

## **RANKING MARITIME COUNTRIES BY THE SUSTAINABILITY OF THEIR FISHERIES<sup>1</sup>**

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### ABSTRACT

In response to a lack of an international system for assessing marine fisheries, a series of sustainable fisheries management indicators were developed to address the many dimensions of the fisheries sector (social, economic and environmental). A set of eight indicators were used to assess whether 53 maritime countries, accounting for over 95% of the global catch, could be reliably ranked in terms of sustainability of their fisheries and marine ecosystems. The resulting scores, for both developing and developed countries, were evenly distributed across the rankings, without breaks. Overall, the study showed that the maritime countries of the world can be reliably ranked in terms of the sustainability of their fisheries and marine ecosystems.

### INTRODUCTION

Fisheries are in crisis throughout the world (Pauly *et al.*, 2002), with most extant fisheries predicted to collapse by the mid century under a business-as-usual scenario (Worm *et al.*, 2006). Most of the world's marine fish stocks are fully or overexploited, or have collapsed. Instead of rebuilding the stocks, however, governments and the fishing industry continue to try to maintain or even increase catches by fishing further offshore and lower down the food chain. These practices not only have the potential to aggravate the state of the resource, but also to further degrade the marine ecosystems that provide a wide range of services to humankind (Balmford *et al.*, 2005; MEA, 2005).

Fisheries management and policy-makers are grappling all over the world with the problem of how fisheries can be made to operate sustainably. Criteria useful for assessing how well countries are doing in managing their marine resources are, however, scarce to non-existent. There are programs that assess the sustainability of fish stocks (MSC, 2002) and there are guidelines on how to sustainably manage fisheries (FAO, 1995). However, there is no system that assesses the overall performance of countries in managing their marine fisheries and ecosystems, and which ranks the performance of countries in a systematic and consistent manner.

In this contribution, we present a set of indicators appropriate for assessing the sustainability of marine fisheries and ecosystems, developed based on explicit criteria and use current and publicly available data. The indicators were developed to address the many dimensions of the fisheries sector (social, economic and environmental), making the indicators multivariate (Rochet *et al.*, 2005). Integrating a number of indicators, that are both relevant and robust, helps to even out those biases which are inherent in some indicators, as well as capture the multifaceted nature of sustainability. Fisheries sustainability indicators that are measurable through time also allow tracking the performance of countries.

The validity of the proposed indicators was tested by assessing a selection of countries, ranking these countries for fisheries sustainability based on the indicator set, and assessing the internal and external coherence of the results. For the purpose of this study, a 'sustainable fisheries indicator' is defined as a

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metric that measures the state of a country's fisheries, and/or reflects how well a country manages its fisheries sector and its impact on the ecosystem(s) within its 200 mile Exclusive Economic Zone (EEZ).

### *Defining Sustainable Fisheries*

Sustainable fisheries can be defined as the result of adequate management of marine species and ecosystems, as described in the FAO Code of Conduct for Responsible Fisheries (FAO, 1995), and by the Marine Stewardship Council Principles and Criteria for Sustainable Fisheries (MSC, 2002). The FAO and the MSC have identified the following components of sustainable fisheries management systems which take into account biological, technical, economic, social, environmental and commercial aspects:

- Conserve and maintain the integrity of aquatic resources;
- Maintain sufficient biomass of targeted species for present and future generations, as well as the biomass of non-target species associated with the target species;
- Base decisions on best scientific evidence available and apply a precautionary approach;
- Develop environmentally safe fishing gear and practices;
- Minimize negative impacts from harvesting to processing and reduce waste;
- Protect and rehabilitate marine fisheries habitat where possible;
- Integrate fisheries interests into coastal management;
- Ensure fleet compliance with conservation and management measures and with relevant local, national and international laws and trade laws.

Also, indicators should be available to inform on the sustainability of the fisheries. Numerous definitions have been given to the term 'indicator'. For the purpose of this study, a 'sustainable fisheries indicator' is defined as a number which quantifies an aspect of the state of a country's fisheries or marine ecosystems, and/or reflects how well or poorly a country manages its fisheries sector. FAO (1999a) defines an indicator as: "...quantitative or qualitative value, a variable, pointer, or index related to a criterion. Its fluctuations reveal the variations of the criteria. A reference point indicates a particular state of a fisheries indicator corresponding to a situation considered as desirable, or undesirable and requiring immediate action".

## MATERIAL AND METHODS

A Logical Framework Analysis (BOND, 2003) and the Pressure-State-Response (PSR) Model (OECD, 2003) were used to develop the fisheries indicators presented here. For each indicator, the framework in Table 1 identifies the problem, its stressor, and the objective. The problem identifies an aspect of the fisheries crisis, the stressor shows why the problem exists, and the objective identifies the purpose of the indicator. An indicator, thus, is a number that measures the state of a country's fisheries with respect to an issue (e.g., the state of major fish stocks), a concept or measure (e.g., the setting up of Marine Protected Areas) or set of factors (e.g., income, subsidies), and/or reflects how well or poorly a country manages its fisheries sector.

**Table 1.** Framework for developing sustainable fisheries indicators.

Indicator	Problem	Stressor	Objective
The indicator is a number that measures the sustainability of a country's fisheries, and/or reflects how well a country manages its fisheries sector.	The problem identifies the crisis.	The stressor identifies the reason for the problem.	The objective identifies the purpose of the indicator.

### *Identifying Potential Sustainable Fisheries Indicators*

The goal of the framework was to help in the identification of indicators that could be used to rank the sustainability of marine fisheries and ecosystems of selected maritime countries. The FAO's Code of Conduct for Sustainable Fisheries and the MSC components of sustainable fisheries also guided this process. There are a number of potential criteria that could be used. However, in this study, only those criteria that reflect sustainability and were 'SMART' (simple, measurable, accessible, relevant, and timely; NORAD, 1999) were selected (Table 2). In Table 2, criteria A to M reflect sustainable fisheries components, while criteria N to X reflect components for SMART data sets. To be selected as a sustainable fisheries indicator, a potential variable had to meet at least 7 out of the 13 criteria in A to M and 6 out of

the 11 criteria from N to X. For example, MPA coverage meets 10 of 13 sustainable fisheries criteria (A to M) and all the SMART criteria (N to X).

Using Table 2, a final list of indicators was developed; the indicators it contains are summarized below and discussed in detail in Appendix 1. This list is by no means exhaustive, but is intended to provide a useful inventory for developing sustainable fisheries indicators. The objective of sustainable fisheries indicators is to provide a measuring tool to monitor progress and/or trends of fisheries management practices that address many of the issues of overfishing and habitat degradation.

**Table 2.** Criteria for selecting sustainable fisheries indicators (the relevance of these criteria to sustainability is covered in Table 3).

Criteria	Description
A	Demonstrates willingness to implement measures and practices aiming to conserve and maintain the integrity of aquatic resources and ecosystems (e.g. through MPAs).
B	Demonstrates fishing practices allowing the persistence of species (high abundances) for present and future generations, and ecosystem well-being.
C	Implements environmentally safe fishing practices and uses environmentally safe fishing gear.
D	Minimizes negative harvesting and processing impacts, and reduces waste.
E	Integrates fisheries interests into coastal management.
F	Demonstrates compliance with laws and enforces conservation and management measures, ensures vessels are in compliance with relevant local and national laws, and encourages compliance with international trade laws; also enables conflict resolution.
G	Measures overfishing (directly or indirectly).
H	Demonstrates change in alternative and/or supplementary sources of income.
I	Demonstrates change in alternative sources of protein other than fish.
J	Demonstrates limited use of aquaculture
K	Demonstrates limited provision of capacity-enhancing fisheries subsidies.
L	Demonstrates low fishing effort (e.g., fleet size and GRT*).
M	Demonstrates low fuel consumption by the fishery sector.
N	Data are available to calculate indicator and evaluate progress against the objective.
O	Methods of data collection and analysis are technically feasible, efficient, comparable, consistent over time, and accessible.
P	Data are scientifically valid, i.e., based on peer-reviewed literature, or issued by organizations that have some sort of internal quality control.
Q	Method is useable today and in the future.
R	Method and indicator are understandable to both decision-makers and other users.
S	Indicator is sensitive to changes in social, economic or environmental conditions.
T	Indicator is internally and externally coherent (i.e., on its own, and compared with other indicators).
U	Synthesized large quantity of information in a single numerical value.
V	Convenient and economically feasible to collect so measures could be carried out frequently.
W	Relevant to fisheries and other elements of sustainability (social, economic and ecological).
X	Indicator is adequately documented.

\* Gross Registered Tonnage (GRT) is a standard to define boat size and a proxy for the capacity of a fleet and is based on FAO's fleet statistics for 1995.

**Table 3.** List of sustainable fisheries indicators (see Table 2 for relevance criteria)

Variable	Objective	Stressor	Problem	Relevance
Marine Protected Area Coverage (MPA <sub>area</sub> ).	Quantifying the attempt by maritime countries to protect some of their marine species and parts of their ecosystems from fishing.	Unrestricted fishing, i.e., lack of designated marine protected areas.	Increased fish mortality, habitat loss, by-catch of non-target species, gear impact on habitat and species.	A, B, C, D, E, F, G, J, L, M, N, O, P, Q, R, S, T, U, V, W, X
Fishmeal Consumption by Mariculture (MEAL <sub>mar</sub> ).	Quantifying the consumption of fishmeal per unit of aquaculture production.	Use of fishmeal in aquaculture feed.	Additional stress to often depleted stocks of small pelagic fishes.	A, B, C, D, E, F, G, J, K, M, N, O, P, Q, R, S, T, U, V, W, X
Change in EEZ Area Trawled (EEZ <sub>trawl</sub> ).	Quantifying the impact of trawlers and dredgers on the shelves of maritime countries.	Demersal (bottom) trawl fishing and dredging to catch bottom-dwelling species.	Destruction of marine benthic habitats.	A, B, C, D, F, G, K, L, M, N, O, P, Q, R, S, T, U, V, W, X
Catch Relative to Fuel Consumption (CATCH <sub>fuel</sub> ).	Quantifying the fuel consumption of the fleets operating in the EEZ of each maritime country.	Use of energy by the fishing sector.	Increased pressure to already declining fish stocks and continuous habitat degradation.	E, F, G, D, G, L, M, N, O, P, Q, R, S, T, U, V, W, X
Compliance with the FAO Code of Conduct (CODE <sub>FAO</sub> ).	Quantifying countries' willingness to work toward sustainable fisheries management.	Lack of voluntary compliance with enforcement and regulations.	Unsustainable fisheries management.	A, B, C, D, E, F, G, L, M, N, O, P, Q, R, S, T, U, V, W, X
Landed Value* Relative to GDP (LV <sub>GDP</sub> )*.*.	Quantifying the contribution of fishing to the overall economy of countries.	Fishing tends to overexploit fish stocks and wreck its own resource base.	Mismanagement of fisheries.	A, B, C, D, E, F, G, H, I, J, K, L, M, O, P, Q, R, S, T, U, V, W, X
'Good' to 'Good + Bad' Subsidies Ratio (SUB <sub>good</sub> ).	Quantifying efforts towards fisheries management, services and research, thus considered to improve the sustainability of fisheries.	Reduces stress by investing in management programs, services and research.	Fishing overcapacity and overfishing.	A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X
Subsidies Relative to Landed Value (SUB <sub>LV</sub> ).	Quantifying the contribution of subsidies to fisheries.	Funds programs that increase capacity.	Subsidies can contribute to overcapacity, leading to overfishing.	A, B, C, D, E, G, K, L, M, N, O, P, Q, R, S, U, V, W, X

\*Landed value: Monetary (ex-vessel) value of fish landed;

\*\*GDP (Gross Domestic Product) is a measure of the goods and services sold in a year in a country, providing a rough measure the size of its economy.

### Country Selection

The two criteria for selecting maritime countries to be included here were: (1) that data should be available to give values to the indicators, and (2) that the countries selected should jointly account for most of the world's fisheries catches. The second of these criteria was met by using the list of countries (Appendix 2) also used by Pitcher *et al.* (2008) in their study of compliance to the FAO Code of Conduct [see also Alder and Pauly (this volume)]. These countries represent over 95% of the reported world catch. The Faroe Islands were treated as a 'country', because they are a self-governed part of the Kingdom of Denmark, and thus autonomous in their fisheries management practices (FAO, 2001). Of the 53 countries, 32 are developing and 21 are developed countries. Small island states, mainly found in the Caribbean and Oceania, are not represented in Table 2, and Oceania is represented by only two countries, Australia and New Zealand.

### Data Sources

Only brief descriptions of the indicators and their sources are given here; see Appendix 1 for more details.

#### Marine Protected Area Coverage (MPA<sub>area</sub>)

Data from MPA Global (Wood *et al.* 2008; [www.mpaglobal.org](http://www.mpaglobal.org)) were provided by Dr Louisa Wood for the 53 maritime countries listed in Appendix 2 (L. Wood, IUCN, San Francisco, pers. comm.). The data referred to statutory or non-statutory designated MPAs, covering the overwhelming bulk of marine protected area in the world up to 2005. The percentage of MPA in each EEZ (MPA<sub>area</sub>) was estimated using

an aggregate layer of EEZ claims from the Global Maritime Boundaries database (General Dynamics Advanced Information Systems, 2007).

#### Fishmeal Consumption by Mariculture (MEAL<sub>mar</sub>)

The data on fishmeal consumption per unit of aquaculture production (MEAL<sub>mar</sub>) are documented in Campbell and Alder (2006), and originated from the *Sea Around Us* Project database ([www.seaaroundus.org](http://www.seaaroundus.org)). The fishmeal consumption for the selected countries came from FAO's database of Processed Products, and their aquaculture production was based on FAO's aquaculture production database. Both data sets refer to the year 2000. These 53 countries in Appendix 2 account for more than 90% of the world aquaculture production (marine, brackish and freshwater) and nearly 100% of marine production. Unlike capture fisheries, the levels of miscellaneous species reported is much lower, which reduces uncertainty.

#### Change in EEZ Area Trawled (EEZ<sub>trawl</sub>)

Four variables are used to calculate this indicator with data derived from various sources: a) the area of a country's EEZ was as described above for MPA<sub>area</sub>; b) the area within the EEZ that is trawled in 2000 and 2004 was based on Watson *et al.* (2006) and described in detail in Appendix 1; c) the total gross registered tonnage (GRT) which is a proxy for effort is based on FAO's database Global Fishing Fleets (FAO, 2007a); and d) the total catch that was taken using bottom trawls and dredges based on Watson *et al.* (2006). The shelf area trawled is based on associations or gears and catches of reported species and is expressed as a fraction of total EEZ. The ratio of the proportion of area trawled for the year 2000 and 2004 is used. This ratio indicates a country's trend towards either increasing or decreasing trawling activities which are known to have a high impact on marine ecosystems (Chuenpagdee *et al.*, 2003). The proportion of the fleet based on GRT that is bottom trawlers and dredgers is also calculated. The EEZ<sub>trawl</sub> indicator is then calculated as:

$$(\text{area trawled 2000}/\text{area trawled in 2004})/(\text{100-\% of fleet}_{\text{trawlers and dredges}}) \quad \dots 1)$$

#### Catch relative to fuel consumption (CATCH<sub>fuel</sub>)

Catch relative to fuel consumption (CATCH<sub>fuel</sub>) for year 2000 was retrieved from the *Sea Around Us* project database ([www.seaaroundus.org](http://www.seaaroundus.org)) and are based on the study by Tyedmers *et al.* (2005). The catch data are explained above (see also (Watson *et al.*, 2004). The indicator involved a log transformation (see Appendix 1).

#### Compliance with the FAO Code of Conduct (CODE<sub>FAO</sub>)

Compliance with the FAO Code of Conduct (CODE<sub>FAO</sub>) was quantified by Pitcher *et al.* (2008). The data used by Pitcher *et al.* (2008) largely apply to the 2000s. The evaluation of the data was based on an adaptation of the appraisal scheme of 44 questions, each scored on a scale of zero to ten. The scores were based on published and unpublished literature, and expert opinions (Pitcher *et al.*, 2008).

#### Subsidies-related indicators (SUB<sub>good</sub> and SUB<sub>LY</sub>)

Two subsidies-related indicators, were derived for the year 2000 from the subsidies data in (Khan *et al.*, 2006; Sumaila *et al.*, 2006) and the *Sea Around Us* database ([www.seaaroundus.org](http://www.seaaroundus.org)), respectively, the fraction of 'good' to 'good' + 'bad' subsidies, and total subsidies (adjusted by purchasing power parity per fisher (see Appendix 1 for the purchasing power parity adjustment). The subsidies, which are 'bad' for fisheries sustainability when they lead to fleet capacity growth, and 'good' otherwise, refer only to marine capture fisheries, and were estimated when reported data were not available (Khan *et al.*, 2006). [Khan *et al.* (2006) also defined 'ugly' subsidies, discussed in Appendix 1.] The landed value data is described below.

### Landed value relative to GDP ( $LV_{GDP}$ )

Landed value and GDP data, whose ratio provided an indicator ( $LV_{GDP}$ ) were obtained for the year 2000. The landed value data came from the *Sea Around Us* database ([www.seaaroundus.org](http://www.seaaroundus.org)) and consists of vessel prices multiplied with landed weight (Sumaila *et al.*, 2007). The GDP values stem mainly from the World Bank ([www.worldbank.org](http://www.worldbank.org)), and are expressed in real 2000 US \$.

### Data Analysis

The raw indicator scores were computed, standardized between zero and ten, tested for significance, and analyzed to identify the variation amongst the eight indicators for 53 maritime countries (Appendix 2). ‘Performance scores’ were selected because common units were needed to combine the cumulative results of each indicator for each country. The raw data for each indicator was rescaled to a performance score between zero and ten (bad to good) to convey how well each maritime country ranked against the indicator with respect to sustainable fisheries management and/or practices. Table 4 lists the ranges and values necessary for each indicator to be assigned a performance score between 0 and 10. The performance score for each indicator was plotted as a frequency distribution to show the distribution along the x-axis (score between zero and ten).

**Table 4.** Ranges used to assign each indicator value a performance score (0 to 10, with 10 indicating practice leading to sustainable fisheries).

SCORE	$MPA_{area}$	$EEZ_{trawl}$	$MEAL_{mar}$	$CODE_{FAO}$	$CATCH_{fuel}$	$SUB_{good}$	$SUB_{LV}$	$LV_{GDP}$
0	$x \leq 0$	$x > 15$	$x \geq 100$	$x < 1$	$x \leq 0$	$x < 10$	$x \geq 100$	$x \leq 0$
1	$0 < x \leq 1$	$10 < x \leq 15$	$90 \leq x < 100$	$1 \leq x < 2$	$0 < x \leq 0.3$	$10 \leq x < 20$	$90 \leq x < 100$	$0 < x \leq 0.01$
2	$1 < x \leq 2$	$5 < x \leq 10$	$80 \leq x < 90$	$2 \leq x < 3$	$0.3 < x \leq 0.6$	$20 \leq x < 30$	$80 \leq x < 90$	$.01 < x \leq 0.02$
3	$2 < x \leq 3$	$2 < x \leq 5$	$70 \leq x < 80$	$3 \leq x < 4$	$0.6 < x \leq 0.9$	$30 \leq x < 40$	$70 \leq x < 80$	$.02 < x \leq 0.03$
4	$3 < x \leq 4$	$1 < x \leq 2$	$60 \leq x < 70$	$4 \leq x < 5$	$0.9 < x \leq 1.2$	$40 \leq x < 50$	$60 \leq x < 70$	$.03 < x \leq 0.04$
5	$4 < x \leq 5$	$0.8 < x \leq 1$	$50 \leq x < 60$	$5 \leq x < 6$	$1.2 < x \leq 1.5$	$50 \leq x < 60$	$50 \leq x < 60$	$.04 < x \leq .05$
6	$5 < x \leq 6$	$0.6 < x \leq 0.8$	$40 \leq x < 50$	$6 \leq x < 7$	$1.5 < x \leq 1.8$	$60 \leq x < 70$	$40 \leq x < 50$	$0.05 < x \leq 0.1$
7	$6 < x \leq 7$	$0.4 < x \leq 0.6$	$30 \leq x < 40$	$7 \leq x < 8$	$1.8 < x \leq 2.1$	$70 \leq x < 80$	$30 \leq x < 40$	$0.1 < x \leq 0.5$
8	$7 < x \leq 8$	$0.2 < x \leq 0.4$	$20 \leq x < 30$	$8 \leq x < 9$	$2.1 < x \leq 2.4$	$80 \leq x < 90$	$20 \leq x < 30$	$0.5 < x \leq 1.0$
9	$8 < x \leq 9$	$0 < x \leq 0.2$	$10 \leq x < 20$	$9 \leq x < 10$	$2.4 < x \leq 2.7$	$90 \leq x < 100$	$10 \leq x < 20$	$1.0 < x \leq 10$
10	$x > 9$	$x \leq 0$	$x < 10$	$x \geq 10$	$x > 2.7$	$x \geq 100$	$x < 10$	$x > 10$

Average performance scores were computed for each country, and the countries were ranked. The cross correlations between the performance scores for the 53 countries and eight indicators were computed to determine their relationship and significance. A principal component analysis (PCA) was performed from the standardized scores using the STATA Statistical Software (StataCorp, 2003) to identify the level of variation amongst the eight variables and assess their influence on position of our 53 maritime countries.

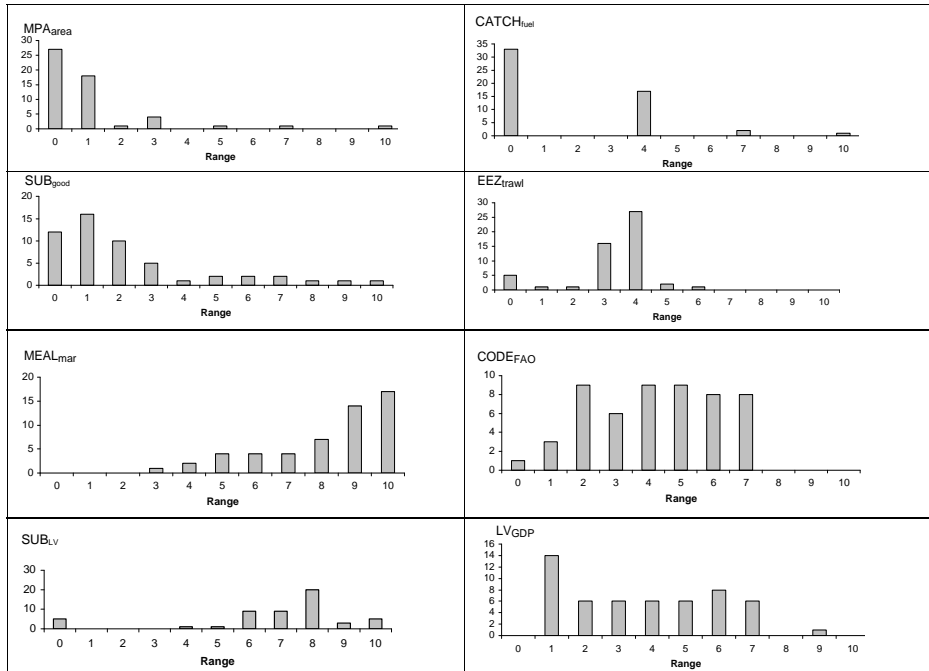
## RESULTS AND DISCUSSION

The performance score distributions for the 53 countries along the zero to ten scale were either skewed to left (zero) or the right (ten), bimodal, or relatively evenly distributed along a scale (Appendix 3). The indicators that we skewed to the left of the scale were  $MPA_{area}$  and  $SUB_{good}$ . Those skewed to the right were  $MEAL_{mar}$  and  $SUB_{LV}$ .  $CATCH_{fuel}$  had a bimodal distribution. The indicators evenly distributed along the scale were  $EEZ_{trawl}$ ,  $CODE_{FAO}$  and  $LV_{GDP}$  (Figure 1). The average performance score conveyed how each maritime country ranked against the others (Table 6). The highest ranking country was Peru, with a score of 6, while the Faeroes Islands ranked lowest, with a score of 2. The majority of countries had scores between 4 and 5. Interestingly, there was a strong overlap between developing and developed countries.

A PCA, with principal axis  $Z_1$  and  $Z_2$ , identified a relatively low level of variation amongst the eight indicators (Table 6). The difference between the highest and the lowest absolute value was not large, indicating that no indicator dominated the analysis (Figure 2; details in Mondoux, 2008).

The fact that some indicators are skewed to the left, and some to the right (see above) had the effect that the aggregated performance scores were not skewed, as indicated in the PCA (with the exception of the

MPAs, which are highly skewed to the left). This confirmed that no particular indicator determines the ranking of countries in Table 7.



**Figure 1.** Frequency distributions of the scores of 53 maritime countries for the eight indicators presented here,  $MPA_{area}$ ,  $EEZ_{trawl}$ ,  $MEAL_{mar}$ ,  $CODE_{FAO}$ ,  $CATCH_{fuel}$ ,  $SUB_{good}$ ,  $SUB_{LV}$ ,  $LV_{GDP}$  (see text for definitions).

The maritime countries of the world can be reliably ranked in terms of the sustainability of their fisheries and marine ecosystem, and the 8 indicators presented here appear plausible and robust. The integration of the indicators, designed to address the many dimensions of the fisheries sector (social, economic, and environmental) also performed as expected.

The data collection and analysis of these eight indicators is technically feasible and efficient because all the data were accessible on-line, through databases that are freely available, and

which can be presumed to be maintained in the future. The databases are also from reliable sources because the organizations providing the data are research or science-based institutions (FAO, WRI, the World Bank and the *Sea Around Us* Project). Often the pedigree of data was available along with details on the collection and quality of the data (i.e., metadata).

**Table 5.** Principal component analysis, ranked from highest degree of association to lowest.

Variable	Scoring coeff	Rank
$CODE_{FAO}$	0.521	1
$MEAL_{mar}$	-0.491	2
$SUB_{LV}$	-0.473	3
$CATCH_{fuel}$	0.298	4
$SUB_{good}$	0.281	5
$LV_{GDP}$	0.228	6
$EEZ_{trawl}$	0.201	7
$MPA_{area}$	0.065	8

The ecological aspects of sustainable fisheries indicators assess the environmental conditions of a country’s EEZ toward protecting, conserving and sustainably managing their marine ecosystem. The social aspect of sustainable fisheries indicators allow for an understanding of the fisheries sector in terms of community interest or need, and the distribution of benefits gained by the fishing community. For example, compliance with the FAO Code of Conduct for Responsible Fisheries may not be a priority for developing countries because of other perceived social or economic needs. On a global basis, the social aspect of sustainable fisheries indicators may assist in identifying

which countries might require international assistance toward achieving sustainable fisheries. The economic aspect of sustainable fisheries indicators touches on the economic dimension of fisheries and their importance to a country’s economy, which may be related to a desire to protect the marine resources and ecosystems.

**Table 6.** Average performance scores for the 53 countries.

Country	Average score	Country	Average score
Peru	6.42	Sweden	3.82
Namibia	5.10	Pakistan	3.81
USA	5.10	Indonesia	3.80
Germany	4.90	Japan	3.78
Poland	4.82	Australia	3.78
Norway	4.71	Spain	3.77
Senegal	4.70	Taiwan	3.75
Chile	4.67	Thailand	3.74
South Africa	4.64	Viet Nam	3.70
Ghana	4.59	Russia	3.67
Netherlands	4.56	Turkey	3.60
New Zealand	4.54	Iceland	3.58
Nigeria	4.45	India	3.57
UK	4.40	Sri Lanka	3.57
Malaysia	4.34	Mexico	3.56
South Korea	4.31	France	3.50
Latvia	4.30	Yemen	3.49
Philippines	4.28	North Korea	3.46
Angola	4.27	Portugal	3.39
Myanmar	4.25	Denmark	3.34
Canada	4.23	Brazil	3.27
Ireland	4.13	Iran	3.12
Italy	4.03	Ecuador	3.00
China	3.96	Bangladesh	2.81
Morocco	3.93	Argentina	2.55
Egypt	3.92	Faroese	2.29
Ukraine	3.90	-----	-----

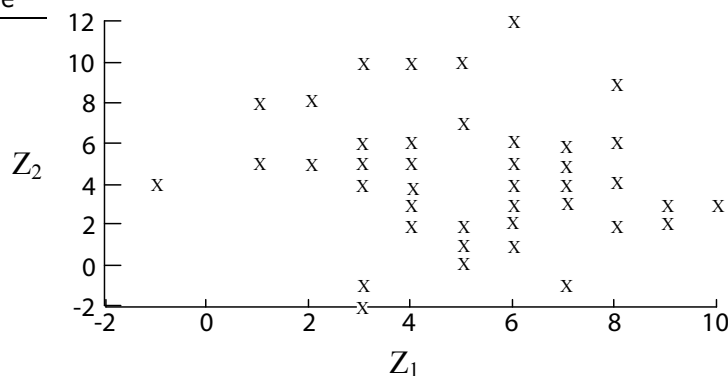
removed from the computation.

The study ranked countries along a scale of poor to good sustainability performance, with countries sitting along this spectrum irrespective of their economic development. However, some of the countries performance scores were unexpected. For example, it was expected that New Zealand would score slightly higher than it actually did, because of their reputation for sustainable fisheries practices.

Although there are limitations and shortcomings in the data used here, a set of sustainable fisheries indicators could be developed, which allowed comparisons on the sustainability of marine fisheries in 53 countries. Sustainable fisheries performance can now be tracked with the same rigor, as say, a country's Human Development Index (UNDP, 2000). Nevertheless, the development of sustainable fisheries indicators is still a work in progress, and further research is needed on the relationship between environmental health and human well-being. The series of indicators developed here may help in this.

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**Figure 2.** Distribution of 53 countries for the  $Z_1$  and  $Z_2$  of the PCA analysis.

Both developing and developed countries were relatively well distributed in the rankings. However, when the indicators with a skewed distribution were removed from the computation, the only significant pattern was that most of the 53 countries scores declined because many of them scored rather high (good sustainable fisheries practices) in the two skewed indicators ( $SUB_{LV}$  and  $MEAL_{mar}$ ). Also, the highly subsidized countries increased their scores when the subsidy-related indicators were



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## APPENDIX 1: DETAILS ON THE EIGHT FISHERIES SUSTAINABILITY INDICATORS

*Marine protected area as a fraction of EEZ (MPA<sub>area</sub>)*

A Marine Protected Area (MPA) is any marine area specifically designated for the protection, maintenance and management of a part of a marine ecosystem and biodiversity for its natural and cultural resources. The role of a marine protected area is to reduce fishing mortality, reduce by-catch of non-target species and conserve habitats, all positive contributions to sustainability. The indicator is not designed to measure whether conservation objectives are being met. Therefore the effectiveness of the action cannot be identified or used.

This indicator demonstrates an attempt by maritime countries to protect some of their species and parts of their ecosystems from fishing – actions that promote sustainable fisheries. Coverage of protected areas is one of a series of indicators identified by the Convention on Biological Diversity (CBD) listed as available for “immediate testing” and used to assess the progress towards the 2010 biodiversity target (CBD, 2005). MPAs’ contribution to sustainable fisheries are that they can contribute to the restoration of species and habitats, address human needs for food and cultural resources, provide economic gain, and possibly increase livelihoods.

Data quality for MPAs is variable because of a lack of data required to update existing information for some countries (Chape *et al.*, 2005; Wood *et al.*, 2008) and a lack of resources (CBD, 2005). However, data were available for the selected 53 maritime countries. In this dataset, two countries, the United States and Australia have large MPAs which skew the data set. However, their large EEZs reduced this potential bias.

As defined, the MPA<sub>area</sub> indicator naturally corresponded to a range of zero to ten (Table 4). The latter value was selected because the CBD (2006) has set a goal of conserving at least 10% of the world marine coastal and ecological regions by 2012.

*Relative use of fishmeal (MEAL<sub>mar</sub>)*

Fishmeal consumption is the use of fish capture in the wild such as small pelagic fish for processing into protein-rich meals, used among other things as feed for the raising of carnivorous fish species. Currently, more than 50% of global fishmeal production is used in aquaculture. Whether a country produces its own fishmeal (or fish oil) or imports it, such uses ultimately puts pressure on capture fisheries, especially small pelagic fisheries, thus contributing to unsustainable fishing levels. Fishmeal consumption usually represents a threat to marine biodiversity and ecosystems as small pelagic fish are key prey species for large fish, seabirds and marine mammals (Alder and Pauly, 2006).

Aquaculture presents both advantages and disadvantages to communities. The aquaculture industry contributes to the national economy, provides a source of affordable protein, and creates local employment. The downside of the aquaculture industry is that the production of fishmeal removes a source of cheap protein for many people (Pauly and Alder, 2005), and the fishmeal processing factories are a source of water and air pollution to the communities (Campbell and Alder, 2006).

It is acknowledged that fishmeal consumption, even when standardized by aquaculture production, only imperfectly reflects the level of impact on the fisheries sector, because of inconsistencies and lack of data. For example, some countries may not only use large quantities of fishmeal, but may also use by-catch as direct feed in aquaculture, which is often not recorded in official production statistics (Campbell and Alder, 2006). Campbell and Alder (2006) also report that data on fishmeal consumption by the aquaculture sector are scarce, and that this consumption is usually estimated based on aquaculture production. Also, there are inconsistencies within and between databases and countries with respect to classifications and quantities reported. For example, quantities may be over-estimated due to how the data were categorized in the past, or because of a poor history of reporting.

The following computation from raw data to performance score was computed for the 53 maritime countries. The indicator is computed as fish consumption relative to aquaculture production, in %. The

MEAL<sub>mar</sub> data were then turned into a performance score (see Table 4), where 10 implies reflects a limited consumption of fishmeal and 0 reflects the maximum range of fishmeal consumed.

### *Shelf Area Trawled relative to GRT (EEZ<sub>trawl</sub>)*

Shelf area trawled refers to an area covered by waters to a depth of 200m, where most fishing activity occurs. For this indicator, only trawls and dredges that are dragged on the sea floor to catch bottom-dwelling species such as flounder and shrimp are considered. The area fished by trawlers and dredgers is based on Watson *et al.* (2006) and described in detail below. It is an indicator of sustainable fisheries in that it quantifies the level of marine habitat degradation from fishing with bottom-impacting gear.

Chuenpagdee *et al.* (2003) report that bottom trawl fishing and dredging to catch bottom-dwelling species is the most destructive fishing gear in use today. The impact from the gear dragging and/or digging into the sediments affects marine habitats, such as coral reefs and seagrass beds, and can change the structure and function of the impacted ecosystems. The destruction of seafloor habitats can last for many years. Usually, trawling and dredging do not allow for a period of recovery.

Fishers who do not use these destructive gears are often impacted since the degraded habitats such as seagrass function as nurseries for a range of commercially important species. The different user groups affect one another depending on the fishing method; particularly, there is competition between small-scale and large-scale fisheries (Chuenpagdee *et al.*, 2006).

Excess tonnage and excess power of fleets result in overfishing (see Brown *et al.*, 2000). Overcapacity is considered one of the most significant reasons for overfishing in global fisheries (FAO, 2007b) and capture-fishery resources and fisheries are under threat with increasing fishing-fleet capacity (Pauly *et al.*, 2002). FAO (2007b) reported that as a result of overcapacity in the mid-1990s, fisheries became economically unsustainable, and as a consequence, many fisheries had to rely on subsidies to continue fishing. Over-capacity results in various problems for fishers, such as low income.

Shelf Area Trawled relative to the GRT of the fleet (EEZ<sub>trawl</sub>) was derived from:

- a. The *Sea Around Us* Project catch database ([www.seaaroundus.org](http://www.seaaroundus.org)) and the work of Watson *et al.* (2006). The catch data (for the year 2000) were based on the global allocation of catch statistics using knowledge of the distribution of the reported taxon on the fishing behavior and access rights of the reporting country. Most of the global catch (~80%) is taken from the productive shelf areas, where most of the fishing occurs, often within 200 miles, which therefore, is the most affected by trawling;
- b. The shelf area and the EEZ were estimated by expressing sea surface areas in km<sup>2</sup> and overlaying a global 2-minute cell raster ESRI grid of surface area values with a matching ESRI grid of EEZ (Cimino *et al.*, 2000; Reg Watson pers. comm., 2007). For each EEZ, the intersecting surface areas based on the 2-minute raster cell were extracted and summed. The area for each 'EEZ Shelf' was prepared in a similar way, but was truncated at 200 m depth, i.e., at the shelf edge, based on the United States National Geophysical Data Center's 'ETOPOS GLOBAL 2' bathymetric map data (Cimino *et al.*, 2000; Reg Watson pers. comm., 2007).
- c. The trawled area of an EEZ claimed by countries was determined by examining *Sea Around Us* Project's 30-minute spatial cell global catch breakdown (Watson *et al.*, 2004). For each spatial cell, the catch by trawling was established by published associations between trawl gears and the catch of reported species (by countries and years; Watson *et al.*, 2006). In order to establish areas which had more than trivial amounts of trawling, we accepted as trawled only those spatial cells where the reported trawl-associated catch in the year was at least 0.05 tonnes per km<sup>2</sup>.
- d. The GRT data (for year 1995) came from the Food and Agriculture Organization of the United Nations (FAO, 2007a) through Sylvie Gu nette (Fisheries Centre, UBC, pers. comm.).

Limitations of the EEZ<sub>trawl</sub> data are that the catch mapped may be incomplete, or erroneously mapped (Watson *et al.*, 2004). Also, the catch of different species may have been assigned to the wrong gear (Watson *et al.*, 2006). The major source of this error is due to reporting of 'miscellaneous fish' by a country. Previous studies (Khan *et al.*, 2006) indicate that a high level of reporting miscellaneous catches occurs in both developed and developing countries throughout the world. The data were received and compiled from a variety of sources, including the FAO data set, which does not include all catches landed by countries.

This indicator is based on the area of the EEZ that is trawled, and is adjusted for the size of the fleet (based on the GRT for vessels that are classified as bottom trawlers and dredgers). We use 2000 as the base year. If a country was increasing its area trawled in 2004 then it scores low. If there was no change, it scores in the middle; if the trawled area is decreasing then it scores high. Countries are then adjusted for the intensity of trawling by weighting by the proportion of the fleet that is trawlers and dredgers.

1. (area trawled in 2000/area trawled in 2004)/(1-proportion of fleet GRT that are trawlers and dredges); then
2. The interim score is mapped onto a scale of 0 to 10 to obtain the final score.

### *Catch per litre of fuel consumed (CATCH<sub>fuel</sub>)*

Catch per litre of fuel indicator is the amount of fish caught (kg) per litre (L) of fuel used. The type of fishing gear used to catch fish is obviously the key factor determining the amount of fuel consumed. Passive fishing gear (nets or traps) used to catch pelagic and groundfish have lower fuel consumptions than active fishing gear, where the gear is dragged long distances through the water (e.g. bottom trawl), thereby greatly contributing to fossil fuel consumption and greenhouse gas emissions.

According to the Danish energy consumption study by Thrane (2004), the most energy-intensive fishery is the Norway lobster fishery. The most efficient fisheries in terms of energy are purse seine fisheries for small pelagic fishes (Tyedmers *et al.*, 2005). Overall, in 2000, “fisheries burned almost 50 billion L of fuel in the process of landing just over 80 million t of marine fish and invertebrates, and emitted more than 130 million t of CO<sub>2</sub> into the atmosphere” (Tyedmers *et al.*, 2005).

Fuel studies were not available for all fisheries in the world or all years, possibly resulting in some extrapolation being incorrect for this indicator. Also, as discussed for the above indicators, the catch may not be completely or accurately reported (e.g., wrong species), and the distribution of the species may be erroneous. Here, the logarithm of catch (in kg) per litre of fuel was used as indicator, to provide a better spread among countries with low scores. This was then rescaled to scores ranging from 0, reflecting a high fuel consumption and 10, for the converse (Table 4).

### *Compliance with FAO Code of Conduct (CODE<sub>FAO</sub>)*

The FAO Code of Conduct for Responsible Fisheries (FAO, 1995) is a set of recommendations and guidelines aimed at national policy makers and fisheries managers to voluntarily incorporate aspects of sustainability into their fishery policies. It aims at ensuring management of fishery resources such that they will be available for present and future generations. The CODE<sub>FAO</sub> as an indicator measures a country’s willingness to work toward sustainable fisheries management by voluntarily complying with the Code of Conduct’s principles (Pitcher *et al.*, 2008).

The limitations of the data and source rest with interpretation and reporting of data. Pitcher *et al.* (2008) report that omissions and errors of interpretation still remain for some countries. Biased conclusions may also be a factor to consider, because the evaluation relied on self-reporting by countries of their own progress, and the uncertainty or levels of accuracy in reporting have not been evaluated. The values of the indicator in Pitcher *et al.* (2008) were re-expressed on a scale from 0 to 10 (see Table 4).

### *Subsidies-related indicators: SUB<sub>good</sub> and SUB<sub>LV</sub>*

A subsidy is a financial payment from the government made to a private firm, or household conveying economic benefit to the recipient. The two subsidies-related indicators are discussed jointly in this section. The first is the ratio of good subsidies to good+bad subsidies (SUB<sub>good</sub>), the second total subsidies (good+bad+ugly) per landed value (SUB<sub>LV</sub>). Khan *et al.* (2006) argue that three categories of subsidies can be created to capture impacts on the fisheries sector:

- 1) Good subsidies are investments in management programs, services and research in order to achieve maximum allocation and benefit of natural resources to society and marine conservation; they do not increase fishing capacity and hence do not contribute to overfishing;
- 2) Bad subsidies develop or support fishing infrastructure (e.g., port facilities), secure access (e.g., to foreign grounds), and cover variable (e.g., bait, insurance) and fixed costs of fishing (e.g., through grants,

loans). They also include price support programs (e.g., government intervention to minimize production cost). These are bad subsidies because they increase fleet capacity, and thus lead to more overfishing; 3) Ugly subsidies, finally, can lead to positive or negative impacts on fleet capacity, depending on the context.

Good subsidies as a fraction of the sum of good and bad subsidies ( $SUB_{good}$ ) represent efforts towards fisheries management, services and research, and therefore can be considered as initiatives to improve the sustainability of fisheries (Table 4). Total subsidies per landed value ( $SUB_{LV}$ ) on the other hand, should have the opposite effect (Table 4).

Some of the information available in the literature did not reflect the true extent of the subsidies provided, and the greatest uncertainty regarding subsidies lies in the area of indirect payments (Khan *et al.*, 2006). The FAO (1999b) also reports that its estimates of fisher numbers may be inaccurate.

The  $SUB_{good}$  indicator was computed from the data of Khan *et al.* (2006), then re-expressed as score, from 0 to 10 (Table 4).

### *Value of the catch as a fraction of GDP ( $LV_{GDP}$ )*

Landed value as a fraction of the GDP ( $LV_{GDP}$ ) demonstrates the importance of the contribution of fishing to the overall economy of a country. Countries that rely heavily on fisheries as a contributor to GDP tend to have better sustainable fisheries practices than countries that do not (Hannesson, 1996). The major advantage of the GDP and hence the  $LV_{GDP}$  as an indicator of sustainable fisheries and economics is that they can be measured frequently (most countries provide information on the GDP on a quarterly basis), widely (some measure of GDP is available for practically every country), and consistently (the same thing is being measured in each country).

The  $LV_{GDP}$  was computed as the landed value of the catch (Sumaila *et al.*, 2007; [www.seaaroundus.org](http://www.seaaroundus.org)) divided by the GDP then re-expressed as a score from 0 to 10 (Table 4).

## APPENDIX 2: PERFORMANCE SCORED BY COUNTRY FOR THE EIGHT INDICATORS

**Table A1.** Performance scores between zero and ten, by country, for the eight indicators.

Country	MPA <sub>area</sub>	EEZ <sub>trawl</sub>	MEAL <sub>mar</sub>	CODE <sub>FAO</sub>	CATCH <sub>fuel</sub>	SUB <sub>good</sub>	SUB <sub>LV</sub>	LV <sub>GDP</sub>
Angola	1	4	10	1	0	2	8	6
Argentina	0	0	8	3	0	1	7	5
Australia	7	3	7	6	0	3	8	4
Bangladesh	0	0	9	1	0	1	6	1
Brazil	1	3	9	3	0	0	0	1
Canada	1	4	6	7	4	4	8	4
Chile	0	4	5	5	7	0	10	6
China	0	4	10	5	0	0	8	3
Denmark	3	3	5	6	4	1	0	5
Ecuador	0	5	8	3	0	2	8	6
Egypt	3	4	10	1	0	2	8	1
Faroese	0	3	3	5	4	1	0	1
France	0	3	9	5	0	1	8	1
Germany	10	2	8	4	4	1	8	1
Ghana	0	4	10	4	4	1	5	4
Iceland	0	4	4	7	4	1	9	9
India	1	3	10	4	0	0	0	1
Indonesia	1	4	9	2	0	1	7	3
Iran	1	0	9	2	0	2	9	1
Ireland	0	3	8	0	4	7	6	3
Italy	1	4	9	4	0	3	6	1
Japan	0	4	8	6	0	6	7	5
Latvia	0	1	10	2	7	2	8	3
Malaysia	1	3	9	5	0	0	8	7
Mexico	1	3	7	4	0	1	8	2
Morocco	0	3	6	3	4	2	7	4
Myanmar	0	4	10	1	0	2	7	7
Namibia	0	3	10	6	4	1	6	7
Netherlands	1	0	10	6	4	1	10	5
New Zealand	0	3	10	6	0	10	10	7
Nigeria	0	4	9	2	0	9	10	3
North Korea	0	4	10	1	0	0	0	4
Norway	0	4	4	7	4	3	8	6
Pakistan	1	4	10	3	0	2	7	2
Peru	0	4	8	4	10	8	9	7
Philippines	1	4	9	3	0	1	6	6
Poland	1	6	9	3	4	5	6	1
Portugal	0	4	6	4	0	2	6	2
Russia	3	4	10	3	0	3	4	3
Senegal	0	5	10	3	4	1	8	7
South Africa	0	4	9	6	4	3	8	1
South Korea	1	4	10	5	0	0	8	5
Spain	1	4	9	5	0	0	6	2
Sri Lanka	0	3	7	2	0	2	8	5
Sweden	3	3	5	5	0	6	8	1
Taiwan	0	4	8	4	0	0	8	4
Thailand	1	3	9	2	0	0	7	6
Turkey	1	4	6	2	4	0	10	2
UK	1	4	5	5	4	5	9	1
Ukraine	2	0	10	2	4	1	6	2
USA	5	4	9	7	0	7	6	1
Viet Nam	0	4	7	2	0	1	8	6
Yemen	0	3	10	1	0	0	7	6