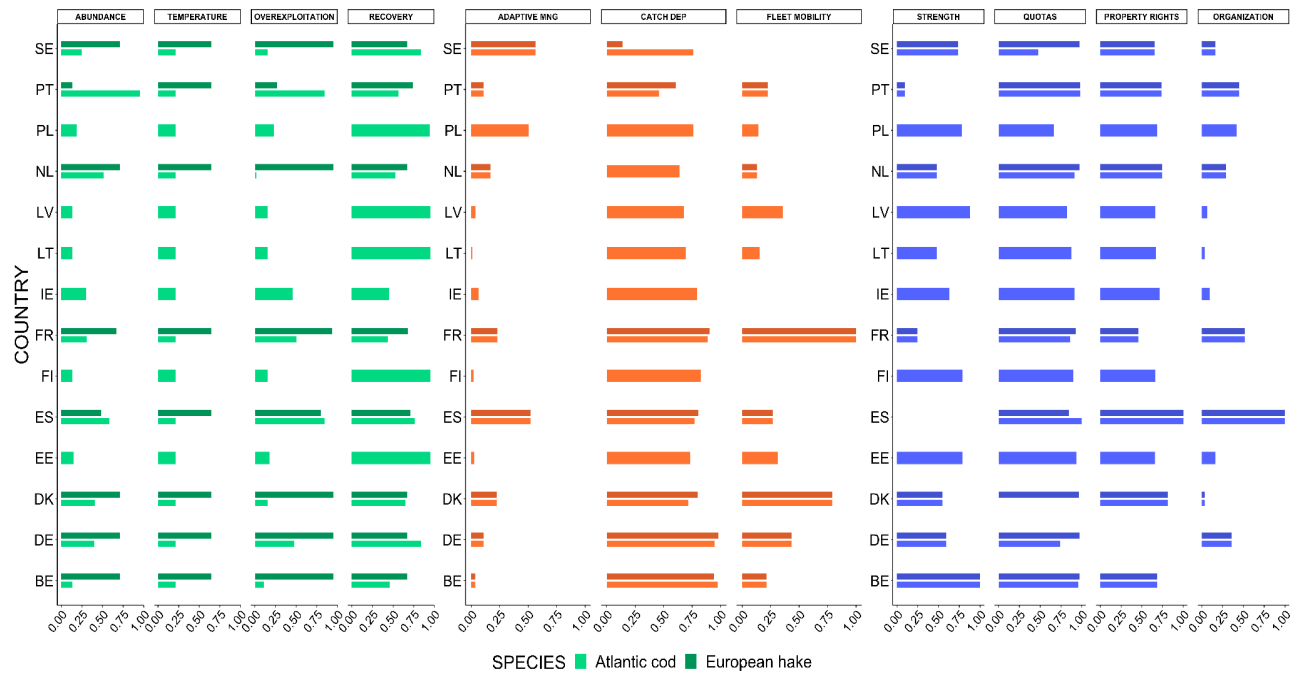
Following [7] and [8] we check our indicators correlation in order to avoid problems in adding up the resilience factors. We estimate the correlation matrices for the ecological, socioeconomic and institutional indicators in Figure SI.2. Indicators that are correlated with a coefficient over 0.76 are dropped from the subsequent analysis as to double counting and inflation of the factors and dimensions in the final index [8]. From the correlation results, only ecological indicators have correlation scores over our threshold, therefore institutional and social factors are computed using all indicators. In the case of ecological factors, we drop the Area indicator as it is highly correlated with Temperature. We also drop SSBhistoric and Rtrend as they correlate with SSBrecent and Ftrend.



**Figure SI.2.** Correlation matrices among indicators for the ecological (left), socioeconomic (centre) and institutional (right) dimensions of the resilience index.

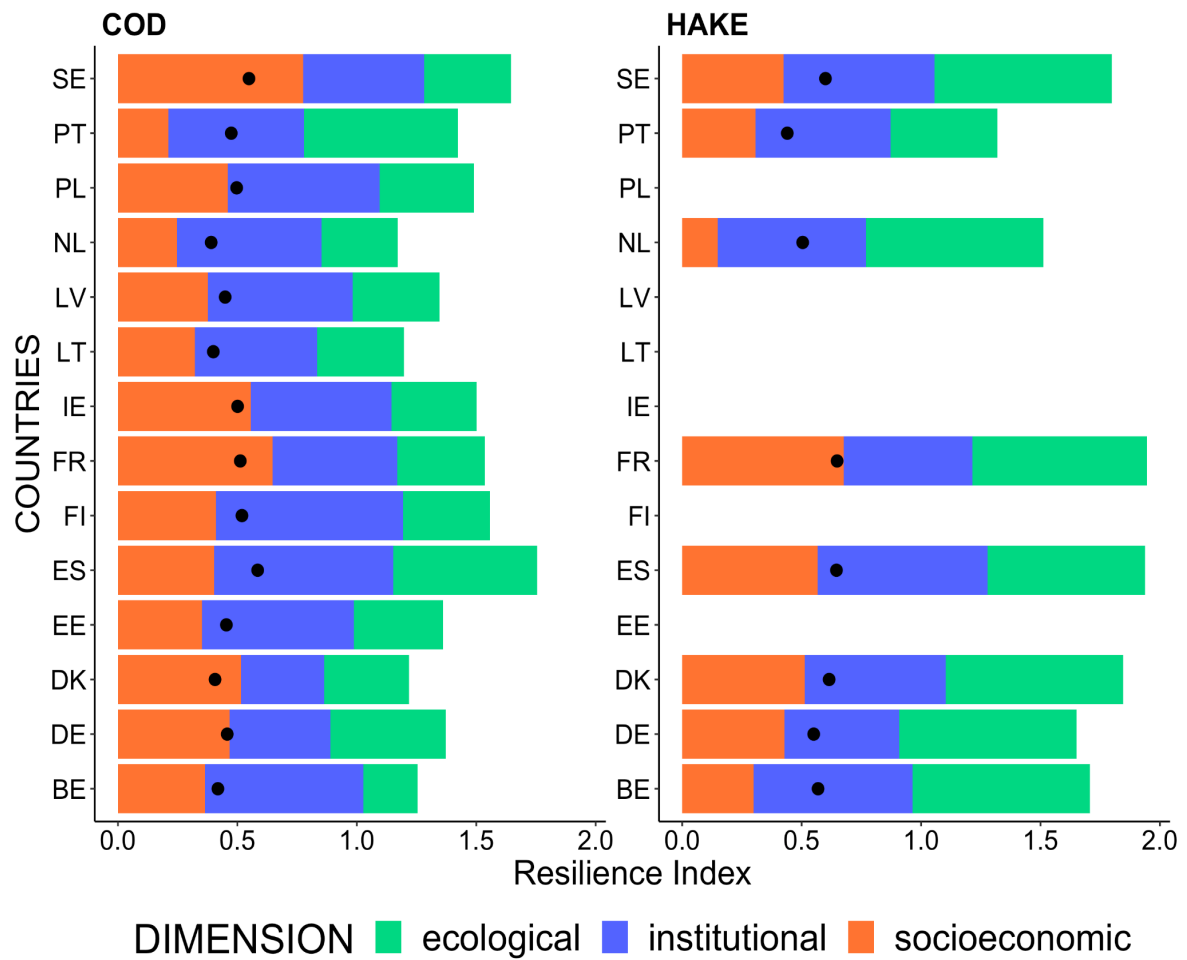
### 2.3. Index aggregation

After performing the correlation analysis and dropping off highly correlated indicators, we combine the remaining set of indicators into factors and dimensions. For each level of aggregation, we use simple averages to obtain the values of the factors and dimensions at the country and species level for ecological, socioeconomic, and institutional resilience. All indicators, factors and dimensions are weightless. Results for the country and species factors are shown in Figure SI.3. Factors are also averaged across dimensions, as shown in Figures SI.4 and mapped in Figure SI.5.



**Figure SI.3.** Factor values for the two species and per country.





**Figure SI.4.** Dimension values for the two species and per country.

### 3. Calculation of index values

#### 3.1 Ecological indicators and factors

##### Area (E1)

This factor captures the expected change in the species' distribution area. Using climate envelope models [13] the projected distribution area of the species was obtained for 2006 and 2100, under climate change scenario RCP 8.5. The factor was then calculated using the formula\*:

$$AREA = \frac{AREA_{100} - AREA_{06}}{AREA_{06}} \quad \text{Eq. 2}$$

The factor was standardized between 0 and 1 assuming a minimum value of -1 (100% area decrease) and +1 (100% area increase) following Eq. 1 (Table SI3).

**Table SI3.** Area indicators and factor

| Species | Area 2006 | Area 2100 | AREA* | Standardized AREA [0 - 1] | AREA* |
|---------|-----------|-----------|-------|---------------------------|-------|
| Hake    | 5918472   | 6210615   | 0.05  | 0.52                      | 0.05  |
| Cod     | 7014930   | 7868484   | 0.12  | 0.56                      | 0.12  |

\*This factor is dropped from the analysis due to high correlation with Temperature.

## Abundance (E2)

The abundance of the stocks was analyzed considering three variables: standing stock biomass (SSB), recruitment (R) and fishing mortality (F). A linear model was constructed where the coefficient for the slope ( $\beta$ ) of each variable against time was used as a measure of the annual change of each indicator (Table SI.4). In the case of SSB, two different time slices were considered: “historic” between 1950 and 2010, and “recent” between 1980 and 2010. To make all stocks across species comparable, these changes were divided by the average of the stock between 1980 and 2010, according to Eq. 3. Raw data were obtained from the RAM legacy stock assessment database (2020) (<http://doi.org/10.5281/zenodo.3676088>).

$$Indicator = \frac{\beta}{stock\ average\ 1980-2010} \quad Eq. 3$$

**Table SI.4.** Value of the coefficients ( $\beta$ ) from the linear models of SSB historic (1950-2010), SSB recent (1980-2010), R and F in RAM legacy.

| Stock      | $\beta$ SSB historic | $\beta$ SSB recent | $\beta$ R | $\beta$ F | SSB average | R average | F average |
|------------|----------------------|--------------------|-----------|-----------|-------------|-----------|-----------|
| CODNEAR    | 15436                | 50925              | -10130000 | 0.0001    | 813051.3    | 578611100 | 0.619     |
| CODNEARNCW | -1887.4              | -1887.4            | -0.04     | -0.0082   | 27552.38    | 1.00      | 0.323     |
| CODFAPL    | -889.4               | -1547.7            | -197174   | 0.0020    | 42874.36    | 15425530  | 0.579     |
| CODICE     | -3686                | 8496               | -1151990  | -0.0009   | 256794.9    | 153450000 | 0.569     |
| CODBA2532  | -6058                | -15166             | -7356000  | -0.0040   | 225250      | 182531200 | 0.853     |
| CODKAT     | -0.06327             | -0.06327           | -0.05     | -0.0402   | 0.9998182   | 1.00      | 1.000     |
| CODIS      | -333.9               | -354.55            | -1732438  | 0.0005    | 6641.132    | 27300770  | 0.906     |
| CODVIa     | -960.57              | -960.57            | -672345   | 0.0038    | 225250      | 11068650  | 0.906     |
| CODIIIaW   | -2838.9              | -1085.6            | -18380000 | -0.0021   | 98135.9     | 461510500 | 0.831     |
| HAKENRTN   | 5617                 | 4892               | 42160     | -0.0124   | 98966.67    | 358487179 | 0.737     |
| HAKESOTH   | -567.4               | -567.4             | 733600    | 0.0064    | 17838.65    | 79467568  | 0.765     |

The normalization of the indicators between 0 and 1 was carried out for all stocks within the sample (Table SI5). Finally, the Abundance factor is computed as the mean of the four normalized indicators according to Eq. 4:

$$ABUNDANCE = \frac{SSB_{recent} + SSB_{historic} + F' + R'}{4} \quad Eq. 4$$

**Table SI5.** Normalization of Abundance indicators and Abundance factor calculation\*.

| Species | Stock      | SSB hist indicator* | SSB recent indicator | R indicator* | F indicator | SSB hist norm.* | SSB recent norm. | R norm*. | F norm. | ABUNDANCE |
|---------|------------|---------------------|----------------------|--------------|-------------|-----------------|------------------|----------|---------|-----------|
| Cod     | CODNEAR    | 0.019               | 0.063                | -0.018       | 0.000       | 0.698           | 1.000            | 0.632    | 0.169   | 0.584     |
| Cod     | CODNEARNCW | -0.069              | -0.069               | -0.040       | -0.025      | 0.000           | 0.000            | 0.323    | 0.695   | 0.347     |
| Cod     | CODFAPL    | -0.021              | -0.036               | -0.013       | 0.003       | 0.381           | 0.247            | 0.697    | 0.101   | 0.174     |
| Cod     | CODICE     | -0.014              | 0.033                | -0.008       | -0.002      | 0.432           | 0.775            | 0.770    | 0.205   | 0.490     |
| Cod     | CODBA2532  | -0.027              | -0.067               | -0.040       | -0.005      | 0.332           | 0.009            | 0.319    | 0.269   | 0.139     |
| Cod     | CODKAT     | -0.063              | -0.063               | -0.050       | -0.040      | 0.042           | 0.040            | 0.185    | 1.000   | 0.520     |

|      |          |        |        |        |        |       |       |       |       |       |
|------|----------|--------|--------|--------|--------|-------|-------|-------|-------|-------|
| Cod  | CODIS    | -0.050 | -0.053 | -0.063 | 0.001  | 0.145 | 0.115 | 0.000 | 0.161 | 0.138 |
| Cod  | CODVIa   | -0.004 | -0.004 | -0.061 | 0.004  | 0.513 | 0.490 | 0.037 | 0.086 | 0.288 |
| Cod  | CODIIaW  | -0.029 | -0.011 | -0.040 | -0.003 | 0.316 | 0.438 | 0.325 | 0.224 | 0.331 |
| Hake | HAKENRTN | 0.057  | 0.049  | 0.000  | -0.017 | 1.000 | 0.899 | 0.875 | 0.519 | 0.709 |
| Hake | HAKESOTH | -0.032 | -0.032 | 0.009  | 0.008  | 0.293 | 0.280 | 1.000 | 0.000 | 0.140 |

\*Indicators dropped due to correlation, not used in factor average.

### Temperature (E3)

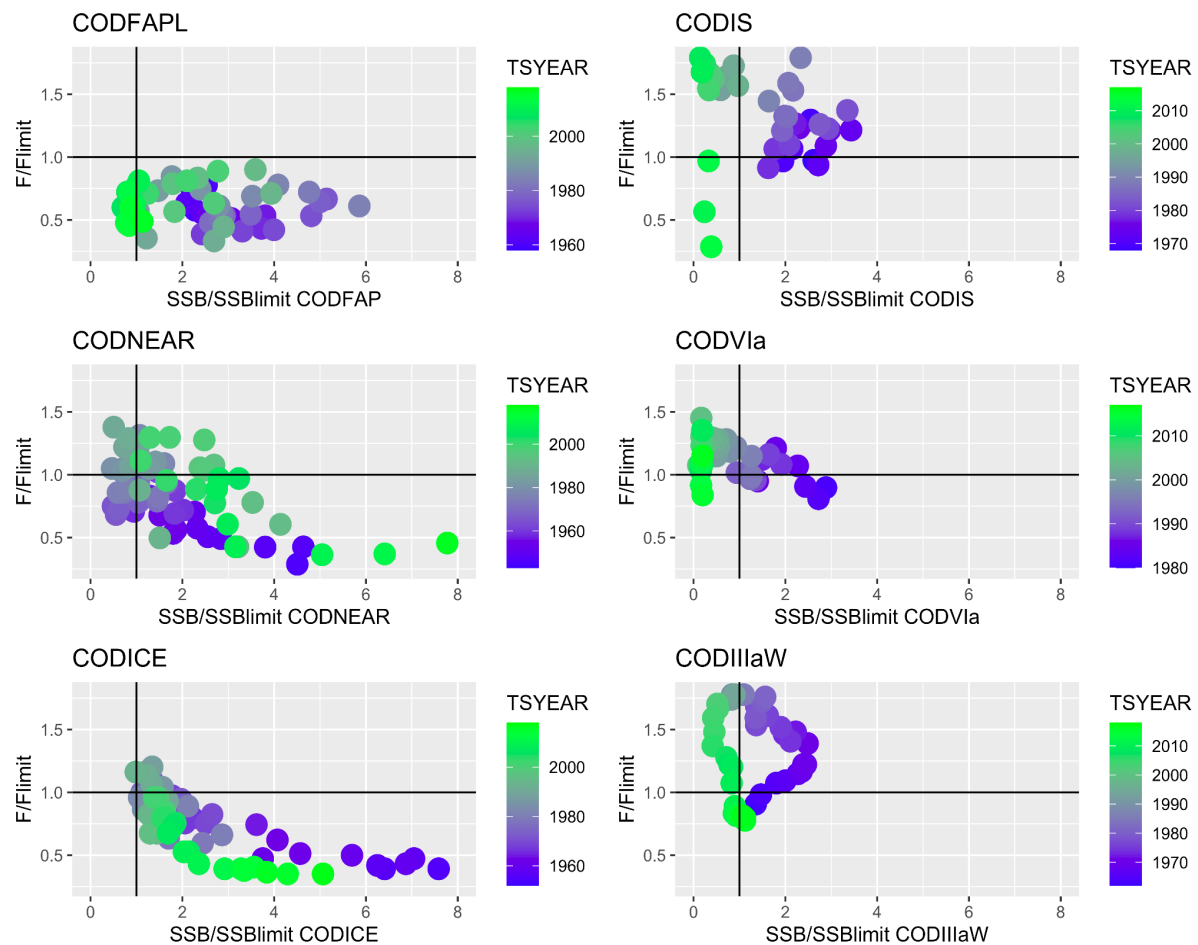
The temperature factor was calculated for each species considering the 50th percentile of their average thermal preference using data from Cheung et al. (2013) [9] (Table SI6). The factor was then standardized using Eq. 1, between 0 and 1, considering the 2nd and 98th percentiles as minimum and maximum values respectively\*.

**Table SI6.** Data and normalization of the average thermal preference of each species. Temperatures are shown in °C.

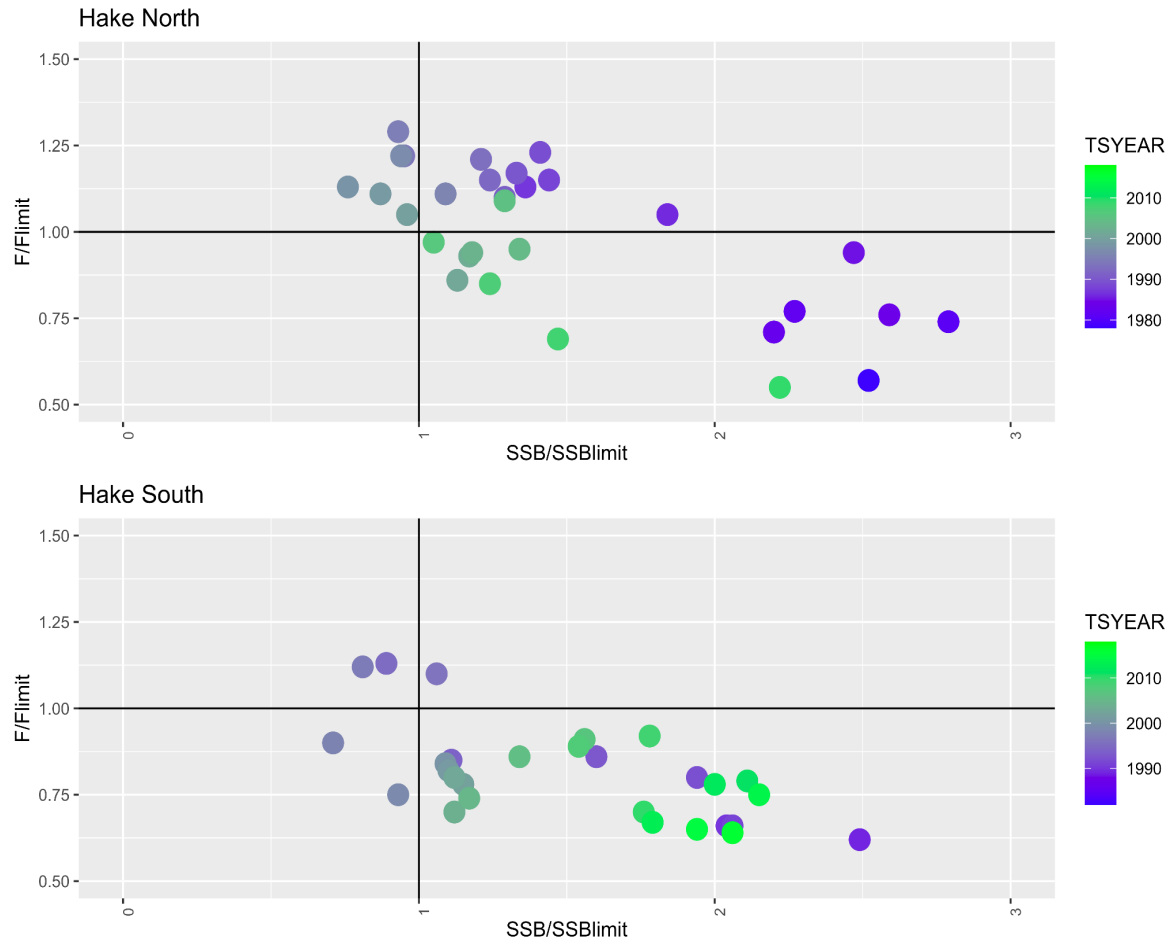
| Species       | Temperature 50th percentile | Temperature 2nd percentile | Temperature 98th percentile | Temperature 50th norm. | TEMPERATURE* |
|---------------|-----------------------------|----------------------------|-----------------------------|------------------------|--------------|
| EUROPEAN HAKE | 18                          | 0                          | 28                          | 0.643                  | 0.643        |
| ATLANTIC COD  | 6                           | 0                          | 28                          | 0.214                  | 0.214        |

## Overexploitation (E4)

Factor overexploitation was composed of two indicators: status and OverMSY. For the Status indicator, standing stock biomass (SSB) and fishing mortality (F) data were used to analyze the historical status of the fishery. We use a Kobe-type plot displaying SSB/SSB<sub>limit</sub> and F/F<sub>limit</sub>. The indicator value results from this plot, where we look at the position of the species in the last year of data within the plot. In this respect, 0: upper left; 1: upper right; 2: down left; 3: down right. (Fig. SI.5 for cod; Fig. SI.6 for hake). Raw data were obtained from the RAM legacy stock assessment database (2020) (<http://doi.org/10.5281/zenodo.3676088>).



**Figure SI.5.** Kobe-type plot limited at SSB/SSB<sub>limit</sub> and F/F<sub>limit</sub> for cod stocks.



**Figure SI.6.** Kobe-type plot limited at SSB/SSBlimit and F/Flimit for hake stocks.

OverMSY is the difference between the observed catch (F) and the MSY (FMSY) estimate for the stock in 2012 as resulting from the model by Costello et al., 2016 (Eq. 5).

$$OverMSY = (F / FMSY) \quad \text{Eq. 5}$$

Note that both the Status and OverMSY indicators have opposite directions for resilience, while Status is positively related, OverMSY is negative. OverMSY is normalized using the inverse normalization formula, so it can be aggregated in the computation of the factor Overexploitation as follows\*:

$$OVEREXPLOITATION = (Status + OverMSY) / 2 \quad \text{Eq. 6}$$

**Table SI7.** Overexploitation indicators, normalization and factor

| Stock      | Status | Status norm. | OverMSY | OverMSY norm. (inverse) | OVEREXPLOITATION |
|------------|--------|--------------|---------|-------------------------|------------------|
| CODNEAR    | 3      | 1            | 5.1167  | 0                       | 0.500            |
| CODNEARNCW |        |              |         |                         |                  |
| CODFAPL    | 2      | 0.75         | 0.2727  | 0.951                   | 0.809            |
| CODICE     | 3      | 1            |         |                         | 1                |
| CODBA2532  |        |              | 0.7489  | 0.857                   | 0.857            |
| CODKAT     |        |              |         |                         |                  |
| CODIS      | 2      | 0.5          | 1.3019  | 0.749                   | 0.708            |
| CODVIa     | 0      | 0            | 0.0219  | 1                       | 0.500            |
| CODIIIaW   | 2      | 0.5          | 0.4189  | 0.922                   | 0.794            |
| HAKENRTN   | 3      | 1            | 5.0269  | 0.018                   | 0.509            |
| HAKESOTH   | 3      | 1            | 0.4272  | 0.92                    | 0.960            |



## Recovery (E5)

Recovery time is observed in the time series data for each stock (ICES advice 2016) as the number of years between a stock going under the SSB limit established by ICES (*SSBlimit*) and going back to  $1.5 * SSBlimit$ . There are two stocks that never go back to  $1.5 * SSBlimit$  during the time series, so for these two stocks we assume the largest recovery time observed in our sample (25 years). The recovery factor is based on one single indicator, Recovery, which is normalized considering the 2% and 98% of their sample as minimum and maximum respectively (Table SI.8).

**Table SI.8.** Recovery indicator, normalization, and factor.

| <i>STOCK</i>      | <i>recovery</i> | <i>recovery 2%</i> | <i>recovery 98%</i> | <i>RECOVERY</i> |
|-------------------|-----------------|--------------------|---------------------|-----------------|
| <i>CODNEAR</i>    | 11.00           | 1.00               | 43.34               | 0.76            |
| <i>CODNEARNCW</i> | 18.00           | 1.00               | 43.34               | 0.60            |
| <i>CODFAPL</i>    | 12.00           | 1.00               | 43.34               | 0.74            |
| <i>CODICE</i>     | 4.00            | 1.00               | 43.34               | 0.93            |
| <i>CODBA2532</i>  | 3.00            | 1.00               | 43.34               | 0.95            |
| <i>CODKAT</i>     | 21.00           | 1.00               | 43.34               | 0.53            |
| <i>CODIS</i>      | 24.00           | 1.00               | 43.34               | 0.46            |
| <i>CODVIa</i>     | 25.00           | 1.00               | 43.34               | 0.43            |
| <i>CODIIIaW</i>   | 25.00           | 1.00               | 43.34               | 0.43            |
| <i>HAKENRTN</i>   | 15.00           | 1.00               | 43.34               | 0.67            |
| <i>HAKESOTH</i>   | 12.00           | 1.00               | 43.34               | 0.74            |

## Ecological factors summary

**Table SI.9.** Ecological factors per stock.

| <i>STOCK</i>      | <i>ABUNDANCE</i> | <i>TEMPERATURE</i> | <i>OVEREXPLOITATION</i> | <i>RECOVERY</i> |
|-------------------|------------------|--------------------|-------------------------|-----------------|
| <i>CODNEAR</i>    | 0.584            | 0.545              | 0.500                   | 0.764           |
| <i>CODNEARNCW</i> | 0.347            | 0.545              | -                       | 0.598           |
| <i>CODFAPL</i>    | 0.174            | 0.545              | 0.809                   | 0.740           |
| <i>CODICE</i>     | 0.490            | 0.545              | 1.000                   | 0.929           |
| <i>CODBA2532</i>  | 0.139            | 0.545              | 0.857                   | 0.953           |
| <i>CODKAT</i>     | 0.520            | 0.545              | -                       | 0.528           |
| <i>CODIS</i>      | 0.138            | 0.545              | 0.708                   | 0.457           |
| <i>CODVIa</i>     | 0.288            | 0.545              | 0.500                   | 0.433           |
| <i>CODIIIaW</i>   | 0.331            | 0.545              | 0.794                   | 0.433           |
| <i>HAKEARTN</i>   | 0.709            | 0.455              | 0.509                   | 0.669           |
| <i>HAKEOTH</i>    | 0.140            | 0.455              | 0.960                   | 0.740           |

Ecological factors per stock are converted to factors per country based on whether the stock is being fished by the EU member country, based on the data from ICES Historical Nominal Catches 1950-2010 (<https://gis.ices.dk/geonetwork/srv/api/records/c6ab8e49-324d-4940-9e9c-0281faa65310>) (Table SI.8). The values of ecological factors in countries are calculated as the mean of the values of ecological factors in stocks that these countries fish (Table SI.9).

**Table SI.10.** Stocks that are being fished by EU countries (2006-2010).

| <i>STOCK</i>      | <i>BE</i> | <i>DK</i> | <i>DE</i> | <i>EE</i> | <i>IE</i> | <i>ES</i> | <i>FR</i> | <i>LV</i> | <i>LT</i> | <i>NL</i> | <i>PL</i> | <i>PT</i> | <i>FI</i> | <i>SE</i> |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| <i>HAKENRTN</i>   | yes       | yes       | yes       | -         | -         | yes       | yes       | -         | -         | yes       | -         | yes       | -         | yes       |
| <i>HAKESOTH</i>   | -         | -         | -         | -         | -         | yes       | yes       | -         | -         | -         | -         | yes       | -         | -         |
| <i>CODNEARNCW</i> | -         | yes       | yes       | yes       | yes       | yes       | yes       | -         | -         | -         | yes       | yes       | -         | -         |
| <i>CODNEAR</i>    | -         | yes       | yes       | yes       | yes       | yes       | yes       | -         | -         | -         | yes       | yes       | -         | -         |
| <i>CODFAPL</i>    | -         | -         | yes       | -         | -         | -         | -         | -         | -         | -         | -         | -         | -         | -         |
| <i>CODICE</i>     | -         | -         | yes       | -         | -         | -         | -         | -         | -         | -         | -         | -         | -         | -         |
| <i>CODBA2532</i>  | -         | yes       | yes       | yes       | -         | -         | -         | yes       | yes       | -         | yes       | -         | yes       | yes       |
| <i>CODKAT</i>     | -         | yes       | yes       | -         | -         | -         | yes       | -         | -         | yes       | -         | yes       | -         | yes       |
| <i>CODIS</i>      | yes       | -         | -         | -         | yes       | -         | yes       | -         | -         | -         | -         | -         | -         | -         |
| <i>CODVIa</i>     | -         | -         | yes       | -         | yes       | -         | yes       | -         | -         | -         | -         | -         | -         | -         |
| <i>CODIIIaW</i>   | -         | -         | -         | -         | -         | -         | yes       | -         | -         | -         | -         | -         | -         | -         |

**Table SI.11.** Ecological factors per fishing country and species.

|           | COD       |                   |          |             | HAKE      |                   |          |             |
|-----------|-----------|-------------------|----------|-------------|-----------|-------------------|----------|-------------|
| COUNTRIES | ABUNDANCE | OVEREXPLOITA-TION | RECOVERY | TEMPERATURE | ABUNDANCE | OVEREXPLOITA-TION | RECOVERY | TEMPERATURE |
| <i>BE</i> | 0.115     | 0.708             | 0.457    | 0.545       | 0.899     | 0.509             | 0.669    | 0.455       |
| <i>DK</i> | 0.262     | 0.679             | 0.711    | 0.545       | 0.899     | 0.509             | 0.669    | 0.455       |
| <i>DE</i> | 0.366     | 0.733             | 0.706    | 0.545       | 0.899     | 0.509             | 0.669    | 0.455       |
| <i>EE</i> | 0.336     | 0.679             | 0.772    | 0.545       | -         | -                 | -        | -           |
| <i>IE</i> | 0.401     | 0.569             | 0.563    | 0.545       | -         | -                 | -        | -           |
| <i>ES</i> | 0.500     | 0.500             | 0.681    | 0.545       | 0.590     | 0.735             | 0.705    | 0.455       |
| <i>FR</i> | 0.347     | 0.626             | 0.536    | 0.545       | 0.590     | 0.735             | 0.705    | 0.455       |
| <i>LV</i> | 0.009     | 0.857             | 0.953    | 0.545       | -         | -                 | -        | -           |
| <i>LT</i> | 0.009     | 0.857             | 0.953    | 0.545       | -         | -                 | -        | -           |
| <i>NL</i> | 0.040     | -                 | 0.528    | 0.545       | 0.899     | 0.509             | 0.669    | 0.455       |
| <i>PL</i> | 0.336     | 0.679             | 0.772    | 0.545       | -         | -                 | -        | -           |
| <i>PT</i> | 0.347     | 0.500             | 0.630    | 0.545       | 0.590     | 0.735             | 0.705    | 0.455       |
| <i>FI</i> | 0.009     | 0.857             | 0.953    | 0.545       | -         | -                 | -        | -           |
| <i>SE</i> | 0.024     | 0.857             | 0.740    | 0.545       | 0.899     | 0.509             | 0.669    | 0.455       |

#### 4. Socioeconomic indicators and factors

##### Gear diversity (S1)

Gear Diversity was calculated considering only one indicator (SPgear) and is normalized within the sample (Table SI.12). Data was obtained from the Sea Around Us portal.

**Table SI.12.** Values and normalization of Gear Diversity.

| Fishing Countries | Species | Gear Diversity | Normalized gear diversity | GEAR DIVERSITY |
|-------------------|---------|----------------|---------------------------|----------------|
| BE                | Cod     | 6              | 0.238                     | 0.238          |
|                   | Hake    | 1              | 0.000                     | 0.000          |
| DE                | Cod     | 9              | 0.381                     | 0.381          |
|                   | Hake    | 5              | 0.190                     | 0.190          |
| DK                | Cod     | 8              | 0.333                     | 0.333          |
|                   | Hake    | 6              | 0.238                     | 0.238          |
| EE                | Cod     | 8              | 0.333                     | 0.333          |
| ES                | Cod     | 2              | 0.048                     | 0.048          |
|                   | Hake    | 15             | 0.667                     | 0.667          |
| FI                | Cod     | 9              | 0.381                     | 0.381          |
| FR                | Cod     | 11             | 0.476                     | 0.476          |
|                   | Hake    | 13             | 0.571                     | 0.571          |
| IE                | Cod     | 18             | 0.809                     | 0.809          |
| LT                | Cod     | 10             | 0.429                     | 0.429          |
| LV                | Cod     | 10             | 0.429                     | 0.429          |
| NL                | Cod     | 2              | 0.048                     | 0.048          |
| PL                | Cod     | 10             | 0.429                     | 0.429          |
| PT                | Cod     | 2              | 0.0476                    | 0.0476         |
|                   | Hake    | 7              | 0.286                     | 0.286          |
| SE                | Cod     | 22             | 1.000                     | 1.000          |
|                   | Hake    | 13             | 0.571                     | 0.571          |

##### Fleet mobility (S2)

Fleet mobility factor is composed of two indicators:  $ICES_{area5}$  and  $ICES_{areaEU}$ .  $ICES_{area5}$  refers to the mobility of countries within the EU waters, obtained by looking at the ICES areas they have caught the specific stocks in a recent 5-year period. As countries have a history of fishing in foreign areas, we also want to consider the fishing mobility prior to entering the EU in 1993. Therefore  $ICES_{areaEU}$  captures whether a fishing country had higher mobility prior to entering the EU. Indices are available per country and are obtained from the historical nominal catches in the major fishing area 27 of ICES, between 1959 and 2010 (<https://gis.ices.dk/geonetwork/srv/metadata/c6ab8e49-324d-4940-9e9c-0281faa65310>). Indices are normalized within sample and the formula for calculating the indicator is:

$$\text{Fleet mobility} = \frac{ICES_{\text{area5}} + ICES_{\text{areaEU}}}{2} \quad \text{Eq. 7}$$

**Table SI13.** Indicators and normalization of Fleet Mobility factor.

| Countries | ICES <sub>area</sub> | ICES <sub>areaEU</sub> | Normalized ICES <sub>area</sub> | Normalized ICES <sub>areaEU</sub> | FLEET MOBILITY |
|-----------|----------------------|------------------------|---------------------------------|-----------------------------------|----------------|
| BE        | 9.50                 | -2.15                  | 0.43                            | 0.00                              | 0.22           |
| DK        | 12.50                | 5.48                   | 0.59                            | 1.00                              | 0.79           |
| DE        | 13.22                | -0.27                  | 0.63                            | 0.25                              | 0.44           |
| EE        | 3.60                 | 1.66                   | 0.12                            | 0.50                              | 0.31           |
| IE        | -                    | -                      | -                               | -                                 | -              |
| ES        | 5.27                 | 0.37                   | 0.21                            | 0.33                              | 0.27           |
| FR        | 20.41                | 5.50                   | 1.00                            | 1.00                              | 1.00           |
| LV        | 4.00                 | 2.20                   | 0.15                            | 0.57                              | 0.36           |
| LT        | 1.20                 | 0.22                   | 0.00                            | 0.31                              | 0.15           |
| NL        | 5.16                 | -1.76                  | 0.21                            | 0.05                              | 0.13           |
| PL        | 5.22                 | -1.59                  | 0.21                            | 0.07                              | 0.14           |
| PT        | 2.88                 | 0.61                   | 0.09                            | 0.36                              | 0.22           |
| FI        | -                    | -                      | -                               | -                                 | -              |
| SE        | -                    | -                      | -                               | -                                 | -              |

### Catch dependency (S3)

Catch dependency is calculated for each country and stock based on their catches between 2006 and 2010 (data obtained from their historical nominal catches in the major fishing area 27 of ICES, between 1959 and 2010, <https://gis.ices.dk/geonetwork/srv/metadata/c6ab8e49-324d-4940-9e9c-0281faa65310>). For each country, the dependency of a given country on each stock was calculated in relation to the catch of the species under consideration ( $stockdep_{sp}$ ) and in relation to the total catch of the country ( $stockdep_{total}$ ):

$$stockdep_{sp} = \frac{catch_{stock}}{catch_{sp}} \quad \text{Eq. 8}$$

$$stockdep_{total} = \frac{catch_{stock}}{catch_{total}} \quad \text{Eq. 9}$$

Where  $catch_{stock}$  is the country catch of a given stock (annual average between 2006 and 2010),  $catch_{sp}$  is the country total catch of a given species (in 2010), and  $catch_{total}$  is the country's total catch of all species in 2010. Normalization is within the sample. The final formula for the Catch dependency factor is the following:

$$CATCH\ DEPENDENCY = \frac{stockdep_{sp} + stockdep_{total}}{2} \quad \text{Eq. 10}$$

**Table SI.14.** Catch dependency of countries on stocks.

| Country | Stock              | Catch Stock 2006-2010 | Catch sp 2006-2010 | Total catch | Stockdep sp | Stockdep total |
|---------|--------------------|-----------------------|--------------------|-------------|-------------|----------------|
| Belgium | CODBA2532          | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODFAPL            | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODICE             | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODIIIaW           | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODIS              | 38.6                  | 797                | 16128.8     | 0.0484      | 0.0024         |
| Belgium | CODKAT             | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODNEARNCW CODNEAR | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | CODVIa             | 0                     | 797                | 16128.8     | 0           | 0              |
| Belgium | HAKENRTN           | 5.6                   | 69                 | 16128.8     | 0.0812      | 0.0003         |
| Belgium | HAKESOTH           | 0                     | 69                 | 16128.8     | 0           | 0              |
| Germany | CODBA2532          | 2577                  | 19476              | 80086       | 0.1323      | 0.0322         |
| Germany | CODFAPL            | 1                     | 19476              | 80086       | 0.0001      | 0              |
| Germany | CODICE             | 38                    | 19476              | 80086       | 0.002       | 0.0005         |
| Germany | CODIIIaW           | 0                     | 19476              | 80086       | 0           | 0              |
| Germany | CODIS              | 0                     | 19476              | 80086       | 0           | 0              |
| Germany | CODKAT             | 62.8                  | 19476              | 80086       | 0.0032      | 0.0008         |
| Germany | CODNEARNCW CODNEAR | 6415.8                | 19476              | 80086       | 0.3294      | 0.0801         |
| Germany | CODVIa             | 1.66                  | 19476              | 80086       | 0.0001      | 0              |
| Germany | HAKENRTN           | 5.4                   | 278                | 80086       | 0.0194      | 0.0001         |
| Germany | HAKESOTH           | 0                     | 278                | 80086       | 0           | 0              |
| Denmark | CODBA2532          | 7625.6                | 26702              | 1066558.7   | 0.2856      | 0.0071         |
| Denmark | CODFAPL            | 0                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | CODICE             | 0                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | CODIIIaW           | 0                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | CODIS              | 0                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | CODKAT             | 3014.8                | 26702              | 1066558.7   | 0.1129      | 0.0028         |
| Denmark | CODNEARNCW CODNEAR | 1                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | CODVIa             | 0                     | 26702              | 1066558.7   | 0           | 0              |
| Denmark | HAKENRTN           | 406.8                 | 2189               | 1066558.7   | 0.1858      | 0.0004         |
| Denmark | HAKESOTH           | 0                     | 2189               | 1066558.7   | 0           | 0              |
| Estonia | CODBA2532          | 692.8                 | 796                | 84965.08    | 0.8704      | 0.0082         |
| Estonia | CODFAPL            | 0                     | 796                | 84965.08    | 0           | 0              |
| Estonia | CODICE             | 0                     | 796                | 84965.08    | 0           | 0              |
| Estonia | CODIIIaW           | 0                     | 796                | 84965.08    | 0           | 0              |
| Estonia | CODIS              | 0                     | 796                | 84965.08    | 0           | 0              |
| Estonia | CODKAT             | 0                     | 796                | 84965.08    | 0           | 0              |
| Estonia | CODNEARNCW CODNEAR | 15                    | 796                | 84965.08    | 0.0188      | 0.0002         |
| Estonia | CODVIa             | 0                     | 796                | 84965.08    | 0           | 0              |
| Spain   | CODBA2532          |                       |                    | 755465.3    | 0           |                |
| Spain   | CODFAPL            | 0                     | 0                  | 755465.3    | 0           | 0              |

|             |                    |        |         |           |        |        |
|-------------|--------------------|--------|---------|-----------|--------|--------|
| Spain       | CODICE             | 0      | 0       | 755465.3  | 0      | 0      |
| Spain       | CODIIIaW           |        |         | 755465.3  | 0      |        |
| Spain       | CODIS              | 0      | 0       | 755465.3  | 0      | 0      |
| Spain       | CODKAT             |        |         | 755465.3  | 0      |        |
| Spain       | CODNEARNCW CODNEAR | 7788.4 | 12661   | 755465.3  | 0.6151 | 0.0103 |
| Spain       | CODVIa             | 0      | 0       | 755465.3  | 0      | 0      |
| Spain       | HAKENRTN           | 5494.4 | 20681.1 | 755465.3  | 0.2657 | 0.0073 |
| Spain       | HAKESOTH           | 4695.4 | 20681.1 | 755465.3  | 0.227  | 0.0062 |
| Finland     | CODBA2532          | 521.7  | 1028    | 82989.1   | 0.5075 |        |
| Finland     | CODFAPL            |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODICE             |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODIIIaW           |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODIS              |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODKAT             |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODNEARNCW CODNEAR |        | 1028    | 82989.1   | 0      |        |
| Finland     | CODVIa             |        | 1028    | 82989.1   | 0      |        |
| France      | CODBA2532          |        |         | 254876.4  | 0      |        |
| France      | CODFAPL            | 0      | 0       | 254876.4  | 0      | 0      |
| France      | CODICE             | 0      | 0       | 254876.4  | 0      | 0      |
| France      | CODIIIaW           | 1.5    | 5298    | 254876.4  | 0.0003 | 0      |
| France      | CODIS              | 10.4   | 5298    | 254876.4  | 0.002  | 0      |
| France      | CODKAT             | 1      | 5298    | 254876.4  | 0.0002 | 0      |
| France      | CODNEARNCW CODNEAR | 2313.8 | 5298    | 254876.4  | 0.4367 | 0.0091 |
| France      | CODVIa             | 83.2   | 5298    | 254876.4  | 0.0157 | 0.0003 |
| France      | HAKENRTN           | 6333.8 | 19184   | 254876.4  | 0.3302 | 0.0249 |
| France      | HAKESOTH           | 252.6  | 19184   | 254876.4  | 0.0132 | 0.001  |
| Ireland     | CODBA2532          | 0      | 1272    | 247841.15 | 0      | 0      |
| Ireland     | CODFAPL            | 0      | 1272    | 247841.15 | 0      | 0      |
| Ireland     | CODICE             | 0      | 1272    | 247841.15 | 0      | 0      |
| Ireland     | CODIIIaW           | 0      | 1272    | 247841.15 | 0      | 0      |
| Ireland     | CODIS              | 422.6  | 1272    | 247841.15 | 0.3322 | 0.0017 |
| Ireland     | CODKAT             | 0      | 1272    | 247841.15 | 0      | 0      |
| Ireland     | CODNEARNCW CODNEAR | 172.8  | 1272    | 247841.15 | 0.1358 | 0.0007 |
| Ireland     | CODVIa             | 43.8   | 1272    | 247841.15 | 0.0344 | 0.0002 |
| Lithuania   | CODBA2532          | 237.5  | 3213    | 5535.6    | 0.0739 | 0.0429 |
| Lithuania   | CODFAPL            |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODICE             |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODIIIaW           |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODIS              |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODKAT             |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODNEARNCW CODNEAR |        | 3213    | 5535.6    | 0      |        |
| Lithuania   | CODVIa             |        | 3213    | 5535.6    | 0      |        |
| Latvia      | CODBA2532          | 1535.8 | 5160    | 67133.8   | 0.2976 | 0.0229 |
| Latvia      | CODFAPL            |        | 5160    | 67133.8   | 0      |        |
| Latvia      | CODICE             |        | 5160    | 67133.8   | 0      |        |
| Latvia      | CODIIIaW           |        | 5160    | 67133.8   | 0      |        |
| Latvia      | CODIS              |        | 5160    | 67133.8   | 0      |        |
| Latvia      | CODKAT             |        | 5160    | 67133.8   | 0      |        |
| Latvia      | CODNEARNCW CODNEAR | 0      | 5160    | 67133.8   | 0      | 0      |
| Latvia      | CODVIa             |        | 5160    | 67133.8   | 0      |        |
| Netherlands | CODBA2532          |        | 2731    | 444131.5  | 0      |        |
| Netherlands | CODFAPL            | 0      | 2731    | 444131.5  | 0      | 0      |
| Netherlands | CODICE             | 0      | 2731    | 444131.5  | 0      | 0      |
| Netherlands | CODIIIaW           | 0      | 2731    | 444131.5  | 0      | 0      |
| Netherlands | CODIS              | 0      | 2731    | 444131.5  | 0      | 0      |
| Netherlands | CODKAT             | 21.2   | 2731    | 444131.5  | 0.0078 | 0      |
| Netherlands | CODNEARNCW CODNEAR | 0      | 2731    | 444131.5  | 0      | 0      |
| Netherlands | CODVIa             | 0      | 2731    | 444131.5  | 0      | 0      |
| Poland      | CODBA2532          | 6533.2 | 14841   | 84013.2   | 0.4402 | 0.0778 |
| Poland      | CODFAPL            | 0      | 14841   | 84013.2   | 0      | 0      |
| Poland      | CODICE             | 0      | 14841   | 84013.2   | 0      | 0      |
| Poland      | CODIIIaW           |        | 14841   | 84013.2   | 0      |        |
| Poland      | CODIS              |        | 14841   | 84013.2   | 0      |        |
| Poland      | CODKAT             | 0      | 14841   | 84013.2   | 0      | 0      |
| Poland      | CODNEARNCW CODNEAR | 1530.4 | 14841   | 84013.2   | 0.1031 | 0.0182 |
| Poland      | CODVIa             | 0      | 14841   | 84013.2   | 0      | 0      |
| Portugal    | CODBA2532          |        | 4724    | 182939.5  | 0      |        |
| Portugal    | CODFAPL            |        | 4724    | 182939.5  | 0      |        |
| Portugal    | CODICE             |        | 4724    | 182939.5  | 0      |        |
| Portugal    | CODIIIaW           |        | 4724    | 182939.5  | 0      |        |
| Portugal    | CODIS              |        | 4724    | 182939.5  | 0      |        |
| Portugal    | CODKAT             | 346    | 4724    | 182939.5  | 0.0732 | 0.0019 |
| Portugal    | CODNEARNCW CODNEAR | 4379   | 4724    | 182939.5  | 0.927  | 0.0239 |



|          |                    |        |       |          |        |        |
|----------|--------------------|--------|-------|----------|--------|--------|
| Portugal | CODVIa             |        | 4724  | 182939.5 | 0      |        |
| Portugal | HAKENRTN           | 0.5    | 2433  | 182939.5 | 0.0002 | 0      |
| Portugal | HAKESOTH           | 1772.6 | 2433  | 182939.5 | 0.7286 |        |
| Sweden   | CODBA2532          | 9284.6 | 12406 | 220922.7 | 0.7484 | 0.042  |
| Sweden   | CODFAPL            |        | 12406 | 220922.7 | 0      |        |
| Sweden   | CODICE             | 0      | 12406 | 220922.7 | 0      | 0      |
| Sweden   | CODIIIaW           | 0      | 12406 | 220922.7 | 0      | 0      |
| Sweden   | CODIS              |        | 12406 | 220922.7 | 0      |        |
| Sweden   | CODKAT             | 568.4  | 12406 | 220922.7 | 0.0458 | 0.0026 |
| Sweden   | CODNEARNCW CODNEAR | 0      | 12406 | 220922.7 | 0      | 0      |
| Sweden   | CODVIa             | 0      | 12406 | 220922.7 | 0      | 0      |
| Sweden   | HAKENRTN           | 56.8   | 71    | 220922.7 | 0.8    | 0.0003 |
| Sweden   | HAKESOTH           |        | 71    | 220922.7 | 0      |        |
| Finland  | HAKENRTN           |        |       | 82989.1  |        |        |
| Finland  | HAKESOTH           |        |       | 82989.1  |        |        |
| Finland  | CODNEARNCW CODNEAR |        | 1028  | 82989.1  |        |        |
| Finland  | CODFAPL            |        | 1028  | 82989.1  |        |        |
| Finland  | CODICE             |        | 1028  | 82989.1  |        |        |
| Finland  | CODBA2532          | 521.7  | 1028  | 82989.1  |        | 0.0063 |
| Finland  | CODKAT             |        | 1028  | 82989.1  |        |        |
| Finland  | CODIS              |        | 1028  | 82989.1  |        |        |
| Finland  | CODVIa             |        | 1028  | 82989.1  |        |        |
| Finland  | CODIIIaW           |        | 1028  | 82989.1  |        |        |

Note that Catch dependency in Table SI.14 is shown on a country and stock basis. In order to have the Factor per country, we averaged the catch dependency of stocks on each country.

## Adaptive management (S4)

Adaptive Management has two indicators set at the country level: fisheries Management investment and fisheries Research investment. Both indicators are obtained directly from Sea Around Us (<http://www.seaaroundus.org/data/#/feru>). Normalization is within the sample. The formula for the factor Adaptive Management is the following:

$$ADAPTIVE\ MANAGEMENT = \frac{Research + Management}{2} \quad \text{Eq. 11}$$

**Table SI.15.** Adaptive Management indicator values and normalization.

| Countries | Research | Management | Normalized Research | Normalized Management | ADAPTIVE MANAGEMENT |
|-----------|----------|------------|---------------------|-----------------------|---------------------|
| BE        | 5385     | 4333       | 0.070               | 0.000                 | 0.034               |
| DK        | 12472    | 27710      | 0.170               | 0.280                 | 0.223               |
| DE        | 8030     | 13325      | 0.110               | 0.110                 | 0.106               |
| EE        | 806      | 8862       | 0.000               | 0.050                 | 0.029               |
| IE        | 8480     | 5839       | 0.110               | 0.020                 | 0.065               |
| ES        | 17871    | 71934      | 0.250               | 0.800                 | 0.524               |
| FR        | 20341    | 19279      | 0.280               | 0.180                 | 0.229               |
| LV        | 617      | 10759      | 0.000               | 0.080                 | 0.039               |
| LT        | 528      | 5910       | 0.000               | 0.020                 | 0.009               |
| NL        | 12811    | 18128      | 0.170               | 0.160                 | 0.169               |
| PL        | 1431     | 88672      | 0.010               | 1.000                 | 0.506               |
| PT        | 4115     | 18290      | 0.050               | 0.170                 | 0.108               |
| FI        | 2295     | 6021       | 0.030               | 0.020                 | 0.023               |
| SE        | 71149    | 15606      | 1.000               | 0.130                 | 0.567               |

## Social factors summary

Table SI.16 shows the summary of the different social factors across stock.

**Table SI.16.** Summary of the social factors per stock and country.

| Countries | FLEET.MOBILITY | CATCH.DEP.cod | CATCH.DEP.hake | ADAPTIVE.MNG |
|-----------|----------------|---------------|----------------|--------------|
| BE        | 0.22           | 0.970         | 0.996          | 0.034        |
| DK        | 0.79           | 0.959         | 0.995          | 0.223        |
| DE        | 0.44           | 0.764         | 0.999          | 0.106        |
| EE        | 0.31           | 0.948         | -              | 0.029        |
| IE        | -              | 0.989         | -              | 0.065        |
| ES        | 0.27           | 0.871         | 0.916          | 0.524        |
| FR        | 1              | 0.977         | 0.838          | 0.229        |
| LV        | 0.36           | 0.714         | -              | 0.039        |
| LT        | 0.15           | 0.464         | -              | 0.009        |
| NL        | 0.13           | 1.000         | -              | 0.169        |
| PL        | 0.14           | 0.401         | -              | 0.506        |
| PT        | 0.22           | 0.839         | 0.939          | 0.108        |
| FI        | -              | 0.921         | -              | 0.023        |
| SE        | -              | 0.722         | 0.996          | 0.567        |

## 5. Institutional Indicators and Factors

### Co-management (I1)

Co-management uses only one indicator relating the number of fishing organizations in a given country in 2017 (*N.organizations*), which is normalized within sample (Table SI.17). Data were obtained from [https://ec.europa.eu/fisheries/cfp/market/producer\\_organisations\\_en](https://ec.europa.eu/fisheries/cfp/market/producer_organisations_en).

**Table SI.17.** Number of organizations by country, normalization and Co-Management factor estimated.

| Country | <i>N.organizations</i> | <i>N.organizations norm.</i> | Co-management |
|---------|------------------------|------------------------------|---------------|
| BE      | 2                      | 0.00                         | 0.00          |
| DK      | 3                      | 0.03                         | 0.03          |
| DE      | 13                     | 0.33                         | 0.33          |
| EE      | 7                      | 0.15                         | 0.15          |
| IE      | 5                      | 0.10                         | 0.10          |
| ES      | 33                     | 1.00                         | 1.00          |
| FR      | 18                     | 0.51                         | 0.51          |
| LV      | 4                      | 0.08                         | 0.08          |
| LT      | 3                      | 0.05                         | 0.05          |
| NL      | 11                     | 0.28                         | 0.28          |
| PL      | 15                     | 0.26                         | 0.26          |
| PT      | 16                     | 0.36                         | 0.36          |
| SE      | 7                      | 0.13                         | 0.13          |

## Property rights (I2)

Property Rights factor is composed of one indicator (Swaps), which refers to the monetary exchange of quota in a country (Andersen et al., 2009) [10]. It can be negative (the country buys quota in exchange of money) or positive (the country sells quota in exchange of money). The indicator was calculated between 2000 and 2006. Indices are normalized within the sample.

**Table SI18.** Indicators and normalization of Property Rights

| Countries | Swaps<br>(million € 2000 – 2006) | Swaps' normalized | PROPERTY RIGHTS |
|-----------|----------------------------------|-------------------|-----------------|
| BE        | 8.00                             | 0.69              | 0.69            |
| DK        | 39.00                            | 0.81              | 0.81            |
| DE        | -165.00                          | 0.00              | 0.00            |
| EE        | 1.00                             | 0.66              | 0.66            |
| IE        | 15.00                            | 0.71              | 0.71            |
| ES        | 87.00                            | 1.00              | 1.00            |
| FR        | -49.00                           | 0.46              | 0.46            |
| LV        | 2.00                             | 0.66              | 0.66            |
| LT        | 3.00                             | 0.67              | 0.67            |
| NL        | 22.00                            | 0.74              | 0.74            |
| PL        | 8.00                             | 0.69              | 0.69            |
| PT        | 21.00                            | 0.74              | 0.74            |
| FI        | 2.00                             | 0.66              | 0.66            |
| SE        | 0.00                             | 0.65              | 0.65            |

### Quotas (I3)

Quotas are calculated using the Total Allowable Catch (TAC) above advice in 2015. Values were obtained from Carpenter et al. (2016) and depend on species and country, but not on stock. To calculate the percentage of TAC above advice we use the formula  $(TAC - ICES\ advice) / ICES\ advice * 100$ . Normalization is inverse within the sample.

**Table SI19.** Quotas factor per species.

| COUNTRIES | Quotas COD | Quotas HAKE | QUOTAS COD<br>norm (inverse) | QUOTAS HAKE<br>norm (inverse) |
|-----------|------------|-------------|------------------------------|-------------------------------|
| BE        | 71.78      | 10.80       | 0.958                        | 0.976                         |
| DK        | 3616.57    | 133.57      | 0.000                        | 0.967                         |
| DE        | 881.78     | 12.93       | 0.739                        | 0.976                         |
| EE        | 150.53     | -           | 0.936                        | -                             |
| IE        | 222.16     | -           | 0.917                        | -                             |
| ES        | -84.89     | 1723.80     | 1.000                        | 0.844                         |
| FR        | 429.14     | 608.08      | 0.861                        | 0.930                         |
| LV        | 566.17     | -           | 0.824                        | -                             |
| LT        | 380.53     | -           | 0.874                        | -                             |
| NL        | 241.36     | 8.93        | 0.912                        | 0.976                         |
| PL        | 1158.49    | -           | 0.664                        | -                             |
| PT        | -27.41     | -27.41      | 0.984                        | 0.979                         |
| FI        | 281.91     | -           | 0.901                        | -                             |
| SE        | 1842.97    | 13.12       | 0.479                        | 0.976                         |

## Strength (I4)

Strength is a single indicator factor built from the IUU Fishing Index [14], which measures the level of compliance with fishing regulations and effort against Illegal, Unreported, Unregulated Fishing. The compliance index ranges from 1 (best compliance) to 5 (worst compliance), and is therefore reversed in the normalization, using within sample normalization. Table SI.20 shows the original value, normalized values, and factor.

**Table SI.20.** Compliance indicator and Strength factor.

| Countries | Compliance | Compliance'<br>(normalized) (reversed) | STRENGTH |
|-----------|------------|----------------------------------------|----------|
| BE        | 1.430      | 1.000                                  | 1.000    |
| DK        | 1.940      | 0.549                                  | 0.549    |
| DE        | 1.890      | 0.593                                  | 0.593    |
| EE        | 1.670      | 0.788                                  | 0.788    |
| IE        | 1.850      | 0.628                                  | 0.628    |
| ES        | 2.560      | 0.000                                  | 0.000    |
| FR        | 2.280      | 0.248                                  | 0.248    |
| LV        | 1.570      | 0.876                                  | 0.876    |
| LT        | 2.020      | 0.478                                  | 0.478    |
| NL        | 2.020      | 0.478                                  | 0.478    |
| PL        | 1.680      | 0.779                                  | 0.779    |
| PT        | 2.450      | 0.097                                  | 0.097    |
| FI        | 1.670      | 0.788                                  | 0.788    |
| SE        | 1.730      | 0.735                                  | 0.735    |

## Institutional factors summary

The final set of institutional factors per species is available in Table SI.21.

**Table SI.21.** List of Institutional factors.

| COUNTRIES | ORGANIZATION | PROPERTY.RIGHTS | STRENGTH | QUOTAS.cod | QUOTAS.hake |
|-----------|--------------|-----------------|----------|------------|-------------|
| BE        | 0.00         | 0.69            | 0.600    | 0.958      | 0.976       |
| DK        | 0.03         | 0.81            | 0.800    | 0.000      | 0.967       |
| DE        | 0.33         | 0.00            | 0.800    | 0.739      | 0.976       |
| EE        | 0.15         | 0.66            | 0.300    | 0.936      | 0.000       |
| IE        | 0.10         | 0.71            | 0.000    | 0.917      | 0.000       |
| ES        | 1.00         | 1.00            | 0.300    | 1.000      | 0.844       |
| FR        | 0.51         | 0.46            | 0.500    | 0.861      | 0.930       |
| LV        | 0.08         | 0.66            | 0.500    | 0.824      | 0.000       |
| LT        | 0.05         | 0.67            | 0.400    | 0.874      | 0.000       |
| NL        | 0.28         | 0.74            | 0.800    | 0.912      | 0.976       |
| PL        | 0.26         | 0.69            | 0.700    | 0.664      | 0.000       |
| PT        | 0.36         | 0.74            | 1.000    | 0.984      | 0.979       |
| FI        | -            | 0.66            | 0.800    | 0.901      | 0.000       |
| SE        | 0.13         | 0.65            | 1.000    | 0.479      | 0.976       |



## 6. Resilience factors summary

Tables SI.22 and SI.23 show the different factors used to calculate the resilience of countries.

**Table SI.22.** Factors average and standard deviations.

| FACTOR |                     | mean | Standard deviation |
|--------|---------------------|------|--------------------|
| E2     | ABUNDANCE           | 0.47 | 0.18               |
| E3     | TEMPERATURE         | 0.36 | 0.21               |
| E4     | OVEREXPLOITATION    | 0.58 | 0.22               |
| E5     | RECOVERY            | 0.63 | 0.12               |
| S1     | GEAR DIVERSITY      | 0.50 | 0.51               |
| S2     | FLEET MOBILITY      | 0.37 | 0.28               |
| S3     | CATCH DEPENDENCY    | 0.91 | 0.12               |
| S4     | ADAPTIVE MANAGEMENT | 0.19 | 0.20               |
| I1     | CO-MANAGEMENT       | 0.25 | 0.27               |
| I2     | PROPERTY RIGHTS     | 0.65 | 0.22               |
| I3     | QUOTAS              | 0.14 | 0.24               |
| I4     | DEVELOPMENT         | 0.60 | 0.35               |

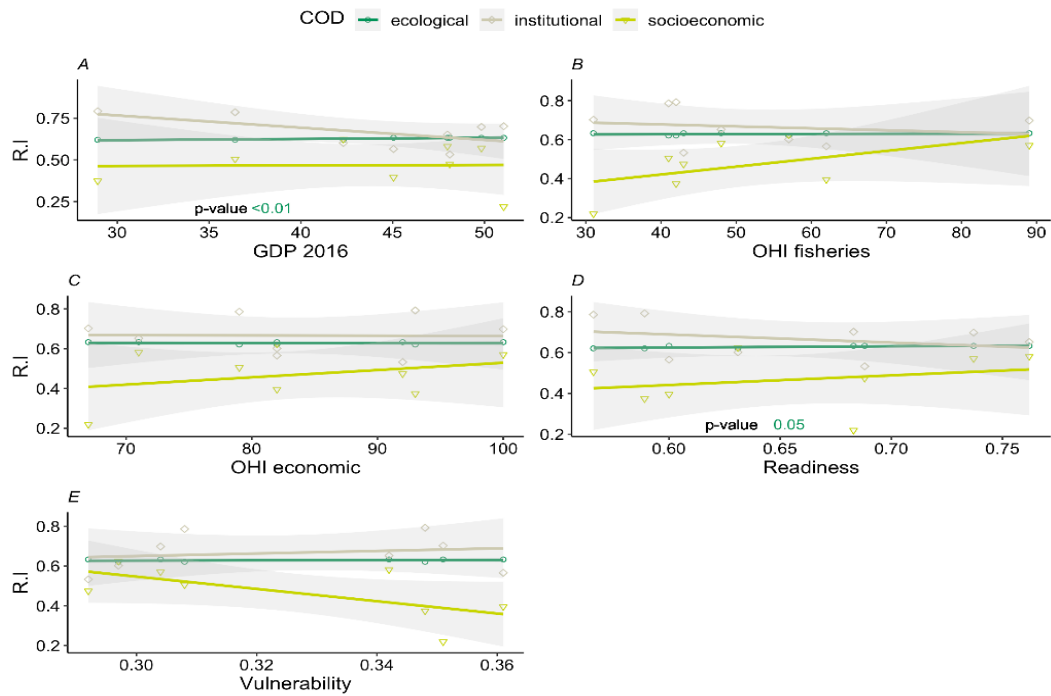
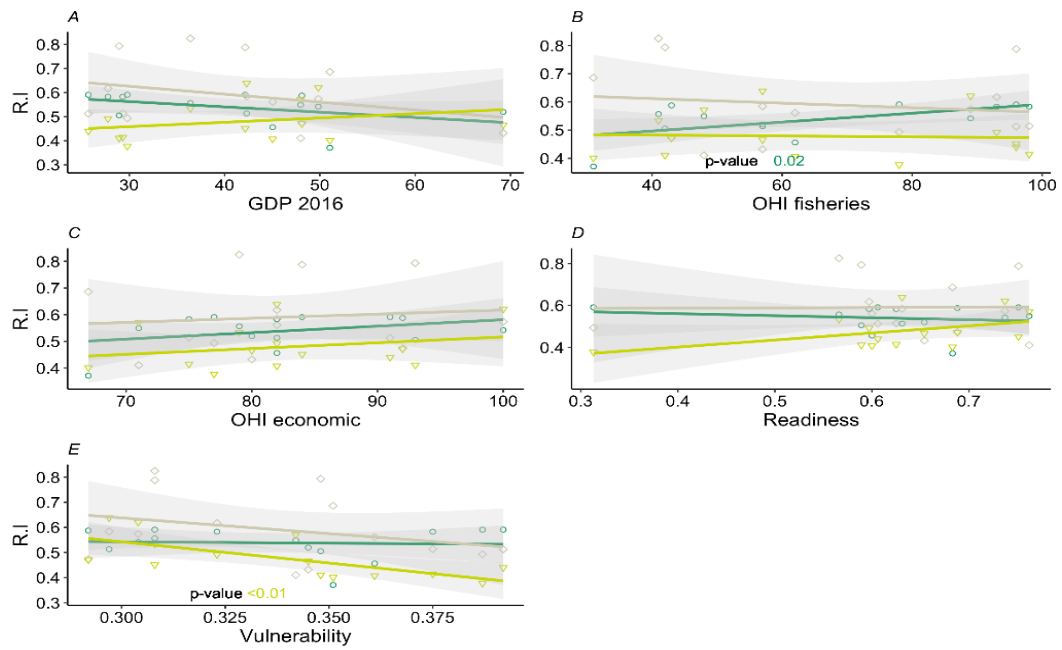
**Table SI.23.** Factors average and standard deviation in index, per species.

| Factor |                     | cod         |           | hake        |           |
|--------|---------------------|-------------|-----------|-------------|-----------|
|        |                     | <i>mean</i> | <i>sd</i> | <i>mean</i> | <i>sd</i> |
| E2     | ABUNDANCE           | 0.41        | 0.19      | 0.60        | 0.05      |
| E3     | TEMPERATURE*        | 0.21        | 0.00      | 0.64        | 0.00      |
| E4     | OVEREXPLOITATION**  | 0.47        | 0.19      | 0.76        | 0.14      |
| E5     | RECOVERY            | 0.62        | 0.14      | 0.63        | 0.06      |
| S1     | CO-MANAGEMENT       | 0.25        | 0.27      | 0.25        | 0.27      |
| S2     | PROPERTY RIGHTS     | 0.65        | 0.22      | 0.65        | 0.22      |
| S3     | DEVELOPMENT         | 0.60        | 0.35      | 0.60        | 0.35      |
| S4     | QUOTAS              | 0.14        | 0.14      | 0.14        | 0.32      |
| I1     | GEAR DIVERSITY*     | 1.00        | 0.00      | 0.00        | 0.00      |
| I2     | FLEET MOBILITY      | 0.37        | 0.28      | 0.37        | 0.28      |
| I3     | CATCH DEPENDENCY**  | 0.88        | 0.14      | 0.98        | 0.03      |
| I4     | ADAPTIVE MANAGEMENT | 0.19        | 0.20      | 0.19        | 0.20      |

\*Factors where indicator data is not available on a country basis. \*\*Reversed direction of factor.

## 7. Index performance

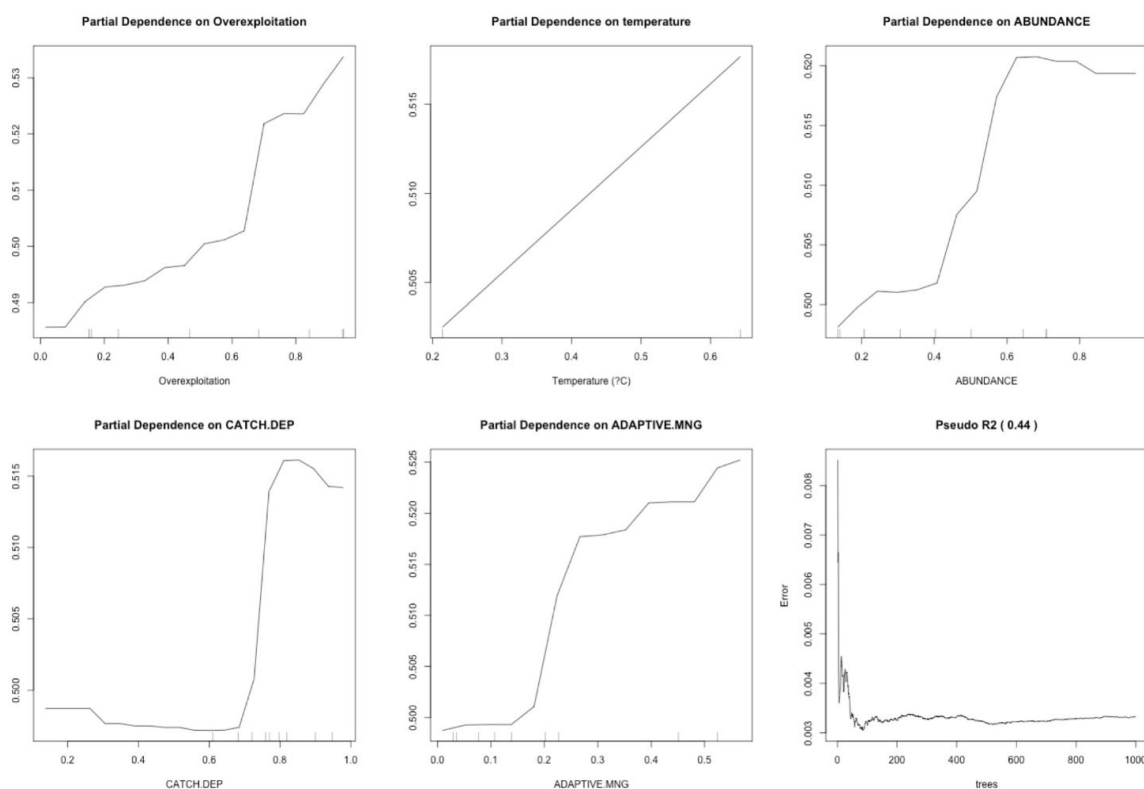
We compare our index to other indices in the literature that are used in climate change vulnerability and fisheries performance, following [7]. Figure SI.8 shows the results for the correlation of our resilience index with the Ocean Health Index [15], Gross Domestic Product in countries (WB), Readiness and Vulnerability [16]. COD fisheries index (ecological dimension) is positively correlated with the OHI fisheries (cod,  $p < 0.02$ ); and negatively correlated (its institutional dimension) with the Vulnerability index. For Hake, the index results are correlated with GDP ( $< 0.01$ ) and to the readiness index ( $< 0.05$ ), in both cases only the ecological resilience dimension.



**Figure SI.7.** COD (above) and hake (below) resilience index comparison with country GDP, OHI, Readiness and vulnerability indices.

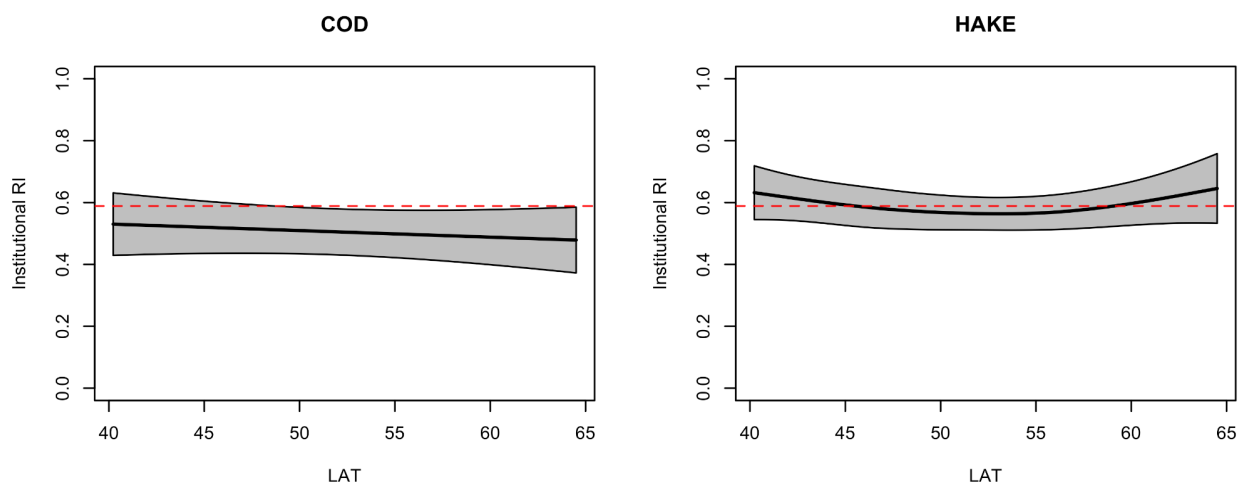
## 8. Additional analyses

We perform a Random Forest model for exploring which factors have more influence on the resilience index value. We use the “randomForest” package (version 4.6-14 [17]) in R, following Rubio et al (2020) [18] and other applications in the fisheries science (i.e., Melnychuk, Banobi, & Hilborn, 2013 [19]). Random forest models allow us to explore non-linear relationships among predictors (index factors) and the response variable (resilience index), with no assumptions made on the distribution of the response variable [18]. The random forest model we use builds 1,000 regression trees to stabilize the mean squared error (MSE) of the model. From these models the best predictors are chosen once the tree is completed, and the variable importance is shown as  $\%lnvMSE$  (Figure 3 in main text). To explore the directionality of the predictors, we show in Figure SI.9 the partial dependence plots.



**Figure SI.8.** Partial dependence and Pseudo R2 of the random forest model.

We have also applied Generalized additive models (GAM) with quasibinomial family and logit link to analyze whether the resilience scores vary with latitude. GAM fitting was conducted with the ‘mgcv’ package of R [20, 21]. GAM fits for the institutional dimension of resilience as a function of latitude of countries are shown in Figure SI.10. We find differences between species, with higher institutional resilience for Hake, but no evidence of a significant effect of latitude on the index for any species.



**Figure SI.9** GAM fits of institutional resilience as a function of latitude by species for the institutional dimension. Estimator (black line) with 95% confidence bands (grey band), and mean institutional resilience index (dashed red line).

Finally, we count the missing indicator data across the index calculation to keep track on the uncertainty of our results. We do this as an alternative to a confidence analysis based in expert opinion on the quality of indicators, as we have not performed a stakeholder analysis and involvement in this approach. We find that missing values are very minor both for hake and cod, and the summary tables are presented in Table SI.24 and SI.25.

**Table SI.24** Indicator missing values counting for the resilience index for cod.

| Country          | NA count-cod |                |               |
|------------------|--------------|----------------|---------------|
|                  | Ecological   | Socio-economic | Institutional |
| <b>BE</b>        | 0            | 0              | 0             |
| <b>DK</b>        | 0            | 0              | 0             |
| <b>DE</b>        | 0            | 0              | 1             |
| <b>EE</b>        | 0            | 0              | 0             |
| <b>IE</b>        | 0            | 2              | 0             |
| <b>ES</b>        | 0            | 0              | 0             |
| <b>FR</b>        | 0            | 0              | 0             |
| <b>LV</b>        | 0            | 0              | 0             |
| <b>LT</b>        | 0            | 0              | 0             |
| <b>NL</b>        | 0            | 0              | 0             |
| <b>PL</b>        | 0            | 0              | 0             |
| <b>PT</b>        | 0            | 0              | 0             |
| <b>FI</b>        | 0            | 1              | 0             |
| <b>SE</b>        | 0            | 2              | 0             |
| <b>Total NAs</b> | 0            | 5              | 1             |

**Table SI.25** Indicator missing values counting for the resilience index for hake.

| Country          | NA count-hake |                |               |
|------------------|---------------|----------------|---------------|
|                  | Ecological    | Socio-economic | Institutional |
| <b>BE</b>        | 0             | 0              | 0             |
| <b>DK</b>        | 0             | 0              | 0             |
| <b>DE</b>        | 0             | 0              | 0             |
| <b>ES</b>        | 0             | 0              | 0             |
| <b>FR</b>        | 0             | 0              | 0             |
| <b>NL</b>        | 0             | 2              | 0             |
| <b>PT</b>        | 0             | 2              | 0             |
| <b>SE</b>        | 0             | 1              | 0             |
| <b>Total NAs</b> | 0             | 5              | 0             |

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