THE GLOBAL FISHING INDEX
2021

Technical Methods

About

This document outlines the methods used by the Minderoo Foundation to produce the 2021 Global Fishing Index. It should be read in conjunction with the Global Fishing Index Key Insights report, Governance Conceptual Framework and Indicator Codebook.

Research partners

The Sea Around Us is a research initiative at the University of British Colombia and the University of Western Australia. Their work focuses on assessing the impacts of fisheries on marine ecosystems and offering mitigating solutions for stakeholders. For the Global Fishing Index, the Sea Around Us supported the analysis of the state of fish stocks, including collating publicly available data and generating novel estimates of the relative abundance of fish stocks.

Data statement

Visit www.globalfishingindex.org to explore the data behind the Global Fishing Index and download country-level results.

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Additional detail is available by contacting globalfishingindex@minderoo.org.

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Cover Image: Shoal of saitfish, Similan Islands National Park. Photo credit: James R.D. Scott via Getty Images.

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OVERVIEW

The Global Fishing Index (the Index) assesses global and country-level progress towards the United Nations' Sustainable Development Goal (SDG) target 14.4:

"...to effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics".

The Index uses two metrics to assess performance in coastal countries around the world:

1. **Progress towards SDG 14.4, based on the state of fish[1] stocks in national waters.**
2. **Fisheries governance and the mechanisms in place to ensure fishing is sustainable.**

These two metrics are combined to award each country an overall grade that captures current performance and the outlook for improving fisheries, based on our assessment results. The 2021 report includes 142 coastal countries and territories,[2] which together account for about 95 per cent of total global marine catches in 2018,[3] our baseline year for data.

Our analysis focuses on fisheries within each country's national waters, a band of ocean that extends 200 nautical miles offshore from the coastline. This includes national, shared and straddling stocks that are managed by regional fisheries management organisations (RFMOs) but are caught within national waters. We aim to expand coverage to include additional countries and jurisdictions, including the High Seas, in future editions of the Index.

Trawler fleet docked at pier - Middelburg, Netherlands
Photo credit: Cavan Images via Getty Images

MEASURING PROGRESS TOWARDS SDG TARGET 14.4

The primary aim of SDG target 14.4 is for every coastal country to implement effective management systems and take action to restore fish populations in their waters to levels of abundance that will produce maximum sustainable yield (MSY).

MSY is the maximum catch that can be harvested continuously from a stock, under constant and current environmental conditions, without affecting the stock's long-term productivity. MSY is the most common type of reference point used in fisheries to determine sustainability and is embedded in international policy, including the *1982 United Nations Convention for the Law of the Sea.*

To measure each country's progress towards SDG target 14.4, we used publicly available information and reconstructed catch estimates generated by the Sea Around Us initiative to develop two metrics:

1. **Stock sustainability:** the proportion of assessed stocks that are estimated to be at or above a level of abundance that enables MSY.
2. **Data availability:** the proportion of a country's total reconstructed catch that comes from 'assessed' stocks, namely stocks that have sufficient data to determine their relative abundance (based on biomass) and are included in our dataset.

We combined these two metrics to produce a single Progress score, which represents a country's current level of progress towards SDG target 14.4. The score ranges from 0 (no evidence of progress) to 100 (all fish stocks assessed and estimated to be at or above sustainable levels of abundance).

RECONSTRUCTING FISHERIES CATCHES

The Food and Agriculture Organization of the United Nations (FAO) has published annual global fisheries statistics (such as catch) since 1950. While these statistics are comprehensive in their coverage of the coastal countries included, reporting differences between countries makes comparison difficult. For example, catch data may not be collected for particular fisheries sectors (e.g. artisanal or recreational fishing), catch types (e.g. discards), species or may be collected at varying levels of detail between countries or between sectors within a country.[4] Additionally, countries may not report all data they collect to the FAO, leading to gaps in coverage.[5-6] Specifically, data on the artisanal, subsistence and recreational fishing sectors, collectively referred to as 'small-scale fisheries', are often missing.[7]

The Sea Around Us' catch reconstruction process[8,9,10] is based on the idea that no fishery is invisible: even if catch data are not recorded or reported, fisheries interact with the society in which they are embedded, leaving a 'shadow' that can be used to estimate missing information.[11] As part of the reconstruction process, the Sea Around Us considered additional types of information (such as trade records, household consumption, employment data and vessel registries) to estimate catches not captured in official statistics.[12]

This catch reconstruction process involved several steps. First, historical information on *reported* catch was collated, including data reported to the FAO and published national catch statistics.[13] Next, potential *unreported* fisheries sectors or catch data components were identified and, using alternative sources of information, their catch values were estimated to generate a complete catch time series dating from 1950 through 2018. Additionally, the *taxonomic resolution* of the data – that is, the precision with which species (taxa) are identified in the catch records – was improved using information on what was caught, traded and consumed, and where it was available. Once the *total reconstructed* catch had been estimated, each component was *spatially allocated* to the location where it was most likely caught, based on the source of the original catch data, the characteristics of the fleet taking the catch, known fishing rights and access agreements and the biology and known geographic distribution of the species caught. The result is a time series of mapped catch data[14] that includes spatially-disaggregated estimates of annual catch, allocated to a distinct area of the ocean, and further split by fishing country (flag of the fishing vessel harvesting the catch), species, reporting status and fishing gear.

ASSESSING STOCK SUSTAINABILITY

To calculate stock sustainability, we quantified the proportion of assessed fish stocks, globally and within each country's waters, estimated to be at or above a level of abundance that enables MSY.

From a fisheries management perspective, a fish stock is a discrete population of a species from which catches are taken in a fishery, and that is spatially or ecologically separate to other populations of the same species, such that changes in one population does not, in theory, impact another. We used a 'single species' approach to estimate and classify the biological sustainability of fish stocks, based on their current abundance (measured in biomass) relative to unfished levels. Our approach did not consider the broader impacts of fishing on marine communities or ecological sustainability. Despite their importance, there is a general absence of information and methods for assessing these broader aspects of sustainability at a global level. We are committed to advancing the use of these broader integrated, ecosystem approaches in future iterations of the Index. For now, we are unable to estimate ecological sustainability at a global scale.

Sardine shoal, blocking the sunlight - Cebu, Philippines
Photo credit: Paul Cowell photography via Getty Images

Identifying fish stocks

Estimating the relative abundance of fish stocks requires data on both the biology of the species (such as their natural mortality, productivity and reproduction rate) and the level of exploitation (such as catch or fishing effort estimates over time). The availability of these data varies substantially, with some fisheries and areas subject to intense, longer-term monitoring, while others are entirely absent from official fisheries records. To build a global dataset of relative abundance estimates, we conducted detailed research on a country-by-country and stock-by-stock basis.

To identify stocks for inclusion in our analysis, we compiled a list of the species with the highest total estimated catches from 1950 to 2018 (based on reconstructed data) within countries' national waters. Where available, we used formally-defined stock boundaries to identify distinct fish stocks within a given species. In the absence of formally-defined boundaries, we used marine ecoregions to split catches of a given species into separate stocks. Marine ecoregions are used to classify the world's marine coasts and shelves based on biogeography and represent broad-scale patterns of species and communities in the ocean.[15] These ecoregions comprise ecologically distinct areas, which can be used as proxies for the geographical ranges of individual stocks, assuming that the species is not migratory. Using the mapped reconstructed catch data, we then generated stock-level catch times series data for each 'stock' and allocated it to national waters based on their overlap.

Estimating stock abundance

We collated published assessment results and other fisheries information to build a global dataset of relative abundance for as many stocks as possible within each country's waters, including national, shared and straddling stocks.[16]

Research efforts focused on identifying recent stock assessments that could be used to evaluate a stock's current abundance relative to unfished levels. We used a tiered approach to estimate relative abundance of each stock (Figure 1), with methods applied preferentially in descending order, based on data availability:

1. **Relative abundance estimates for stocks with recent published official assessments** were included as reported. Recent 'official' assessments are those published by national management authorities since 2016 or by RFMOs since 2014. Exceptions were made where local experts confirmed earlier reported estimates were still accurate and current. Information from older assessments, or assessments from other sources, were used to inform steps 2 and 3.
2. **Stocks with catch time series data, plus an index of relative abundance over time** (e.g. times series of catch-per-unit-effort (CPUE) or relative abundance from scientific surveys) were analysed using the Bayesian Schaefer Model (BSM).[17]
3. **Stocks with catch time series data, plus qualitative or quantitative information on current stock abundance** (e.g. from peer-reviewed literature, older stock assessments, length-based estimates of stock depletion and expert knowledge) were analysed using an updated version of CMSY.[18] Additional exploratory analyses were conducted using CMSY++ when only catch and biological data were available, but these results were excluded from the Index due to their lower reliability.[19,20] These could be integrated with additional information as it becomes available to expand the scope of the Index in the future.

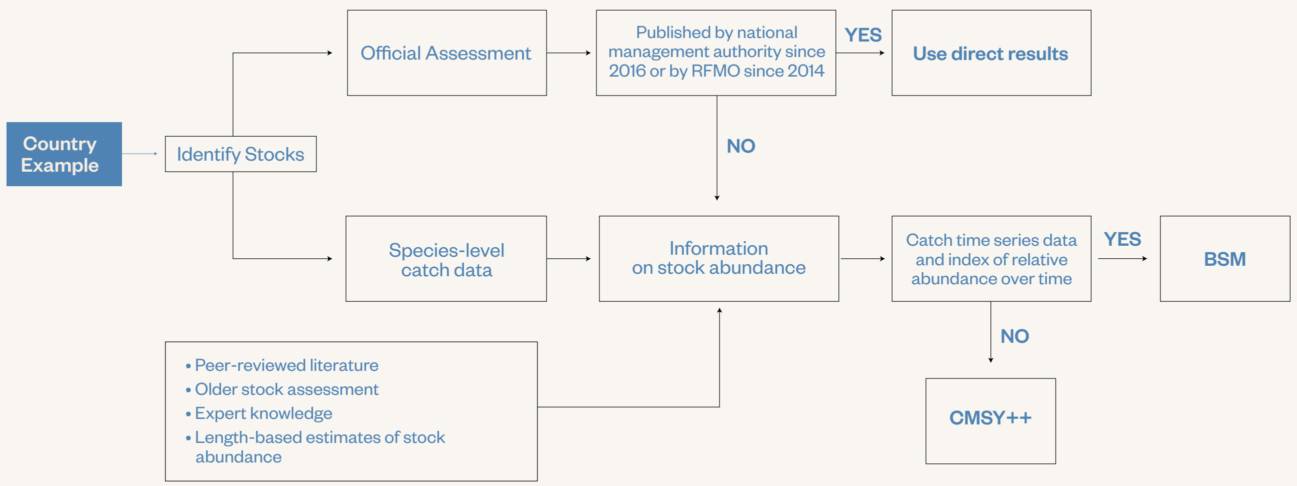


***Figure 1:** Approach for estimating current stock abundance, based on the data available for a given stock. Where available, published recent official assessment results were used directly. Where stocks lacked a recent official assessment but catch time series data and an index of abundance over time were available, we used the Bayesian Schaefer Model (BSM). Stocks with only catch time series data, and recent qualitative or quantitative information about stock abundance, were analysed using an updated version of CMSY (CMSY++), to produce novel estimates of relative abundance.*

Stocks lacking recent published official assessments or sufficient data to estimate abundance with a high level of confidence were excluded from the Index and are considered 'unassessed'.

Using this tiered approach, we built a global database of relative abundance (B/B_0 estimates) for 1,439 fish stocks. Nearly a third of these (527 stocks) have relative abundance estimates obtained directly from recent official assessments. The relative abundance of the other 912 stocks are novel estimates, produced using the data-limited models described above (Table 1).

Table 1: Number of stocks included in the Index, based on the method used to generate the current (2018) estimate of abundance relative to unfished levels.

Estimate source	Number of stocks
Official assessment	527
BSM	516
CMSY++ with abundance priors	396
Total	1,439

Stocks with recent official assessments

For stocks with recent official assessments, the reported estimate of current abundance, relative to unfished levels, was accepted as the current relative abundance of the stock. Where the assessment provided an estimate of current abundance relative to abundance at MSY (B/B_{MSY}), we divided this estimate by two to convert it to current abundance relative to unfished levels (B/B_0). This assumed that MSY occurs at 50 per cent of unfished levels of abundance.

We undertook desk-based research and used the 'Sea Around Us' existing networks of local fisheries experts to identify official stock assessments and published fisheries data for each country. The research team conducted data searches predominantly in English and research networks are not evenly distributed worldwide, this resulted in some bias towards English-speaking countries and regions. Additional detailed searches and expert workshops were undertaken in China, given its importance as the highest global producer of fisheries catch[21] and limited public availability of fisheries statistics and assessment results. For example, a large portion of China's national catch is reported in national statistics as 'miscellaneous fish', with only a small proportion of catches reported at species level.[22]

Stocks without recent official assessments

Many fish stocks globally lack recent official assessments, largely due to a lack of data, technical expertise and resources.[23] However, recent advances have resulted in the development of new methods that can estimate stock abundance with limited data, such as by combining biological data, catch time series data and additional information to generate estimates of current abundance, relative to unfished levels.[24,25,26,27,28]

We used two such models (BSM[29] and CMSY++[30]) to produce novel estimates of abundance for stocks that lack recent official assessments but have sufficient catch, effort and/or relative abundance data.

These methods are based on an approach formulated by Schaefer[31-32] to mathematically describe and understand fish population dynamics. This approach ('surplus-production' modelling) assumes that there is a specific carrying capacity (k, similar to a stock's unfished biomass [B_0]) for any fish stock in a given ecosystem, and if the abundance of that stock is reduced (such as through fishing) the stock will tend to grow back towards its carrying capacity.

In this context, the population growth rate (r) will be determined by the attributes of the individuals in the population (e.g. individual growth rate, age at first maturity, natural mortality, fecundity etc.) and by the current abundance (or biomass, B) of the population. For example, a very small population cannot grow by a large amount, even if its growth rate is relatively high. Alternatively, a population near its carrying capacity will also not grow by a large amount. Consequently, the maximum growth rate of any given population is approximately half the carrying capacity (i.e. $B_0/2$). Based on this theory, fish stocks can be maintained at any given biomass by extracting (e.g. via fishing) the amount of biomass equivalent to the population's natural growth rate each year. Given that the growth rate is highest at approximately 50 per cent of unfished biomass, this biomass is considered to generate the maximum sustainable yield (i.e. B_{MSY}).

Both BSM and CMSY++ are built on this theory and estimate parameters including MSY and B_{MSY}, based on the most probable r and k pairs filtered by a Monte Carlo test. The BSM method relies on catch time series and relative abundance data, such as catch per unit of effort. The CMSY++ approach consists of tracing a number of potential trajectories of an exploited fish stock's likely biomass and identifying the trajectories that remain viable (it does not predict that the stock will go extinct) when considering the catch times series and other constraints, such as relative abundance estimates, ranges for the stock's carrying capacity (k) and the range of likely values for the population's growth rate (r).[33] The model then identifies the average of the r and k pairs that produce the 'most viable' abundance (biomass) trajectory, and then estimates current abundance relative to unfished levels (B/B_0) for the last year of assessment (2018).

Constraints applied to the model refer specifically to independent prior knowledge about the reduction of biomass by fishing (in per cent) relative to the unfished biomass at the start of the time series (or the year when the fishery was opened) and the reduction in biomass at the end of the time series, also relative to the unfished biomass. If available, an intermediate estimate of the relative biomass at a given point within the time series is also used to improve model precision.

Data to inform these 'priors' was obtained from reports by government agencies, academic institutions and research agencies and peer-reviewed literature including:

- estimates of relative stock abundance, including current abundance (biomass, 'B') relative to unfished abundance (unfished biomass, 'B_0') and/or abundance relative to abundance at MSY (biomass at MSY, 'B_{MSY}')[34] from previous assessments
- relative biomass estimates derived from a length-based Bayesian biomass estimation method (LBB),[35] which allows the estimation of intermediate biomass priors from published length frequency data
- fisheries independent survey data
- indices that can be used as a proxy for relative abundance, for example CPUE.

Additional qualitative knowledge about the state of a given stock by a local expert (e.g. 'good', 'not as good as it used to be', 'bad' and 'very bad') was also used to generate model priors. This information was translated into broad percentages or ranges relative to unfished biomass and used as model constraints. For example, an expert assessment as 'good' translated into a relative biomass window of 40–80 per cent of unfished biomass, while a 'bad' assessment was assigned a window of 10–40 per cent of unfished biomass.

Quality control of stock abundance data

All BSM and CMSY++ analyses underwent an initial internal review, in which results were compared against inputs to identify possible errors, with uncertain or unreliable results excluded from the dataset. Additionally, only stocks with a minimum of 20 consecutive years of catch data were considered suitable for analysis. This is the minimum time in which catch volume fluctuations could reasonably be expected to reflect changes in underlying biomass, rather than other short-term variations. Finally, stocks with more than 20 per cent of their total catch classified as 'discards' were excluded from the dataset, as discards are often poorly documented over time, resulting in an unreliable catch time series.[36]

Classifying stock status

We used the relative abundance estimates to classify the status of each stock. Stocks whose current abundance was estimated to be at or above the level that produces MSY were classified as 'sustainable', while those whose abundance was below this level were classified as 'overfished'. This approach recognises that MSY should be viewed as a lower limit, not a target for stock sustainability.

While we recognise that abundance-based reference points are likely to vary between stocks based on their biological characteristics, we applied a single threshold for all stocks in our dataset. This threshold is based on fisheries theory, which predicts that MSY occurs at 50 per cent of unfished levels of abundance.[37] However, to account for uncertainties in the data and models, we considered stocks estimated to be at or above 40 per cent of unfished levels as 'sustainable'. This 10 per cent confidence band aligns with the uncertainty observed in our data for relative abundance estimates generated using CMSY++ and is consistent with the classification method used by the FAO.[38]

In our dataset, 219 stocks were assessed based on spawning potential. In these instances, stocks with a relative value of spawning stock biomass greater than or equal to 20 per cent of the unfished level were classified as 'sustainable', while those whose abundance was below this level were classified as 'overfished'.

This approach enables direct comparison of results across countries within our dataset and with other estimates. The use of a single reference point for all species also removes any incentive for countries to set lower, unsupported levels of MSY.

We conducted sensitivity analyses to explore how reducing the confidence band around MSY to define a stock as sustainable or overfished would impact Index results. Specifically, we tested the impacts of including a 10 per cent confidence band around MSY, a five per cent confidence band around MSY and removing the band all together.

As expected, changing the confidence band resulted in an increase in the number of stocks that are considered overfished, from 642 stocks globally using a 10 per cent confidence band to 728 and 812 stocks at five per cent and no band, respectively. As a result of these changes, the global stock sustainability score (estimated as the proportion of assessed stocks that are classified as 'sustainable')Would drop from 55 per cent to 49 and 44 per cent, respectively. Country-level stock sustainability would also reduce, from an average of 70 per cent to 66 and 60 per cent, respectively (Figure 2a). These changes in stock sustainability would reduce the Progress score for 105 countries (5 per cent band) and 125 (no band), Figure 2b,c).

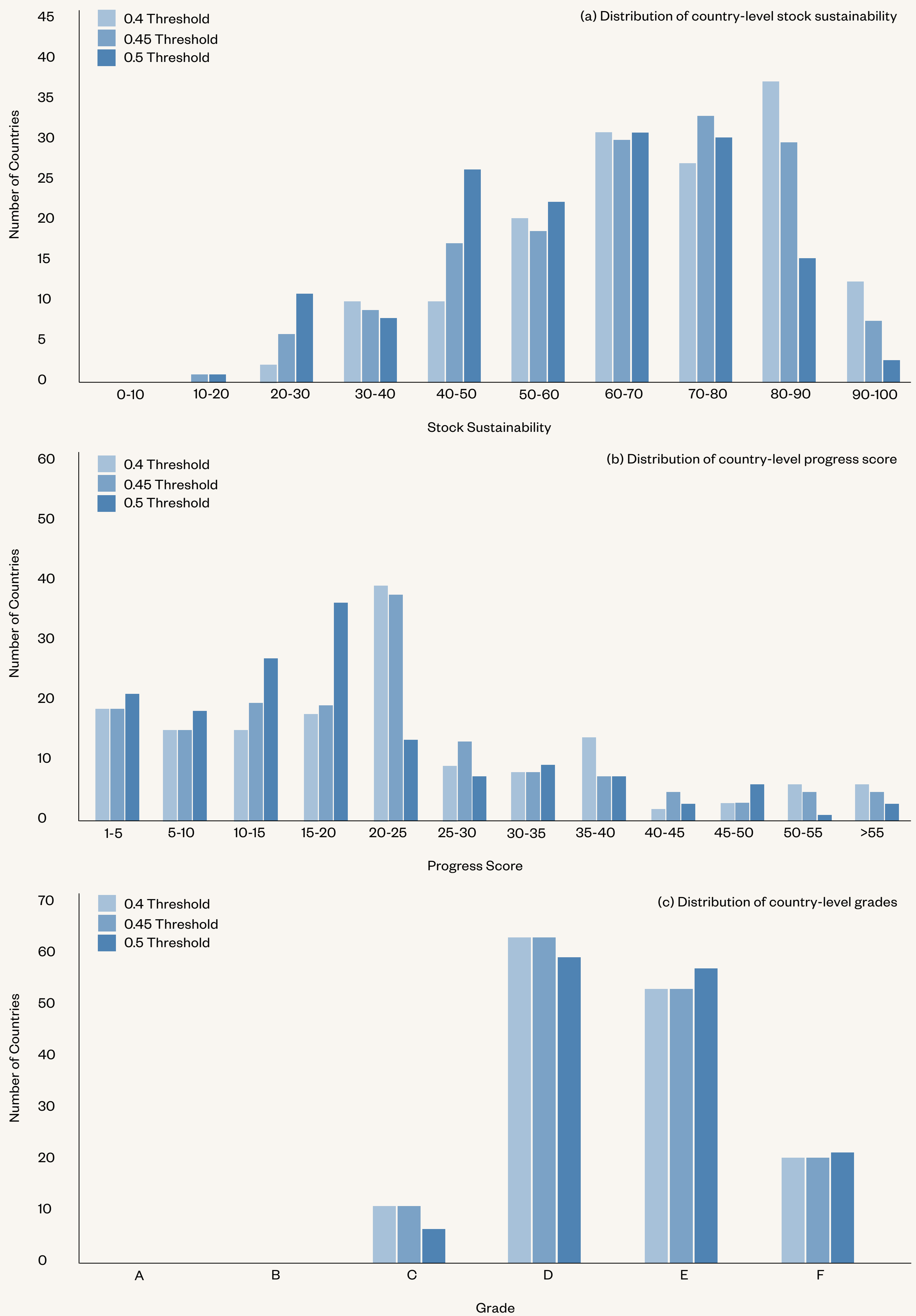


Figure 2: Distribution of country-level (a) stock sustainability, (b) Progress score and (c) overall grades under the scenarios of 10 per cent, 5 per cent, or no confidence band around MSY when scoring stock sustainability.

Stock exclusion criteria

We excluded stocks with insufficient data to estimate stock abundance, including stock estimates generated by CMSY++ without an 'end biomass' prior. Additionally, all stocks within a country's national waters with less than one tonne total reconstructed catch between 1990 and 2018 were excluded to ensure country-level stocks were not misidentified due to the catch allocation process.

We also excluded all salmon stocks (*Oncorhynchus* spp. and *Salmo* spp.) assessed using CMSY++ from the Index dataset. The CMSY model does not account for the distinct life history features of anadromous species like salmon, where the interaction between population dynamics and life history is directly impacted by changes to environmental conditions (i.e. spatial separation when migrating between two habitats, in the case of salmon stocks from brackish or marine water to freshwater for breeding).[39,40] Additionally, there is little year-to-year carryover or accumulation of salmon spawning biomass, as the spawning stock is primarily comprised of new recruitment first-time spawners.[41]

Quality control of stock sustainability data

To ensure integrity and reliability of the stock-level data included in the Index and that country-level results were based on the best available data, we undertook a comprehensive quality control process. We included only robust, complete and accurate stock-level data. We used a quality assurance protocol to maintain consistency and standardisation between annotators, eliminate any data manipulation and reduce human error and data mishandling.

The process consisted of a robust country-level review of each individual stock with data available (that is, before applying inclusion/exclusion filters) and included desk-based research to:

1. compare allocated catch to the baseline reconstructed catch values (Quantitative Aquatics i.e. QA1) per species from the Sea Around Us website.
2. review publicly available information to improve country-level data, including the number of stocks assessed, total catch values, catch data sources and stock abundance. Discrepancies in literature and dataset were investigated with either in-country experts or analysts from the Sea Around Us.
3. collect additional information, including recent government reports or other published fisheries assessments for model priors. This applied especially to data-limited stocks within a country's national waters that would be excluded from the Index based on reliability requirements.
4. ensure the relative abundance (B/B_0) estimates aligned with current and available information of stocks in that country's national waters.
5. compare the sum of stock level catches within our dataset to the total catch value reported for each country (based on reconstructed catches for 1990–2018) to identify stocks with species level catch that were potentially missing from our dataset
6. identify and address any user errors in data compilation and transfer.

Additionally, we consulted local (regional and/or country level) experts with specific country or technical knowledge as an external expert review process.

These experts were asked to validate or improve the stock-level datasets by reviewing the list of stocks included in a country's assessment, the relative levels of catch and the stock abundance estimates applied to each stock. Additionally, local experts were asked to identify any missing or excluded species/stocks and provide recent data sources/references for specific information gaps, such as biological status or stock abundance (i.e. qualitative or quantitative biomass priors), to improve the reliability of model estimates.

We contacted a total of 164 local fisheries experts, with 48 providing input to improve the data for 63 out of 142 countries.[42]

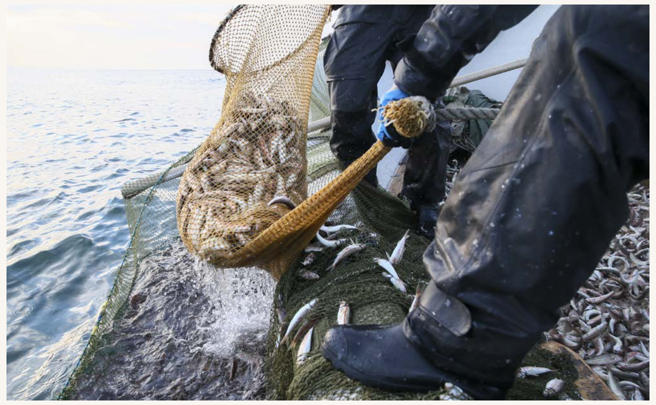
MEASURING DATA AVAILABILITY

To measure data availability for each country, we divided the combined catch (in tonnes) of the assessed stocks in our dataset by the total reconstructed catch within each country's waters for 1990 to 2018.

Stock level catches for 1990–2018 were obtained from the Sea Around Us reconstructed catch database. Where reconstructed catch data was missing (such as stocks identified from official assessments rather than marine ecoregion), catch data were extracted from official assessment reports. We focused on this historical period to account for stocks that were previously abundant or caught in high amounts but have since been reduced to very low levels.

Ideally, data availability would be measured using the proportion of total stocks that are assessed in each country. However, we did not have a clear understanding of how many stocks existed in a country or region to calculate this figure. Instead, we used catch as a proxy for fisheries data availability. We recognise that this is not a perfect proxy, as the ability to assess a large proportion of the catch depends on the size and diversity of fisheries in a country's waters. For example, temperate countries' fisheries are often dominated by a small number of species, while countries in the tropics have highly diverse, multispecies fisheries.

Countries in the current version of the Index have 27 stocks included on average, although this ranges from three to 188 stocks. We acknowledge that differences in fisheries complexity and size across countries may advantage countries whose fisheries are dominated by a few, large stocks. This allows for relatively high scores despite a lack of data for smaller stocks that can be ecologically, socially or economically important.



Seasonal red mullet fishing in Sochi, Russia - October 13 2021
Photo credit: Dmitry Feoktistov\TASS via Getty Images

CALCULATING THE PROGRESS SCORE

Scoring

We multiplied each country's stock sustainability and data availability scores to produce a single Progress score for each country, out of 100. This Progress score represents each country's progress towards SDG target 14.4, in which all fish stocks are restored to sustainable levels of abundance (Figure 3).

Applying the scoring 'cap'

The current Index provides a country-level assessment of progress towards SDG target 14.4 based on the state of a country's fish stocks. The Index's database includes 1,332 national or shared stocks (92 per cent of the stocks included) and 107 straddling stocks, which are managed by one of the five tuna RFMOs.[43] In some cases, these RFMO-managed stocks dominate a country's total catch. While these stocks occur within their national waters, these are not managed by the country directly and may not accurately reflect country performance in terms of national fisheries sustainability. However, we recognise the importance of these stocks and the role individual countries play in ensuring sustainable management at a regional level.

To ensure that the Progress score reflects country-level performance, we 'capped' the score for any country with less than 10 per cent of their total catch from nationally managed stocks assessed. This includes catches from national or shared stocks but excludes catches from straddling stocks that are managed by RFMOs.

The cap is set at the global median Progress score (23 out of 100) and has the effect of holding 'capped' countries in the middle scoring range, until more than 10 per cent of their national catch has been assessed and the cap is removed. While 68 countries meet the 'cap' criteria, only 26 countries had their scores adjusted, as the other countries already scored below the global median. Countries that had their score capped include American Samoa, Aruba, Bermuda, Cabo Verde, Comoros, Cook Islands, Costa Rica, Federated States of Micronesia, French Polynesia, Grenada, Jordan, Kiribati, Maldives, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Seychelles, Solomon Islands, Timor-Leste, Tokelau, Tuvalu, United Arab Emirates, Vanuatu and Wallis and Futuna Islands.

This approach ensures that the Progress score reflects a country's management and fisheries performance, rather than that of regional management bodies. This measure also provides an added incentive for all countries to improve their management of national stocks.

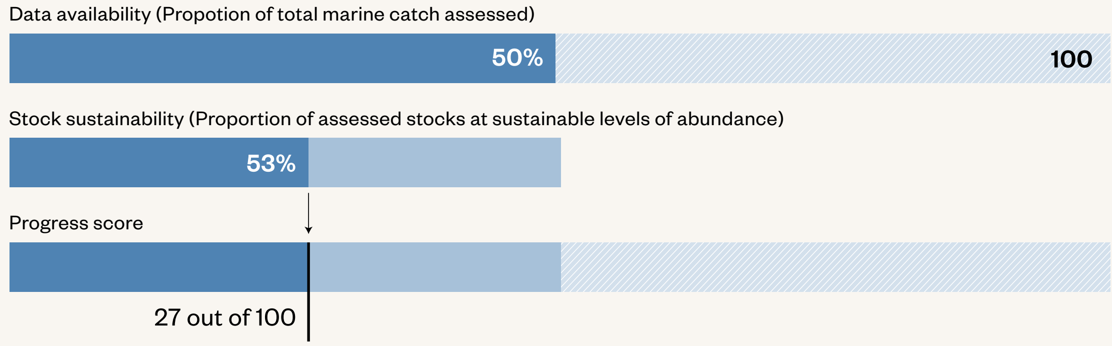


***Figure 3:** Example calculation of the Global Fishing Index Progress score, which is used to indicate the extent of a country's total fish stocks that are known to be at sustainable levels of abundance. Stock sustainability refers to the proportion of assessed stocks within a country's national waters that are at or above sustainable levels of abundance, relative to MSY. Data availability is the proportion of total catch represented by the assessed stocks within a country's national waters.*

QUALITY ASSURANCE FOR THE PROGRESS SCORE DATA

This process was designed to ensure data collection for all countries followed a consistent research protocol, so that analyses did not introduce human errors and there was no mishandling or manipulation of the data.

Internal quality assurance

The internal quality assurance process consisted of:

1. checking stock and country-level data to ensure completion, accuracy and consistency (See Quality control of stock sustainability data section, pg. 12)
2. checking Python scripts used to compile country-level data into a single, global data frame
3. checking Python and R scripts used for automating data compilation and scoring
4. checking output datasets from the automated data compilation and scoring.

We collated the 142 quality-assured country files into a single data frame using the NumPy and Pandas libraries in Python 3. Files were joined based on identical column headers, a feature rigorously assured by quality assurance processes. The data frame underwent procedural checks to ensure the collation process introduced no errors. Any updated CMSY++ stock assessment and additions resulting from quality assurance on stock-level data and in-country expert reviews were incorporated to the collated data frame based on the stock name, replacing the redundant rows, and filling in the added stocks for the entire dataset.

External review

Ernst and Young has undertaken independent assessment of the Global Fishing Index Progree Score analyses and based on the activities undertaken it has been determined that:

- the analyses processes align to the agreed technical methods and documentation
- the analyses processes do not alter or manipulate the relevant dataset(s) beyond the stated intent and agreed technical methods
- comments within the scripts reflect the content and methods contained within the scripts

Women dry anchovies along Lhokseudu beach in Aceh province - January 26, 2021.
Photo credit: CHAIDEER MAHYUDDIN/AFP via Getty Images

ASSESSING FISHERIES GOVERNANCE

Fisheries governance is the economic, political and administrative system which guides the regulation of the fisheries sector.[44] This includes customary social arrangements alongside laws, policies and rules implemented by government, as well as through the private sector, including fisher organisations, seafood buyers and market-related measures.

In line with SDG target 14.4, the Index's Governance Conceptual Framework assessed a country's fisheries governance system to effectively regulate harvesting, end overfishing and where needed, help restore marine fish stocks to sustainable levels.

We assessed 142 coastal countries, using a multi-criteria approach to determine each country's capacity to effectively govern fisheries within their waters to achieve this goal.

The Governance Conceptual Framework used to assess each country was organised around six 'dimensions', the key features of an effective governance system for ensuring sustainable fisheries within a country's waters. These dimensions are:

1. Policy and objectives: evaluating a country's laws and policies on fisheries, including its environmental, economic and social sustainability goals. This includes the ratification of key international agreements on fisheries management and conservation, as well as worker rights and safety. This dimension also assessed harmful subsidies (government funding that enhances fishing capacity and is linked with overfishing).
2. Management capacity: assessing the resources, expertise and tools available to manage fisheries, including financial, technical and professional capacity. This dimension also assessed various management measures, particularly science-based measures, such as harvest control rules.
3. Information availability and monitoring: measuring the range, quality and resolution of information available in each country to inform fisheries management and decision-making. This included information about fisheries catch and effort, the state of fish stocks and the size and structure of the fishing fleets operating inside a country's national waters.
4. Level and control of access to fisheries resources: assessing the extent to which fishing fleets (domestic and foreign) have access to a country's fisheries. This dimension also assessed the diversity of tools used to regulate and monitor access, including fishing licences, spatial zoning (such as marine protection or exclusion areas) and registration databases.
5. Compliance management system: evaluating the strength of a country's fisheries compliance and enforcement program, including monitoring and surveillance to detect illegal fishing and the use of sanctions to penalise infractions. This dimension also examined the perceived integrity of the fisheries authority and judicial system and the level of high-risk fishing activities, including flags of convenience vessels registered to foreign countries to evade regulation or tax.
6. Stakeholder engagement and participation: assessing the capacity of stakeholders (including fishers, seafood processers, governmental and non-governmental organisations, research institutions and local communities) to meaningfully participate in fisheries governance and management processes. This included whether the managing authority enables these interactions and whether the stakeholders have the capacity to engage, such as through fisher organisations.

These dimensions were further broken down into 'attributes', which represent specific, but interconnected elements of governance and were measured using indicators. The indicators were combined into a single overall score, used to summarise each country's performance.

The Index's governance methods followed the process outlined by the Organisation for Economic Co-Operation and Development (OECD) Handbook on Constructing Composite Indicators[45] and were developed in consultation with an Expert Advisory Panel, which consisted of 11 international, independent fisheries experts including representatives from the scientific community, fishing industry and civil society organisations.

Our assessments took a coastal state perspective, focusing on the governance of fishing activities that occur within a country's national waters – from large-scale, industrial fishing by domestic and foreign fleets, to small-scale, artisanal fishing for commercial and non-commercial (such as recreational or subsistence) purposes. However, it did not assess fishing activities conducted by a country's fleet outside national waters, such as distant water fishing.

A security ship crew of Ministry of Maritime Affairs and Fisheries, monitor radar during a patrol in the South China Sea on August 17, 2016 - Natuna, Ranai, Indonesia. Photo credit: SONNY TUMBELAKA/AFP via GettyImages

GOVERNANCE CONCEPTUAL FRAMEWORK

Development

In developing the Index's Governance Conceptual Framework, we asked *What aspects of fisheries governance enable or limit overfishing within a country's national waters?*

The initial framework was based on scientific evidence and prevailing theories regarding the drivers of overfishing in national waters. To collate this information, we conducted a scoping review of peer-reviewed scientific literature in 2019 to understand the most commonly-cited drivers of overfishing.

We identified and screened 1,646 studies for inclusion, based on a review of each study's title, abstract and keywords, with 162 articles meeting the screening criteria. These articles were published over 30 years in 42 countries and were used to identify common causes and drivers of overfishing.

These drivers were grouped into common themes, which formed the basis of the initial framework structure.[46]

These included:

- policy and institutional factors
- profit incentives
- technological factors
- demographic factors
- cultural or stakeholder factors
- fleet and fish behaviour
- socio-ecological and biological vulnerability.

The Index's Governance Conceptual Framework was developed in consultation with fisheries researchers at a workshop in Tasmania, Australia, in March 2019. Workshop participants included five independent academic researchers, each with experience working in fisheries around the world. These experts were asked to identify key components of governance related to overfishing, group these components into themes and sub-themes and identify potential indicators that could be used to measure each component.

The Minderoo research team further refined this conceptual framework throughout the following year, in consultation with research partners and external fisheries experts.

Structure

The Index's Governance Conceptual Framework has a two-level hierarchical structure and evaluates countries across six dimensions of fisheries governance (Figure 4), which are critical for limiting overfishing and effectively regulating the harvesting of fish stocks in national waters. Each of the six dimensions is further divided into attributes, with 18 attributes in total across the framework.

The Index's Governance Conceptual Framework is accompanied by 72 indicators, which are used to characterise and evaluate each attribute (see *Governance Conceptual Framework*). Indicators were selected for inclusion based on their broad applicability across fisheries contexts, ability to describe the state of governance systems with minimal subjectivity and data availability and coverage.

We will review the indicators before each iteration of the Index. They are designed to be updated, expanded or exchanged as new data or methods become available.

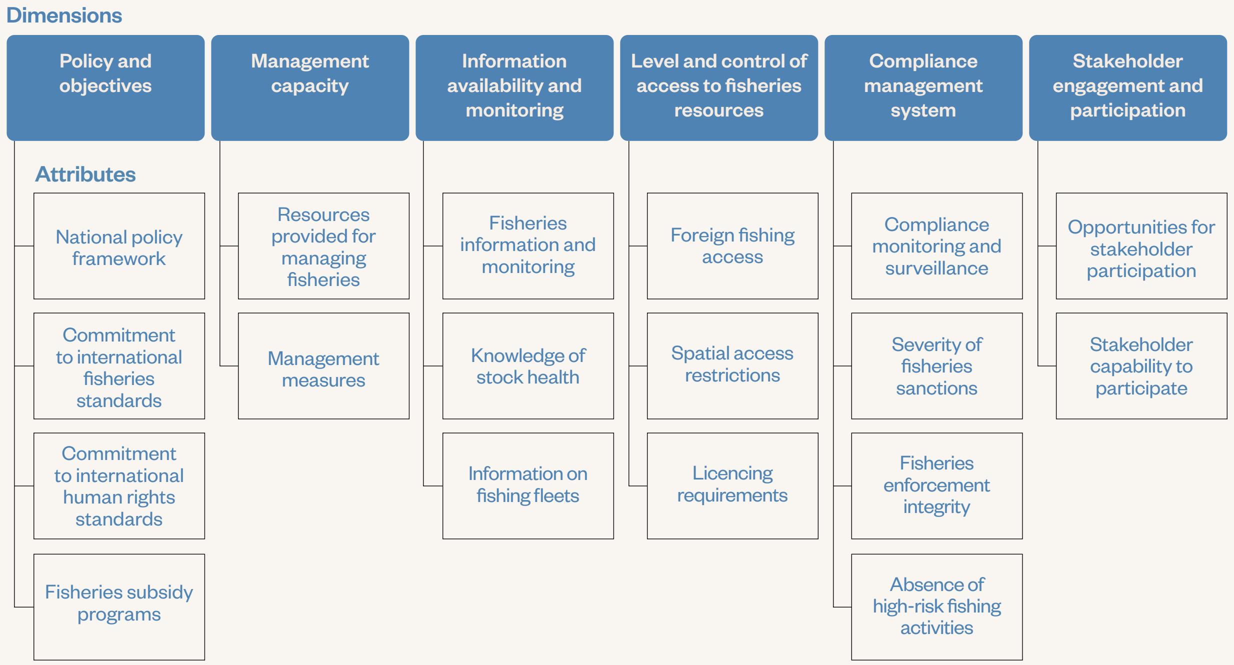


Figure 4: *Our fisheries governance framework. The framework comprises 18 attributes grouped across six dimensions: policy and objectives (Dimension 1), management capacity (Dimension 2), information availability and monitoring (Dimension 3), level and control of access to fisheries resources (Dimension 4), compliance management system (Dimension 5) and stakeholder engagement and participation (Dimension 6).*

Key considerations and limitations

Our governance results represent an evaluation of a country's fisheries governance system against certain 'universal' criteria recognised to reduce or prevent overfishing and effectively regulate harvesting of fish stocks in national waters. However, we recognise that fisheries governance is multifaceted and unique to the local context in which each fishery operates. No single governance structure represents the optimal settings for governing fisheries globally, due to differences in social, cultural, environmental and economic contexts.

Our assessment framework is limited by global data availability. As a result, the measured indicators are biased towards conventional top-down governance approaches. Further refinement and expansion of our indicators (to better capture other approaches, including community-based and customary management) are a key focus for future versions of the Index. In some cases, a country may score poorly in a specific attribute or dimension due to the indicators used, despite having an alternative system in place which may achieve the same outcome, such as traditional management practices.

The governance results do not necessarily reflect the performance or effectiveness of the elements in place. Achieving sustainable fisheries will depend on a country's ability to implement policy, plans and management activities that are committed to 'on paper'. Countries must first make these commitments and build the systems capable of effective governance. Then they must work on implementing them fully and effectively.

Our governance assessment results are designed to help identify general areas of strength and weakness and identify key gaps within a country's current fisheries governance system. Assessment results are used to develop country-specific recommendations that can be used to improve effectiveness and ultimately, the sustainability of their fisheries. Our vision is that the assessment results and recommendations are used by local stakeholders to develop actionable strategies for improvement.

DATA COLLECTION AND ANALYSES

Data collection

Data were collected at the indicator level (see Table 2 for an example), using a combination of primary and secondary data sources. Primary data represents data collected directly from country-specific experts and publicly available literature. These data were collected using the Index's governance assessment instrument, with researchers relying on a combination of desk-based research, online open access questionnaire responses and expert interviews. Fifty of the 72 indicators assessed used primary data.

Alternatively, 22 of the indicators used secondary data, which is data collected by an external organisation, but available for others to use. This included data from existing global datasets, such as the Varieties of Democracy dataset (V-Dem),[47] public lists (such as ratifications for international agreements) or novel data generated in partnership with other research organisations, such as Global Fishing Watch.

Table 2: *Example of the Index's Governance Conceptual Framework structure, including dimension, attribute and indicator details for Attribute 3.1 in Dimension 3: The scope, quality and resolution of fisheries information that is collected on a regular basis.*

Dimension 3: Information availability and monitoring

Assesses the range, quality and resolution of fisheries information available to inform management decisions.

Attribute	Attribute description	Indicator
3.1 Fisheries information and monitoring	The scope, quality and resolution of fisheries information collected on a regular basis	3.1.1 Collection and verification of catch data in the most valuable fishery
		3.1.2 Collection and verification of effort data in the most valuable fishery
		3.1.3 Availability of biological information for the most valuable fishery
		3.1.4 Data collection in-port

Primary indicators

Few existing global datasets are available to measure many of the aspects of fisheries governance identified in the Index's Governance Conceptual Framework, requiring the collection of new data. This information was collected using the Index's structured 80-question Governance Assessment Instrument. Most questions within the assessment instrument were directed at national-level aspects of fisheries governance, but 13 questions related to a country's 'single most valuable fishery' (as identified by the respondent). This fishery is used as a proxy for 'best practice' governance within the country and enables direct comparison across different contexts. In some cases, the most valuable fishery was identified as a regionally managed fishery or a freshwater species, although we recognise there are differences in the management approaches to these stocks.
This standardised approach was necessary across diverse fisheries contexts but did result in some positive bias in our results.

Where possible, the questions were closed-ended and respondents provided with pre-determined categories including multiple choice and Likert-type scales. However, respondents were asked to provide commentary to further explain their responses.

All primary data collection was conducted in accordance with the Australian National Statement on Ethical Conduct in Human Research.

Secondary indicators

Secondary data were collected for 22 indicators. Six of these indicators were sourced from existing global datasets, including V-Dem,[48] the Marine Conservation Institute's Marine Protection Atlas[49] and a global dataset[50] on subsidies in the fisheries sector.

We partnered with Global Fishing Watch to develop four novel indicators using Automatic Identification System and public Vessel Monitoring System data. These indicators assessed fisheries monitoring by measuring the presence of public vessel tracking technology in a country's fishing fleet, the extent of foreign fishing effort within a country's national waters and the presence of 'high-risk' activities for illegal fishing.

The remaining 12 indicators were obtained from data from existing regional or global sources, such as the International Labour Organization and the International Maritime Organization.

Assessment process

The governance assessments were completed by a global team of 48 researchers, based in 22 countries and territories, with all data collected between August 2019 and May 2020.

Researchers used three data sources to complete each country's assessment:

- desk-based research
- responses to an online, open access questionnaire
- structured face-to-face or phone interviews with country-specific experts.

Depending on the methods used, countries were categorised into two tiers of reliability: tier one (higher reliability), which included interviews with country experts and tier two (lower reliability), which was based on desk-based research and questionnaire responses only. Seventy-six of the 142 countries (54 per cent) assessed were tier 1. The use of multiple methods allowed for the triangulation of assessment results through a weight-of-evidence approach.

The tier two assessments were limited to primarily English language documents (the main language spoken by the research team). This language bias also prevented the verification of documentation, particularly in Arabic.

Each researcher followed a standard, four-step process when assessing each country:

1. **Review published literature**
   Most literature searches were performed in English, with automatic translation services used to translate non-English text for assessment purposes. Sources included: national legislation (e.g. Fisheries Acts and Regulations), reports by intergovernmental agencies (e.g. World Bank, FAO), national governments and conservation organisations (e.g. World Wide Fund for Nature, Marine Stewardship Council) and peer-reviewed scientific literature.

2. **Interview local fisheries experts (tier one countries only) to confirm accuracy of published information, fill data gaps and collect additional information**
   All interviews were conducted by a team of international, independent consultants with experience working in the selected country's fisheries sector and an established network of local contacts. Consultants requested face-to-face or phone meetings with local fisheries experts to conduct the questionnaire, using a structured interview process.
   Country researchers aimed to secure at least one interview with a current or recent employee of the national fisheries management agency. Other interviewees included fisheries consultants, policy advisors, academics, scientific researchers and non-government organisation employees. When possible, interviews were conducted in the local language, with interview questions translated by the country researchers. Between one and five interviews were conducted in each of the 76 tier-one countries, resulting in a total of 216 interviews.

3. **Review and integrate responses from the online questionnaire**
   The Index's governance assessment instrument was formatted into a questionnaire using the Qualtrics^{XM} online survey platform. We invited individuals identified as working in, or closely associated with, fisheries in a specific country to complete the questionnaire using an anonymous, open-access link. Participants were also able to suggest other potential participants (snowball sampling), resulting in a total of 3,323 individuals globally, across a diverse range of sectors (including industry, government and non-government, policy and fish processing) invited to participate. In total, 274 individuals from 116 countries and territories completed the questionnaire (completion rate of 8.4 per cent). Of the 274 respondents, 65 per cent identified as a 'researcher', 34 per cent as a 'manager' and 32 per cent as 'working in the policy sector'. Survey responses were collected from 12 August to 6 December 2019. Country-specific responses were provided to researchers to inform their assessment process. Questionnaire responses were available for 116 of the 142 countries, with each country ranging from one to 13 unique respondents.

4. **Complete a final assessment for each country using all available information**
   Country researchers reviewed the results of the desk-based literature search, responses from interviewees (tier one countries only) and the online questionnaire responses, in combination with their own knowledge, to determine a final response.
   In cases where information differed across sources, researchers determined the final response by evaluating the quality of the information source, level of agreement among interview and questionnaire participants and participant credentials (if provided). If researchers were unable to determine a final response for a question, they selected 'unknown'. In this instance, the country researcher was asked to provide details of their research method to ensure exhaustive review.
   Researchers were also asked to explain their rationale, including research notes, supporting references and key information gaps, and to estimate their confidence in the accuracy of the final response selected for each question.

Quality control

Our research team verified the final responses and supporting documentation to ensure that a consistent research approach was applied across all countries, including scoring of confidence levels, based on source reliability and level of agreement among sources (Figure 5).

Collecting data for 72 indicators across 142 countries is a difficult and complex undertaking. In many countries, fisheries governance information was not publicly available. Thus, a low overall assessment score may be due to a limited or weak application of assessed criteria, gaps in data availability and/or the use of alternative systems not currently captured in our framework.

It is also difficult to measure the extent to which some indicators are implemented. Where able, we used a weight-of-evidence approach to identify when a policy may be in place but is not regularly enforced, such as *Indicator 5.1.3: Use of targeted on-water inspections.* Where there was evidence a policy was not regularly implemented or enforced (for example, based on comments or reports provided by participants) it was given a lower score.

While this approach provides the first step towards measuring implementation and effectiveness, more remains to be done in getting at the reality of what is occurring on the ground/water, as opposed to what is reported publicly. This is a key area we are working to improve in future iterations of the Index.

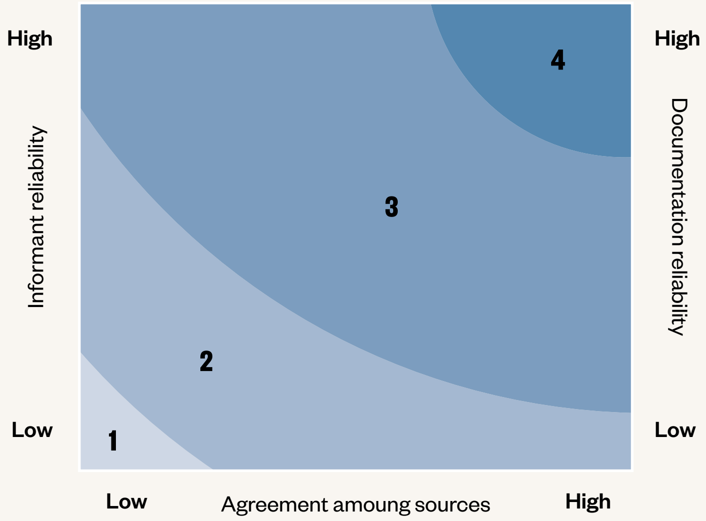


Figure 5: *Confidence assessment scoring guide, during data quality assurance process. The confidence assessments consider the reliability of the information source (i.e. interview/questionnaire informant or document) and agreement among different information sources. For example, where information documented in a peer-reviewed government report (considered high reliability) aligned with a 'high-reliability' informant's response, it would be given a 4 (high) confidence assessment score.*

Scoring

Assessment results were converted into ordinal indicator-level scores. Indicator scores were based on the Index's Governance Conceptual Framework, with a higher score provided to response categories considered to be more effective at limiting overfishing. Conversely, conditions recognised to enable overfishing were given the lowest score. Responses deemed equally influential for constraining overfishing were given the same score.

Sixty-five of the 72 indicators in the Index's Governance Conceptual Framework are 'positive' indicators, i.e. considered to support effective governance and ensure overfishing does not occur. The remaining 11 indicators are 'negative', i.e. they are considered to enable overfishing or hinder governance effectiveness in combatting overfishing.

Each indicator was scored on a zero to 100 scale, with zero representing the lowest score and 100 representing the highest score. A score of 100 on a positive indicator signalled that the (positive) feature was present, while a score of 100 on a negative indicator meant that the (negative) feature was absent.The number of scoring levels varied based on the number of response options available for each indicator (between two and six options, depending on indicator design). Each incremental scoring level between zero and 100 was represented as a proportion of 100, unless the indicator was binary, in which case it scored either zero or 100. This process ensured each indicator contributed proportionately in the weighting and aggregation steps.

All scoring rules were applied using the computing language R[51] (version 4.0.0) and conducted in RStudio.[52] We did not perform any standardisation, as the scores represented categorical data and any redistribution would obscure the meaning behind the scores.

The full scoring system for each indicator is described in the Governance Indicator Codebook. All indicator data, country level results and scripts are available for download from the Global Fishing Index website.

Missing data

Missing data includes instances where:

- no information could be found for a particular indicator in a country, resulting in an assessment result of 'unknown'
- an indicator was determined to be 'not applicable' for a country[53]
- a country was not included in a secondary data source.

We reviewed all instances of missing data to identify firstly if there were any indicators or countries that should be removed due to limited information, and then the appropriate methods for imputing missing data, such as using expert judgement or statistical methods.

Missing data in the 50 primary indicators due to a final assessment response of 'unknown' were given the lowest score. This scoring decision was applied to promote transparency and increase data availability within the fisheries sector, widely recognised as a key component of natural resource governance.[54]

Missing data where an indicator was 'not applicable' or where a country was not represented in a secondary dataset were imputed using statistical imputation. Exceptions to this approach were *Indicators 3.3.3: Registration of foreign fishing vessels* and *4.3.2: Licence requirements for foreign fishing vessels.* Where *Indicators 3.3.3* and *4.3.2* were identified as 'not applicable' for a country, i.e. due to a lack of access provided to foreign fishing vessels, this was taken as a sign of strong governance and assigned the highest score.

We first explored median imputation. However, this method was rejected to prevent countries from being either unfairly rewarded or punished for missing data. Instead, we used the k-nearest neighbours (kNN) method, which assumes that similar countries will act similarly and imputes responses based on a country's 'nearest neighbour' in the dataset: a country is considered likely to score like other countries that are similar for other indicators. kNN imputation was conducted using the *VIM* package[55] in R (k=5, as per Jonsson and Wohlin).[56]

We imputed 221 data points using kNN across 14 of 72 indicators for 48 countries, comprising less than three per cent of the total data. Pitcairn, Wallis and Futuna and Montserrat had the highest proportion of these indicators statistically imputed, at 13.9 per cent, 11.6 per cent and 11.6 per cent respectively. *Indicators 5.3.2: Perceived integrity of the judicial system, 5.3.3: Routine removal of corrupt or inept judges from post* and *5.3.4: Prevalence of executive bribery or corrupt exchanges* had the highest proportion of countries statistically imputed, at 23 per cent each.

The highest proportion of missing data (across all datatypes) for an individual indicator was 33 per cent (*Indicator 3.3.3: Registration of foreign fishing vessels*). Similarly, the highest proportion of missing data in a single country was 21.3 per cent (Pitcairn). Countries with more than 25 per cent of indicators with high uncertainty (confidence assessment score of 1) were removed from the Index due to low confidence in the accuracy of results.

Multivariate analysis

The Index's Governance Conceptual Framework was tested for statistical coherence using multivariate analyses, including clustering the indicators using principal component analysis and k-means cluster analysis. Optimal clusters were explored using Cattell's scree test for the principal component analysis and the elbow method, average silhouette test and the gap statistic for the k-means analysis.

To test internal consistency, Cronbach's alphas were calculated for each dimension and attribute using the R package *psych*. The Cronbach score assesses the internal consistency of the indicators, attributes and dimensions in measuring the fisheries governance component of interest. While some Cronbach scores were low, we decided to keep all indicators, attributes and dimensions as originally conceived.

To avoid potential instances of redundancy or substitution of an attribute or dimension, we tested for collinearity. Correlation matrices were produced using the R package *performance analytics* for both dimension and attribute scores. The highest correlation score was 0.62, implying that collinearity did not exist and no restructure was required.

Weighting and aggregation

The individual indicators, attributes and dimensions were aggregated into a single composite assessment score for each country.

Weighting

As part of the aggregation process, weights can be applied to reflect the relative importance of different dimensions in the overall score.[57] Equal weighting implies each dimension is equally important in influencing a country's ability to ensure that fishing activities do not result in overfishing. However, despite a conceptually equal weight, this approach results in implicit weighting when the number of attributes within each dimension is not equal, as occurs in our framework.

To explore how to best weigh each dimension, we conducted an online survey of independent fisheries experts using the analytical hierarchy process (AHP).[58] Specifically, we asked experts to rank the relative importance of each dimension for ensuring fishing activities do not result in overfishing using a series of pair-wise comparisons. Our questionnaire consisted of 15 pair-wise comparisons, with importance expressed on a numeric scale ranging from one (equally important) to nine (much more important). To aid completion, participants were provided with an overview of the Index's Governance Conceptual Framework, research aims and a short description of each dimension, including examples of the types of activities/policy captured in each dimension.

Table 3: *Demographic information for fisheries governance experts used to inform weighting process. Only respondents with an inconsistency ratio lower than 0.2 were used to determine the dimension weights.*

Demographics	All respondents (n = 43)	After inconsistent responses removed (n = 18)
Sector		
Academia	10	3
Consultancy	8	5
Government	10	5
Non-governmental organisations	10	2
Industry	5	3
Region		
Africa	12	3
Americas	13	7
Asia	10	3
Europe	3	2
Oceania	5	3
Area of expertise		
Small-scale, artisanal or subsistence fisheries	25	12
Large-scale or industrial fisheries	15	8
Fisheries in least developed countries	10	3
Fisheries in small island developing states	11	4
Fisheries in less economically developed countries	18	5
Fisheries in more economically developed countries	13	7
Maritime enforcement and interagency cooperation	1	1
Tuna RFMO	1	0
Multi-disciplinary	1	1

This questionnaire was administered via the Qualtrics[XM] online survey platform in June 2020. Potential respondents were identified based on their extensive experience in fisheries governance and management. In total, 124 personalised single-use Qualtrics[XM] survey links were sent to selected experts, with 43 completed responses (35 per cent response rate). We collected demographic information including geographic location, sector, position, work focus, years-experience and area of expertise to measure participant diversity (Table 3). The use of a personalised link allowed us to track participation, but all responses were anonymised prior to analysis.

The AHP method requires consistent and logical ranking by participants. For example, if A was twice as important as B, and B was of equal importance to C, then A must also be twice as important as C (perfect consistency). However, perfect consistency in preference ranking is impossible for most respondents due to natural human error.[59] Thus, responses were screened following completion for inconsistent preferences, using inconsistency ratios. Respondents with an inconsistency ratio greater than 0.2 were removed from the sample. Of the 43 respondents, 18 passed the consistency check and were included in the final analysis. Interestingly, the mean inconsistency among all participants was 0.51, suggesting experts found decision-making difficult.[60]

Preference eigenvalues were calculated using the R package ahpsurvey.[61] Individual preference eigenvalues were aggregated using a geometric mean[62] and rescaled into a weighting factor out of 100 for each dimension.

Figure 6 describes the final weighting applied for the governance dimensions, based on the result of the AHP. *Dimension 1: Policy and objectives* was identified as most important and given the greatest weight (22 per cent), while the rest of the dimensions were weighted between 14 and 17 per cent. These weighting factors were applied individually to all six dimensions when generating the final assessment score per country.

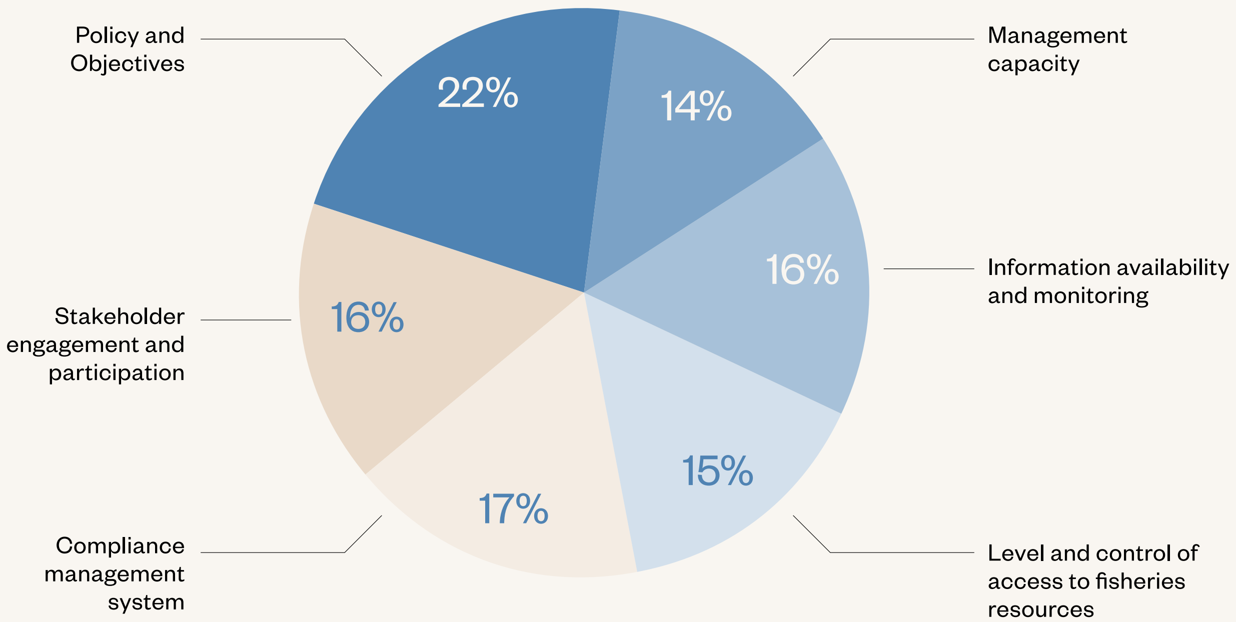


***Figure 6:** Expert-based weighting of each dimension applied during aggregation to an overall assessment score*

Aggregation

A key consideration during the aggregation process was the level of compensation among components. Compensation is the ability to offset poor performance in one dimension by strong performance in another.

We used an arithmetic mean to aggregate indicator scores into a single attribute score, and again to aggregate attribute scores into a single dimension score, per country (Table 4). This process allows for compensation among indicators within a single attribute and among attributes within a dimension.

However, the Expert Advisory Panel advised limited compensation between dimensions, particularly where the goal is to maintain long-term stability of fisheries governance systems. Thus, to limit compensability we applied a weighted geometric mean to aggregate the six weighted dimensions scores into a single assessment score out of 100 (Table 4).

***Table 4:** Weighting and aggregation methods applied at the indicator level (when aggregated to attributes), attribute level (when aggregated to dimensions) and dimension level (when aggregated to an overall assessment score).*

	Indicator level	**Attribute level**	**Dimension level**
Weighting	Equal	Equal	Expert derived
Aggregation	Arithmetic	Arithmetic	Geometric

Each country's governance is presented as a level between zero and 12, representing its capacity for ensuring that fishing activities do not contribute to the overexploitation of fish stocks, as measured by the Index's Governance Conceptual Framework.

Assessment scores were converted to a Governance capacity level using a multi-criteria approach (Table 5), which considers both the strength of the system, based on overall assessment score, and balance across the framework, based on minimum defined dimension-level scores.

Where a country does not meet all required elements, it is capped at the next highest Governance capacity level. For example, countries must achieve a minimum overall assessment score of 55 and score at least 30 across each of the six dimensions to progress from a level 3 to a level 4. Alternatively, if it has an overall assessment score of 70, but one dimension scores less than 30, it is capped at a level 3 until this dimension achieves to a score of 30 or higher (Table 5).

***Table 5:** Rubric used to determine a country's Governance capacity, between zero ('Very low') and 12 ('Very high'), based on overall assessment score and balance across dimensions. A country must meet the assessment score and balance criteria to advance to the next capacity level.*

Assessment score	< 40	40-44.9`	45-49.9`	50-54.9`	55-59.9`	60-64.9`	65-69.9`	70-74.9`	75-79.9`	80-84.9`	85-89.9`	90-94.9`	95-100
Balance criteria	None				Minimum of 30 across all dimensions					Minimum of 60 across all dimensions			
Governance capacity	Very Low	Very low	Low	Low	Low	Med	Med	Med	High	High	High	Very high	Very high
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

Interpretation

The Governance capacity and balance across the framework are used to explore the design and level of development of a country's fisheries governance system. The results characterise a system's overall development and identify which parts are strong or weak, while highlighting any critical gaps within the current structure. This also allows for direct comparison across countries and/or regions.

Our assessment recognises that governance is a continuum (Figure 7). On one end is a comprehensive governance system designed to promote sustainable and responsible fishing (level 12), while the other end represents a weak or under-developed system of fisheries governance, with limited capacity to effectively regulate fishing activities (level 3) or lacks the basic elements for fisheries governance (level 0). Low Governance capacity may also be due to a limited or weak application of recognised means of addressing overfishing, gaps in data availability and/or the use of alternative systems not currently recognised in our framework.

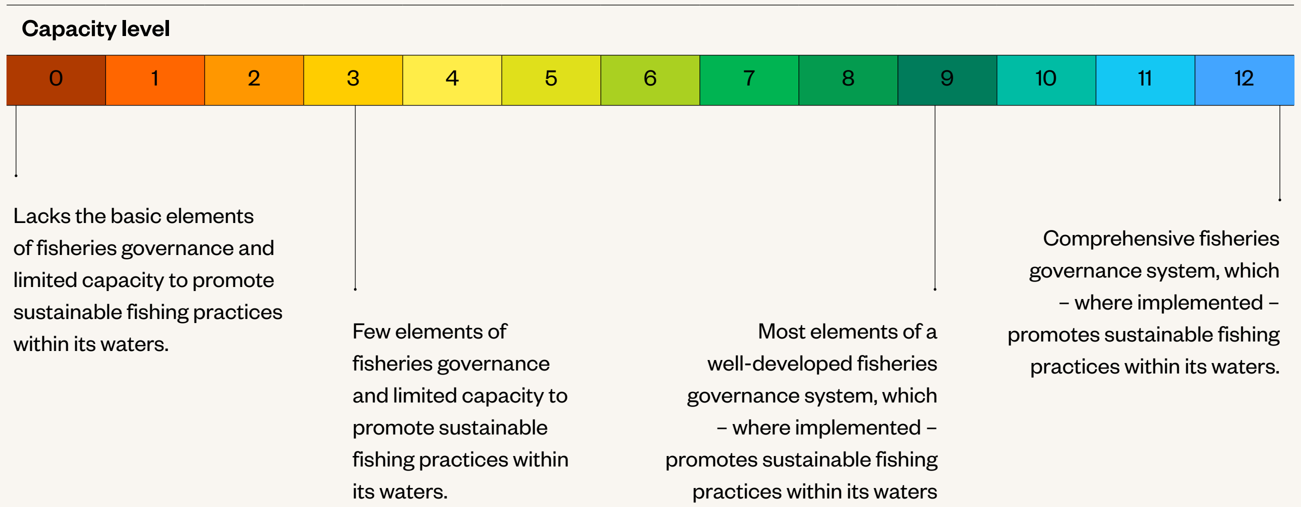


Figure 7: *Description of fisheries Governance capacity levels. This system recognises fisheries governance as a continuum, from a comprehensive system (level 12), to a weak or under-developed system that has limited capacity to effectively regulate fisheries (level 3) or little evidence of even the basic elements of governance needed (level 0).*

ROBUSTNESS AND SENSITIVITY ANALYSES

During our data analysis, the assumptions of different data treatments led to different outcomes. There were four key decision points where data were specifically treated to align with the Index's Governance Conceptual Framework: imputation, normalisation, weighting and aggregation (Table 6).

Where appropriate, we applied sensitivity testing to measure the impact of each choice.

Table 6: *Key decision points for data treatment and options tested. The option that was used is presented in bold, with alternative options that were tested and rejected listed in plain text.*

Data treatment step	Options explored
Imputation	**K-nearest neighbours** Median
Normalisation	**Scored 0-100** Standardisation
Weighting	**Expert elicitation (AHP)** Equal weighting Modified equal weights Correlation weights Monte Carlo Simulation (100 runs)
Aggregation	**Arithmetic mean (indicator and attribute levels)** **Geometric mean (dimension level)** Summation (indicator/attribute/dimension level)

Inspection by police officers at fish market to ensure fisheries regulations are observed - Paimpol, France
Photo credit: Andia/Universal Images Group via Getty Images

QUALITY ASSURANCE FOR GOVERNANCE DATA

This process was designed to ensure all country researchers followed a consistent research protocol, no human errors were introduced during analyses and no mishandling or manipulation of the data occurred.

Internal quality assurance

The internal quality assurance process consisted of:

1. checking primary data to ensure completion and consistency in applied logic across country researchers (See Quality control section, pg. 21)
2. checking secondary data for suitability, including any biases, limitations and/or data gaps
3. checking Python and R scripts used for automating data compilation, indicator mapping, scoring, weighting, aggregation and rating processes
4. checking output datasets from the automated data compilation, indicator mapping, scoring, weighting, aggregation and rating processes.

Each secondary dataset was checked for possible biases, limitations and/or data gaps. Where possible, any identified biases, limitations or data gaps were addressed, either by contacting the original author of the dataset or conducting additional desk-based research to complete the dataset. Any outstanding limitations are reported in full in the Governance Indicator Codebook.

Individual country-level assessments (n = 142) were combined into a single master datasheet using Python (version 3.7.6), with at least 10 per cent of the combined output datasheet validated to ensure no coding errors occurred horizontally (i.e. responses for single countries) or vertically (i.e. responses for a single question).

Primary and secondary data were combined, mapped to the relevant indicators and scored using the computing language R[63] (version 4.0.0) and conducted in RStudio[64]. The scored indicators were aggregated to attribute and dimension scores, and then an overall assessment score before the rating criteria was applied.

Expert-derived weights, used to inform the aggregation of dimension scores to a final assessment score, were reviewed by a secondary analyst to ensure the script applied appropriate methods and execution. This included crosschecking the results produced in step-by-step Excel calculations to ensure each step was applied correctly. Additionally, a minimum of 10 per cent of all output spreadsheets were checked horizontally and vertically to validate coding outputs.

External review

To ensure the Index's governance technical methods were developed in accordance with best industry standards, our methods and analyses were reviewed by the Competence Centre on Composite Indicators and Scoreboards in October 2020. This group is responsible for publishing the *OECD Handbook on constructing composite indicators* and advancing the field of building composite indicators.

Additionally, Ernst & Young has undertaken independent assessment of the Global Fishing Index Governance analyses, and based on the activities undertaken it has been determined that:

- the analyses processes align to the agreed technical methods and documentation
- the analyses processes do not alter or manipulate the relevant dataset(s) beyond the stated intent and agreed technical methods and
- comments within the scripts reflect the content and methods contained within the scripts.

••
Fishermen working on fishing trawler
Photo credit: Morsa Images

COUNTRY-LEVEL GRADES

Each country's overall performance was evaluated and presented as a grade, alongside its Progress score and Governance capacity. This grade represents the national outlook for restoring fish stocks and ensuring sustainable fisheries based on their current level of progress and governance capacity to improve. The highest possible grade is A, followed by B, C, D, E and F.

Countries may receive a grade for different reasons, and it is important to review country-specific results and recommendations on the Global Fishing Index website.

Grades were determined based on a country's Progress score and Governance capacity. First, the Progress score was used to identify the grading band. Progress scores between 0-10 represent 'negligible progress', Progress scores between 10-40 represent 'limited progress', Progress score between 40-70 represent 'some progress', Progress score between 70-90 represent 'significant progress' and Progress score between 90-100 represent achieving SDG target 14.4 and flourishing, sustainable fisheries. We then used the Governance capacity level to determine the final overall grade. Where a country had limited Governance capacity (i.e. level 5 or lower), it was downgraded, representing an increased risk of the over exploitation of fish stocks in the future and/or limited prospect of improvement from current levels of progress towards SDG target 14.4 (Table 7).

Table 7: *Grading rubric used to determine a country's final grade, based on a country's Progress score and Governance capacity.*

	Governance capacity	
Progress score	Medium or above (level 6 – 12)	Very low to low (level 0 – 5)
90 – 100 (Flourishing)	A	B
70 – 90 (Significant progress)	B	C
40 – 70 (Some progress)	C	D
10 – 40 (Limited progress)	D	E
0 – 10 (Negligible progress)	E	F

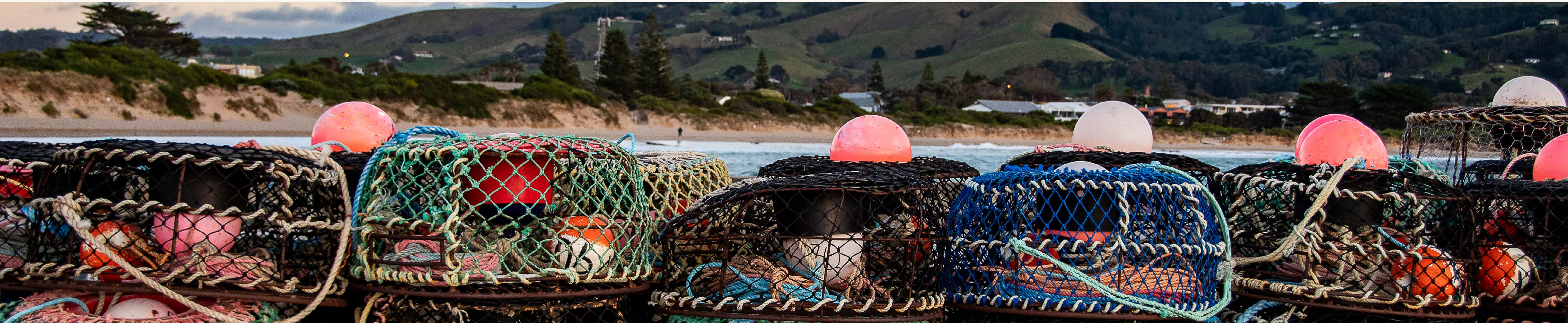
EXPLORATION

We explored the relationship between our global results and independent measures of broader economic and governance setting in instances where we hypothesised an association. We used the Pearson's correlation coefficient to measure the strength of the association between the Progress score and GDP (PPP) per capita. We then used Spearman rank correlation to measure the association between Governance capacity and GDP (PPP) per capita, Political instability and Government effectiveness (Table 8). Independent measures were not available for all 142 countries assessed, resulting in a subset of between 100 and 123 countries where data were available.

Most of the countries that received a 'C' grade have higher economic development statuses, which is not surprising, given that implementing fisheries management is expensive and requires substantial human and technical resources.[68,69] Yet, there is a weak relationship overall between GDP (PPP) per capita and the progress scores. Additionally, the governance results have a weak relationship to GDP (PPP) per capita, and a moderate relationship with political stability and government effectiveness, which capture the broader governance conditions such as political order, social unrest, government functioning and public service delivery. This indicates that while wealth and a well-functioning government can enable sustainable fisheries, they are not essential or sufficient on their own.

Table 8: *Results of correlations between Progress score or Governance capacity and GDP PPP) per capita, Political instability or Government effectiveness, where 0 indicates no relationship and 1/-1 equals a perfect positive/negative relationship between the two variables.*

	GDP (PPP) per capita[65]	**Political instability[66]**	**Government effectiveness[67]**
Progress score	r=0.43; n=123	-	-
Governance capacity	r=0.34; n=123	r=-0.50; n=100	r=0.40; n=128



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Close-up of fishing nets on pier against sky Apollo Bay, Victoria, Australia. Photo credit: Cindy Kley / 500px

GLOSSARY

KEY TERMS AND CONCEPTS

Level of reporting:

We define a **country** as any independent or non-independent territory that reports official fisheries catches to the FAO and has a unique ISO 3-digit code.

Fish includes all harvested or captured marine organisms including fishes, crustaceans, and molluscs, but excluding aquatic plants, amphibians, reptiles, birds and mammals.

A **fish stock** is a population of a single, or sometimes combined, fish species living in a defined area from which catches are taken in a fishery. We group fish stocks into three categories, depending on their distribution and management:

- **National stocks** are located entirely within a country's national waters and are governed entirely by a single country.
- **Shared stocks** occur within the national waters of multiple adjacent countries and are governed by those countries in whose waters they occur.
- **Straddling stocks** move across exclusive economic zone boundaries, often into the high seas, and are caught by multiple countries (for example tuna and swordfish). These stocks are actively managed by one of the five tuna RFMOs, including the Commission for the Conservation of Southern Bluefin Tuna, the Inter-American Tropical Tuna Commission, the International Commission for the Conservation of Atlantic Tuna, the Indian Ocean Tuna Commission and the Western and Central Pacific Fisheries Commission.

Assessing stock health:

Stock assessments use biological information, fishery data such as catch statistics and fishing effort, and where available, scientific survey data to estimate population dynamics of fish stocks. **Official stock assessments** in our dataset include recent stock assessments conducted by a national fisheries authority or scientific body, such as National Oceanic and Atmospheric Administration, the International Council for the Exploration of the Sea or RFMOs, with published relative abundance estimates available.

We use **stock abundance**, measured in biomass (B), to assess stock status by comparing estimates of current biomass (B) relative to unfished levels of biomass (B_0).

We classify stocks into two categories:

- A **sustainable stock** has an estimated relative abundance at or above the level that can produce MSY. MSY is predicted at 50 per cent of unfished levels of abundance, but to account for uncertainties a 10 per cent confidence band was applied. We considered stocks as 'sustainable' when estimated to be at or above 40 per cent of unfished levels. For stocks with relative abundance estimated using spawning stock biomass, values greater than or equal to 20 per cent of the unfished level were considered as sustainable levels.
- An **overfished stock** has an estimated relative abundance below the level that can produce MSY (that is, less than 40 per cent of unfished levels of abundance) or has a relative value of spawning stock biomass that is less than 20 per cent of the unfished level.

Maximum sustainable yield (MSY) is the highest theoretical equilibrium yield (catch) that can be continuously removed from a stock (on average), under existing (average) environmental conditions, without significantly affecting the reproduction process. Based on the Schaefer model,[70] MSY is predicted to occur at 50 per cent of unfished abundance.

Fisheries catch data:

Reconstructed catch combines reported 'official' catch estimates with other information (such as trade records, seafood consumption rates, national employment data and vessel registries) to provide a more comprehensive and accurate estimate of total marine catch within a country's national waters. We use the Sea Around Us[71] reconstructed catch time series within our analyses.

Unassessed catch refers to catch harvested from an unmonitored stock for which no reliable estimates of current abundance exist, or which lacks the necessary data to estimate stock abundance using the data-limited approaches applied.

Nationally managed catch includes catches from fish stocks that occur completely within a country's national waters (national stocks) or are a shared responsibility of neighbouring countries (shared stocks). This excludes catch from stocks that are managed by one of the five tuna RFMOs, including the Commission for the Conservation of Southern Bluefin Tuna, the Inter-American Tropical Tuna Commission, the International Commission for the Conservation of Atlantic Tuna, the Indian Ocean Tuna Commission and the Western and Central Pacific Fisheries Commission.

ABBREVIATIONS

AHP	Analytical hierarchy process
BSM	Bayesian Schaefer Model
CPUE	Catch-per-unit-effort
FAO	Food and Agriculture Organization of the United Nations
GDP PPP	Gross Domestic Product Purchasing Power Parity
IUU fishing	Illegal, unreported and unregulated fishing
kNN	K-nearest neighbours
LBB	Length-based Bayesian biomass
MSY	Maximum sustainable yield
NGO	Non-government organisation
OECD	Organisation for Economic Co-Operation and Development
RFMO	Regional Fisheries Management Organisation
SDG	Sustainable Development Goals
V-Dem	Varieties of Democracy dataset

ENDNOTES

1 'Fish' includes all harvested or captured marine organisms including fishes, crustaceans, and molluscs, but excluding aquatic plants, amphibians, reptiles, birds and mammals

2 We follow the United Nations standards for country names and territories and express no opinion about the legal state of any country, territory or area nor concerning its delimitation, frontier or borders. We consider any disputed waters as belonging to all claimant countries

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