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CONVERGENCE ANALYSIS ON THE FISH STOCK STATUS INDEX FOR 131 COUNTRIES

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Abstract

According to the Food and Agricultural Organization of the United Nations, the share of fish stocks of unsustainable levels or overfished increased from 10% in 1974 to 31.4% in 2013. However, there are some well-managed regions where stocks are stabilizing and many badly managed regions where stock continue to decline. Using Fish Stocks Status data from 1980 to 2014 for 124 countries, this research examines how different income and regional subgroups contributed to reach globally unsustainable high overfished level by the use of convergence analysis. The result is that a majority of subgroups do appear to adjust their current fishing rate, in part, to their past level of overfishing. In other words, they will speed up their rate of catching when their past level of overfishing is low, and vice versa, following the principal of convergence theory. However, one or two subgroups such as Latin America and Caribbean region or the upper middle-income subgroup do not follow this majority's rule, making it harder for other subgroups and countries to control the escalating global overfishing level. Several policy implications from these findings will be discussed.

***Keywords**: Overfished; Fish stock status; Sigma convergence; Gamma convergence; Catch-up*

Introduction

The overexploitation of wide capture marine fish stocks directly impacts ecosystem health and food security, livelihood, and cultural identities of coastal communities worldwide [1-4]. There may also be a wide fisheries exploitation gap between some developed regions and many developing regions around the world. Recent studies in developed regions have demonstrated that significant progress has been made in managing marine fisheries [5-8]. However, other studies on the status of fish stocks in developing regions show that many fisheries are below biologically sustainable levels relative to widely accepted reference points [9-10].

To address this crisis, the Sustainable Development Goal (SDG) was adopted by the United Nations to promote conservation and sustainable use of marine resources [11]. SDG 14.4 states that by 2020, countries should effectively regulate harvesting and end overfishing, illegal, unreported, and unregulated fishing and destructive fishing practices. They should implement science-based management plans to restore fish stocks in the shortest time feasible, at least to levels that can produce a maximum sustainable yield as determined by their biological characteristics. The Food and Agricultural Organization (FAO) of the United Nations also conducts regular stock status reviews focusing on biological overexploitation as defined in

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most fishery-related international treaties. They classify stocks into three categories based on expert opinions: "underfished," "fully fished" including stocks that are within 20% above or below the maximum sustainable yield (MSY), and "overfished."

According to the FAO report [3], the share of fish stocks of biologically unsustainable levels or overfished increased from 10% in 1974 to 31.4% in 2013. Despite the ongoing debate regarding the interpretation of data sources, consensus is emerging to support the FAO's finding that up to one-third of global fishery stocks are now overexploited or collapsed [12-15]. In this category, a majority (58%) were categorized as fully fished, leaving only 10.5% as underfished stocks in 2013. Although assessment of the status of fish stocks presents a greater challenge at the country level due to limited data and capacity for monitoring fishery resources, Srinivasan et al.'s study [16] using catch time-series data of 11,804 stocks in exclusive economic zones (EEZ) estimated that 36 to 53% of commercial species in 55 to 66% of EEZs may have been overfished. That left a maximum of only 68.6% of stocks within biologically sustainable levels in 2013 [3]. Despite these continuing overexploitation patterns, current exploitation and biomass trends differ between some well-managed regions where stocks are stabilizing and even recovering and many badly managed regions where stocks continue to decline [17-18]. For example, the FAO report [3] indicated that the Mediterranean and Black Sea region recorded the highest overfished stock at 59%, followed by the Eastern Central Atlantic region at 46%, and the Southwest Atlantic at 44%. In contrast, the Southwest Pacific region experienced the lowest overfished stock at 12%, followed by the Northeast Pacific region at 14%, and the Eastern Indian Ocean at 15%. Given this wide variation of overfished stocks by region and countries, the central aim of this research is to examine how regions and countries contributed to reach globally unsustainable high overfished level during the period of 1980 to 2014. First, this research examines whether regions and countries with low overfished ratios in early years are increasing their overfished ratios faster to catch-up to regions and countries with higher overfished ratios. If so, we estimate the speed of this catch-up. Second, this research also examines whether regions and countries with high overfished ratios in early years are engaged in slower increase or even reduction of their overfished ratios, reflecting convergence theory.

By using time series data on fish stock status (FSS) from 1980 to 2014 available for 124 countries, we use a simple sigma and gamma convergence methodology to analyze the data. The 124 countries are categorized into four income and five regional subgroups and subjected to the same convergence analysis. The remainder of this article is organized into four sections, presenting the convergence methodology, explaining the data and data sources, the analysis of the results and finally, the conclusions, implications, and limitations.

Convergence Methodology

The initial idea of convergence (also known as the catch-up effect) is based on the hypothesis that economies in poorer countries have tendency to grow faster than richer countries so the former can catch up to the latter. Conventionally, the term "convergence" has two connotations in the economic growth literature. The term refers to a reduction of dispersion among countries, which is known as σ convergence. The term also refers to the phenomenon that poorer countries grow faster than richer ones, which is known as β convergence. In the context of convergence analysis of the FSS index, countries with an initially lower percent in the overfished index are likely to increase their percent of catches faster than countries with an initially higher overfished percent.

The β convergence method [19] regresses the rate of change by comparing the beginning year value with the ending year value of the performance measure for respective countries. When the slope of regression equation is negative and statistically significant, the convergence is confirmed [19-20]. This approach is known as absolute β convergence in which all countries are assumed to move toward a common destination. However, Friedman [21] presented critical objections to the use of regression for convergence analysis by citing the "regression fallacy," which explains the natural tendency of regression towards the mean. Friedman recommended another method for convergence analysis: σ convergence. He asserted that the convergence pattern could be better measured by tracing the fluctuations of the coefficient of variations in the performance measures for a group of countries. If the trend of fluctuation is declining and statistically significant, σ convergence can be demonstrated.

Quah [22] also criticized the use of β convergence analysis because it did not explain the inter-temporal change or intra-distribution of mobility among the countries. Instead, Quah [23] suggested using Markov chain analysis by which a researcher can track the dynamics of cross-country distribution. Similar to Quah's approach, Boyle and McCarthy [24] proposed a simple measure of β convergence. They used rank concordance of Kendall's index to measure chronological changes in the ranking of countries, called γ convergence [25]. They suggested that the combination of σ convergence and γ convergence could be a proper alternative to β convergence because the combination could tell us not only the existence and speed of the catch-up effect but also capture the dynamics of the distribution of the countries.

Since then, numerous studies using γ convergence methodology have been published in areas such as energy, economic growth, inflation, employment, and healthcare [26-35]. For our research, we have adopted the γ convergence method [24] and σ convergence [21] to analyze convergence among 131 countries. The standard deviation and coefficient of variation are commonly used as parameters of dispersion [36]. We used the coefficient of variation (CV) for the σ convergence analysis. CV is measured by dividing the standard deviation by the sample average. The inter-temporal changes can be measured by normalizing a CV of the subsequent year to the initial CV. Hence, the normalized CV of the beginning year is always 1. If the CVs in the subsequent years are less than the CV in the initial year, the normalized CV in subsequent years will be less than 1. When the normalized CVs in the subsequent years continue declining and the differences between the CV of the initial year and that of subsequent years are statistically significant, σ convergence can be confirmed. For a statistical test of the difference, we used a sample t-test for CVs [37]. The test works well if the sample sizes are greater than or equal to 10. Since the sample sizes in our research are much larger than 10, the test should be effective. Boyle and McCarthy [24] proposed the use of rank concordance which measures the mobility of individual countries over time within the cross-country distribution [38-39]. To put it another way, γ convergence quantifies the degree of ordinal ranking change of countries between the initial year and a given year. There are two types of γ convergence methods: the binary Kendall method and the multi-annual Kendall method. We used the binary Kendall method for our analysis. The method is defined as follows:

$$\gamma_t = \left[\frac{var\,(AR\,(Y)_{it} + AR\,(Y)_{io})}{var\,(2 * AR\,(Y)_{io})}\right] \tag{1}$$

where: $AR\ (Y)$ = the actual rank of country i's performance measure, in year t; $AR\ (0)$ = the actual rank of country i's performance measure, in year 0; γ_t = binary Kendall γ index in year t.

Analogous to the normalized CV for σ convergence analysis, the γ index has an important advantage of tracing the degree of change over time. The index can range from zero to unity. If there is no change in the ranking order, the index becomes unity. If a catch-up effect exists, the actual rank of a country in year t will change, which results in a reduction of the nominator, and accordingly, the index will show a value less than unity. The test statistic is chi-square which is used to test whether γ indexes show any significant differences between the ranks of the beginning year and the given year [25]. As the Real Statistics Using Excel website explains [40], the requirement is that there should be five or more countries, or 15 or more years being compared. In our research, the sample size is much larger than five. Therefore, we can use the χ^2 test to validate the null hypothesis stated above.

There are four different cases for using σ and γ index together to evaluate the reduction of dispersion as well as the catch-up process. The simplest case is when both the σ and γ indexes are increasing in value. Under this circumstance, there is neither a reduction of dispersion nor a catch-up process. The second case is that both σ and γ indexes are decreasing which indicates that there is both a reduction of dispersion and a catch-up process. The third case occurs where the σ convergence measure is non-decreasing while the γ convergence value is in decline. Since β convergence is a necessary but insufficient condition for σ convergence, this indicates that there is a catch-up process, but no reduction of dispersion. The fourth case occurs where the γ index is non-decreasing with a substantial decline in the σ index. This indicates that country differences in performance measures remain so there is no rank change among countries. However, performance differences among the countries have diminished considerably, which indicates conditional β convergence. Put another way, there may be a catch-up process within the subgroups of countries.

Data and data sources

For this research, the yearly Fish Stock Status (FSS) measures were downloaded from the Environmental Performance Index (EPI) website [41]. The yearly FSS were available from 1950 to 2014 for 133 countries. Due to missing data for multiple countries in the early years, the period selected for analysis included only 1980 to 2014 for 131 countries. According to the Technical Appendix from the EPI report [42], both the total catch in tonnes and the fish stock class in percentage came from the website Sea Around Us [43]. The FSS measures the percentage of a country's total catch that comes from Taxa and are classified as either over exploited or collapsed.

To categorize the four subgroups of countries by income level, World Bank's GNI per capita data was used. The gross national income to US dollars is converted using the World Bank Atlas method. According to the World Bank, four income groups were defined in 2014 [44]. The high-income group includes countries with a GNI per capita of $12,746 or more followed by the upper middle-income group with a GNI per capita between $4,126 and $12,745. The lower middle-income group includes countries with a GNI per capita between $1,045 and $4,125, while the lower income group includes those countries with a GNI per capita of $1,045 or less. GNI per capita using the Atlas method in current US dollars for countries are available from the World Bank's web site [45]. Out of the 131 countries, 7 countries including Anguilla, Cape Verde, French Guiana, Mayotte, Taiwan, Tokelau, Wallis and Futuna Island were not included since their income levels were not listed in the World Bank data. Thus, for income and regional analysis, the total sample was reduced to 124 countries from the 131 countries with the following groups. The high-income subgroup included 46 countries, followed by the upper middle-income subgroup of 36 countries, the lower middle-income subgroup of 30 countries, and the low-income subgroup of 12 countries.

The World Bank categorizes countries into seven regions including East Asia and Pacific (EAP), Europe and Central Asia (ECA), Latin America and Caribbean (LAC), Europe and Central Asia (ECA), Middle East and North Africa (MENA), North America (NA), South Asia (SA), and sub-Saharan Africa (SSA) [46]. However, due to the small number of countries, NA was combined with ECA, while SA was combined with EAP so there are only five regional subgroups in this study: SA+EAP has 36 countries, followed by SSA region with 24 countries, NA+ECA region with 27 countries, MENA with 11 countries, and LAC region with 26 countries.

Analysis of results

The averaged FSS index for the total group of 131 countries showed that the overfished ratio in 1980 was 10.74% but increased to 31.5% by 2014 at a compounded annual growth rate (CAGR) of 3.22%, as shown in Table 1.

Table 1. Yearly Average FSS, Sigma Index, Gamma Index for Total Group of 131 Countries (1980-2014)

Year	Average	Sigma	Gamma
1980	10.74	1.00	1.00
1981	11.35	1.01	0.98***
1982	11.08	0.95	0.96***
1983	12.53	1.04	0.95***
1984	12.39	1.07	0.93***
1985	12.55	0.95	0.92***
1986	13.45	1.01	0.89***
1987	13.92	1.01	0.86***
1988	14.63	0.96	0.86***
1989	16.40	0.92	0.82***
1990	18.13	0.86	0.80***
1991	18.48	0.84	0.78***
1992	18.62	0.83	0.79***
1993	18.17	0.84	0.78***
1994	17.56	0.85	0.80***
1995	18.11	0.83	0.80***
1996	18.09	0.81	0.79***
1997	18.19	0.79	0.78***
1998	18.90	0.73*	0.77***
1999	18.82	0.69**	0.75***
2000	20.20	0.65**	0.73***
2001	20.97	0.64***	0.71***
2002	21.43	0.65***	0.70***
2003	22.98	0.63***	0.69***
2004	24.13	0.63***	0.70***
2005	25.23	0.64***	0.70***
2006	25.18	0.59***	0.69***
2007	27.17	0.58***	0.69***
2008	29.93	0.58***	0.69***
2009	31.11	0.57***	0.68***
2010	31.50	0.58***	0.65***
2011	31.16	0.53***	0.61***
2012	31.56	0.53***	0.58***
2013	31.72	0.53***	0.55***
2014	31.50	0.55***	0.55***
CAGR	**3.22%**	**-1.75%**	**-1.76%**

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

The normalized yearly σ index beginning with the value of 1.0 in 1980 declined to 0.5489 by 2014 at a negative CAGR of -1.75%. The test indicated that every year after 1998 to 2014, the results were statistically significant. The normalized yearly γ index also declined at a negative CAGR of -1.76%, while meeting the statistical test of significance every year from 1981 to 2014. In short, the results of our analysis established that there was both σ and γ convergence, thus reducing the dispersion of FSS measures and accelerating ranking changes among the countries. Thus, country differences of the FSS measure narrowed substantially over time during the period under analysis, while the averaged FSS measures increased even more rapidly.

The next question is whether the results for the total group of 131 countries remain applicable in the context of developed versus developing countries. Thus, the same sets of questions were examined for the four subgroups of high, upper middle, lower middle-, and low-income countries. The averaged FSS measures at the beginning of 1980 followed the sequence of high to low-income subgroups as follows: the high-income subgroup of 46 countries had the highest average FSS overfished measure at 15.61%, followed by the lower middle subgroup of 30 countries at 9.443%, the upper middle subgroup of 36 counties at 8.90%, and the low-income subgroup of 12 counties at 5.257%. However, the 2014 FSS measure of the high-income subgroup at 37.39 was followed closely by the upper middle-income subgroup at 33.81, by the lower middle-income subgroup at 27.51 and by the low-income subgroup at 17.95. These changes resulted from the variable CAGRs ranging from 4.0% for the upper middle-income group, 3.68% for the low-income group, 3.2% for the low-income group and 2.6% for the high-income group, as show in Table 2.

Table 2. Averaged FSS Measures for 124 countries in 4 income subgroups (1980-2014).

Year	High (46) Average	Upper-middle (36) Average	Lower-middle (30) Average	Low (12) Average
1980	15.61	08.90	09.44	05.26
1981	16.02	09.61	10.45	05.25
1982	15.68	08.91	10.14	05.28
1983	18.37	09.83	11.16	05.77
1984	19.90	08.86	09.68	05.58
1985	19.15	10.49	09.27	05.49
1986	20.84	10.56	10.97	05.08
1987	22.53	11.30	09.44	04.61
1988	22.97	13.14	08.95	05.36
1989	24.83	15.42	10.16	07.93
1990	26.90	17.55	11.19	09.87
1991	26.96	16.73	11.81	14.48
1992	27.15	16.09	11.72	16.62
1993	26.98	14.76	12.09	13.76
1994	25.56	14.00	12.99	14.35
1995	26.81	13.66	12.72	14.70
1996	25.57	13.81	14.08	14.82
1997	27.29	13.37	14.05	13.01
1998	28.41	14.02	14.32	12.56
1999	28.19	13.87	14.40	12.48
2000	29.51	14.90	16.00	12.15
2001	30.09	15.53	16.83	12.58
2002	31.10	16.81	16.17	12.20
2003	32.80	20.74	16.36	12.64
2004	34.05	23.59	17.43	12.69
2005	35.47	24.67	18.16	13.23
2006	34.68	23.59	19.40	14.76
2007	36.85	24.80	21.56	15.58
2008	41.47	26.51	23.63	17.78
2009	42.46	27.16	26.34	17.45
2010	43.03	28.72	25.81	16.80
2011	40.06	29.31	27.91	16.93
2012	39.44	30.32	28.98	17.74
2013	38.44	31.47	29.20	18.31
2014	37.39	33.81	27.51	17.95
CAGR	**2.60%**	**4.00%**	**3.20%**	**3.68%**

To explain, the high-income subgroup generated the slowest CAGR of +2.6% reflecting its highest 1980 averaged FSS of 15.61% following the convergence theory. Similarly, the low-income subgroup also displayed the second most rapid CAGR of +3.68% with its lowest 1980 averaged FSS of 5.26, again following the convergence theory. However, slowing the CAGR at 2.6% by the high-income subgroup was not enough to offset faster CAGR of 3.68% realized by the low-income subgroup for a catch-up, because the upper middle-income subgroup in spite of its relatively high 1980 FSS measures at 8.9 generated the fastest CAGR of 4.0%. Furthermore, the relatively fast CAGR at 3.2% was also realized by the lower middle-income group.

In short, the effect of 1980 FSS measures to respective CAGRs appeared to have worked only partly for the high and the low-income subgroups. Consequently, the average FSS measures in 2014 for both the high and the upper middle-income groups have exceeded the averaged FSS measure for whole 131 countries. Furthermore, if the rapid CAGR of 4% by the upper middle income group proceeds unchecked, its average FSS will reach a crisis level in the near future.

The normalized yearly σ indexes for the four income subgroups generated the fastest annual speed of negative CAGR at -1.96% for the lower middle-income subgroup, followed by -1.85% for the low-income subgroup, -1.63% for the high-income subgroup, and -1.57% for the upper middle-income group. The yearly σ convergence met the statistical test of significance only for the more recent years for the high-income subgroup, for the upper middle-income subgroup, and for the lower middle-income subgroup. For the low-income subgroup, the yearly σ results did not meet the statistical test of significance.

The yearly γ indexes for all four income subgroups met the statistical test of significance every year from 1980 to 2014, thus verifying that γ convergence took place with for each income group. However, the annual speed of γ convergence among the subgroups displayed a greater degree of variation. Unlike the case of σ convergence, the upper middle-income subgroup had the fastest annual speed of γ convergence at -2.85%, followed by -1.84% for the high-income subgroup, -1.82% for the low-income subgroup, and -1.13% for the lower middle-income subgroup with the slowest speed, as shown in Table 3. However, there was no close association between annual speeds of σ or γ convergence to the CAGR of averaged FSS measures with the four income subgroups. Furthermore, there was no apparent association between annual speeds of σ versus γ convergence.

Table 3. Normalized Sigma and Gamma Indices 4 Income Subgroups (1980-2014).

	High (46)		**Upper-middle (36)**		**Lower-middle (30)**		**Low (12)**	
Year	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma
1980	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.95	0.99***	1.03	0.98***	1.08	0.99***	0.86	0.98***
1982	0.96	0.95***	0.95	0.96***	0.92	0.99***	0.87	0.98***
1983	1.07	0.94***	1.00	0.97***	1.02	0.95***	0.80	0.98***
1984	1.12	0.94***	1.02	0.86***	0.82	0.96***	0.82	0.96***
1985	1.00	0.92***	0.90	0.89***	0.79	0.91***	0.88	0.94***
1986	1.02	0.88***	0.91	0.85***	0.94	0.90***	0.93	0.87***
1987	0.95	0.86***	1.06	0.75***	1.00	0.89***	0.93	0.88***
1988	0.91	0.82***	1.00	0.77***	1.02	0.90***	0.84	0.90***
1989	0.84	0.79***	1.14	0.72***	0.91	0.88***	0.68	0.72***
1990	0.79	0.79***	1.05	0.74***	0.81	0.85***	0.90	0.67***
1991	0.73	0.76***	0.98	0.73***	0.79	0.84***	1.28	0.66***
1992	0.76	0.76***	0.87	0.75***	0.80	0.85***	1.10	0.75***
1993	0.77	0.76***	0.94	0.79***	0.84	0.85***	1.15	0.72***
1994	0.80	0.78***	0.92	0.77***	0.81	0.84***	1.13	0.77***
1995	0.76	0.80***	0.99	0.73***	0.77	0.89***	1.09	0.71***
1996	0.78	0.82***	0.99	0.73***	0.71	0.86***	1.09	0.69***
1997	0.76	0.79***	1.00	0.66***	0.66	0.87***	0.75	0.64***
1998	0.69	0.80***	0.87	0.68***	0.64	0.87***	0.71	0.62***
1999	0.64*	0.77***	0.75	0.66***	0.64	0.84***	0.73	0.55***
2000	0.61**	0.74***	0.66	0.59***	0.62	0.83***	0.77	0.59***
2001	0.61**	0.71***	0.69	0.58***	0.59	0.82***	0.73	0.72***
2002	0.62*	0.72***	0.70	0.56***	0.60	0.84***	0.76	0.77***
2003	0.60**	0.69***	0.67	0.55***	0.57	0.80***	0.76	0.74***
2004	0.63*	0.66***	0.61*	0.56***	0.57	0.76***	0.78	0.75***
2005	0.64*	0.67***	0.68	0.57***	0.54	0.76***	0.74	0.71***
2006	0.57**	0.65***	0.61*	0.58***	0.52*	0.75***	0.68	0.71***
2007	0.58**	0.65***	0.64	0.61***	0.47*	0.76***	0.65	0.65***
2008	0.58**	0.67***	0.59*	0.65***	0.46**	0.71***	0.62	0.65***
2009	0.57**	0.65***	0.55**	0.63***	0.49*	0.69***	0.59	0.58***
2010	0.56**	0.63***	0.54**	0.58***	0.55	0.65***	0.62	0.58***
2011	0.51***	0.58***	0.54**	0.48***	0.51*	0.70***	0.54	0.57***
2012	0.56**	0.53***	0.51**	0.47***	0.50*	0.70***	0.54	0.57***
2013	0.56**	0.54***	0.53**	0.39***	0.49*	0.68***	0.56	0.58***
2014	0.57**	0.53***	0.58*	0.37***	0.51*	0.68***	0.53	0.54***
CAGR	**-1.63%**	**-1.84%**	**-1.57%**	**-2.85%**	**-1.96%**	**-1.13%**	**-1.85%**	**-1.82%**

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

Next, we examined the same set of questions for the five regional subgroups of SA+EAP, LAC, NA+ECA, SSA and MENA regions, as listed in Table 4. The averaged lowest FSS measures in 1980 were recorded by the MENA and, SA+EAP, at 5.34 and 7.90. The CAGR of the averaged FSS was the highest at 4.54% for the MENA region, followed by the SA+EAP region at -3.95%, reflecting perfect applications of convergence theory. The remaining three regions of NA+ECA, SAS, and LAC began with the highest 1980 FSS measure in the order of 16.8, 11.36, and 11.0. The NA+ECA region displayed the second lowest CAGR at 2.43%, reflecting an application of convergence theory. The SSA region with its 1980 measure of 11.0 displayed the lowest CAGR of 2.16%, partly reflecting convergence theory. On the other hand, LAC region with its high 1980 measure of 11.36 displayed the third highest CAGR at 3.871% which generated the highest 2014 FSS measure at 40.0 among all five regions. Similar to the case of upper middle-income subgroup, LAC region with its high CAGR may become a hot spot for excessive overfished region, not following a slow-down implied in convergence theory.

Table 4. Average FSS measures for 124 countries in 5 regional subgroups (1980-2014).

	MENA (11)	**SA + EAP (36)**	**SSA (24)**	**LAC (26)**	**NA + ECA (27)**
Year	Average	Average	Average	Average	Average
1980	05.34	07.96	11.36	11.00	16.80
1981	06.08	08.14	11.30	13.30	17.04
1982	06.28	07.11	12.15	11.95	17.04
1983	07.09	09.74	12.35	15.61	16.72
1984	06.78	10.94	12.46	13.26	17.06
1985	06.63	09.61	11.39	15.91	17.58
1986	06.13	11.15	10.20	18.86	18.69
1987	05.64	10.82	09.84	21.30	19.33
1988	05.60	11.74	11.07	21.31	20.04
1989	05.92	12.10	14.41	25.67	20.96
1990	05.86	13.92	15.63	27.58	23.98
1991	05.68	15.13	15.05	27.30	25.01
1992	06.17	16.81	15.16	25.33	24.64
1993	05.56	16.22	14.84	25.06	23.47
1994	05.25	15.88	16.78	23.07	22.20
1995	07.04	15.94	16.75	22.22	24.03
1996	06.87	15.69	16.98	20.87	25.19
1997	07.44	15.38	17.18	20.59	26.95
1998	07.83	15.03	16.77	23.31	27.80
1999	07.49	14.29	16.90	23.61	28.03
2000	10.39	14.61	15.44	27.72	29.02
2001	13.36	14.78	15.16	28.78	29.81
2002	14.82	15.97	14.35	26.25	33.36
2003	15.16	18.43	14.63	28.98	35.62
2004	15.41	19.94	16.05	31.95	36.46
2005	14.92	22.39	17.16	32.27	37.03
2006	15.32	18.76	19.49	33.07	38.14
2007	17.33	19.58	22.12	34.53	40.61
2008	17.91	22.95	25.79	38.48	42.15
2009	16.80	25.05	26.33	40.44	42.83
2010	17.41	26.51	26.40	40.66	42.46
2011	18.28	27.30	25.20	39.52	41.21
2012	18.18	28.53	25.62	38.94	41.70
2013	19.13	29.45	25.21	39.12	40.56
2014	24.20	29.71	23.50	40.00	38.07
CAGR	**4.54%**	**3.95%**	**2.16%**	**3.87%**	**2.43%**

In short, all five regions continued to increase their FSS measures, within a wider range of 2.3% (the maximum of 4.5% - the minimum of 2.2%) compared to 1.4% range from the four income subgroups.

The normalized yearly σ indexes for the five regional subgroups produced the fastest speed of a negative CAGR of -2.24% in the SA+EAP region, followed by -2.06% in the SSA region, and -1.94% in the LAC region. Slower annual speeds of -1.32% was realized for the MENA region, and -1.49% for the NA+ECA region. A statistical test of significance was also obtained for more recent years beginning in 1998 for the LAC region, 2004 for the NA+ECA region, 2006 for the SSA region, and 2007 for the SA+EAP region.

The yearly γ indexes met the statistical test of significance every year in all five regions from 1981 to 2014. The fastest annual speed of γ convergence was realized once again in the SSA region at -2.42%, followed by the NA+ECA region at -2.37%, the LAC region at -1.92%, the SA+EAP region at -1.18%, and the MENA region at -1.08%. Once again, higher annual speeds of σ convergence and annual speeds of γ convergence appear not to be influenced by the CAGRs of the FSS measures of five regional subgroups, as shown in Table 5.

Table 5. Normalized Sigma and Gamma FSS Indices of 5 Regional Subgroups (1980-2014).

	MENA (11)		**SA + EAP (36)**		**SSA (24)**		**LAC (26)**		**NA + ECA (27)**	
Year	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma	Sigma	Gamma
1980	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1981	0.81	1.12***	0.92	0.98***	0.96	0.98***	1.16	0.98***	0.99	1.00***
1982	0.77	1.06***	0.95	0.96***	0.93	0.97***	0.95	0.93***	0.99	0.99***
1983	0.72	0.99***	1.22	0.96***	0.88	0.95***	1.00	0.93***	1.02	0.98***
1984	0.68	1.22***	1.25	0.90***	0.83	0.88***	0.95	0.90***	1.03	0.96***
1985	0.68	1.35***	1.06	0.94***	0.83	0.84***	0.87	0.79***	0.99	0.94***
1986	0.80	1.34***	1.08	0.93***	0.85	0.80***	0.90	0.72***	0.98	0.94***
1987	0.88	1.34***	1.17	0.87***	0.95	0.78***	0.82	0.66***	0.90	0.92***
1988	0.95	1.27***	1.11	0.87***	0.99	0.80***	0.77	0.65***	0.82	0.90***
1989	0.85	1.27***	1.07	0.83***	1.13	0.78***	0.66	0.65***	0.75	0.84***
1990	0.79	1.30***	0.98	0.81***	1.11	0.78***	0.61	0.67***	0.66	0.80***
1991	0.76	1.28***	0.96	0.78***	1.02	0.74***	0.59	0.62***	0.63	0.78***
1992	0.70	1.26***	0.92	0.76***	0.89	0.75***	0.59	0.66***	0.66	0.79***
1993	0.61	1.34***	0.91	0.78***	0.96	0.74***	0.62	0.65***	0.69	0.81***
1994	0.60	1.32***	0.91	0.76***	0.85	0.78***	0.67	0.65***	0.73	0.81***
1995	0.44	1.17***	0.92	0.76***	0.75	0.80***	0.74	0.70***	0.71	0.85***
1996	0.47	1.06***	0.88	0.79***	0.73	0.77***	0.76	0.63***	0.73	0.83***
1997	0.48	1.06***	0.84	0.77***	0.70	0.75***	0.71	0.63***	0.75	0.80***
1998	0.45	1.18***	0.81	0.77***	0.72	0.75***	0.55*	0.65***	0.68	0.82***
1999	0.43	1.10***	0.74	0.73***	0.67	0.74***	0.51*	0.59***	0.68	0.81***
2000	0.59	1.06***	0.65	0.69***	0.67	0.76***	0.51	0.57***	0.67	0.80***
2001	0.62	0.97***	0.63	0.71***	0.64	0.78***	0.49	0.53***	0.68	0.79***
2002	0.62	0.83***	0.64	0.76***	0.68	0.75***	0.55*	0.53***	0.61	0.76***
2003	0.65	0.85***	0.56	0.71***	0.61	0.70***	0.49**	0.61***	0.64	0.69***
2004	0.67	0.92***	0.54	0.71***	0.61	0.63***	0.56	0.60***	0.60*	0.66***
2005	0.71	0.96***	0.60	0.74***	0.60	0.60***	0.56*	0.59***	0.60	0.64***
2006	0.65	1.00***	0.56	0.70***	0.52*	0.59***	0.47**	0.51***	0.56*	0.67***
2007	0.55	1.06***	0.52*	0.67***	0.50*	0.62***	0.49**	0.49***	0.59*	0.68***
2008	0.51	1.02***	0.56	0.67***	0.49*	0.63***	0.46**	0.48***	0.62	0.72***
2009	0.46	0.89***	0.54	0.67***	0.50*	0.60***	0.43**	0.49***	0.62	0.71***
2010	0.41	0.63***	0.55	0.66***	0.52*	0.59***	0.50**	0.54***	0.59*	0.68***
2011	0.36*	0.71***	0.48**	0.59***	0.45**	0.60***	0.48**	0.57***	0.56*	0.58***
2012	0.44	0.68***	0.47**	0.58***	0.43**	0.53**	0.50**	0.59***	0.56*	0.47***
2013	0.49	0.78***	0.46**	0.58***	0.48**	0.48*	0.51**	0.60***	0.55**	0.42***
2014	0.64	0.69***	0.46**	0.67***	0.49*	0.43	0.51*	0.52***	0.60*	0.44***
CAGR	-1.32%	-1.08%	-2.24%	-1.18%	-2.06%	-2.42%	-1.94%	-1.92%	-1.49%	-2.37%

*** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level

Conclusions

The key findings of this study can be summarized as follows. First, for the total group of 131 counties, the averaged FSS overfished measure increased rapidly at a CAGR of 3.22% from 1980 to 2014. For the income subgroups, the slowest increase in CAGR resulted in the high-income subgroup with its the highest 1980 average FSS measure, as expected. On the other hand, the second most rapid CAGR occurred in the low-income subgroup with the lowest 1980 average FSS measure, reflecting the applicability of convergence theory. However, the most rapid CAGR was achieved by the upper middle-income subgroup, even though its 1980 average FSS measure was substantially higher than that of the low income subgroup. Furthermore, the CAGRs among the four income subgroups were within a narrow range of 1.4% (4.0% - 2.6%), suggesting that income categories may not be the most useful differentiating factor compared to the alternative of regional subgroups analyzed.

Second, the growth rate of the FSS index among the five regional subgroups varied more widely compared to the income subgroups. The fastest CAGR in the MENA region was 4.54%, followed by 3.95% for the SA+EAP region, and 3.87% for the LAC region. SSA and NA+ECA regions had slower CAGRs at 2.16% and 2.43%, respectively. The range between the fastest versus the slowest CAGR was 2.38% among the five regions. In addition, the regional CAGRs reflect well the catch-up effect of low-performing subgroups in the early period implied in the convergence theory.

Third, the annual speeds of both σ and γ convergence were nearly identical at -1.75% and -1.76%, respectively, for the total group of 131 counties. The annual speed of σ convergence for the four income subgroups was clustered closely within a narrow range from -1.96% for the lower middle-income subgroup to -1.57% for the upper middle-income subgroup. In contrast, the annual speeds of γ convergence were distributed within a wider range from -2.85% for the high-income subgroup to -1.13% for the lower middle-income subgroup. In other words, the income subgroups generated wider variable speeds for γ convergence compared to the speeds of σ convergence.

Fourth, the annual speeds of σ convergence for the five regional subgroups yielded wider differences among the five regions than the cases of σ convergence in the income subgroups. The fastest annual speed of σ convergence was in the SA+EAP region at a negative CAGR of -2.24%, while the slowest speed was experienced in the MENA region at -1.32%. The remaining regions had annual speeds of -2.06% for the SSA region, -1.64% for the LAC region, and -1.49% for the NA+ECA region. In contrast, the annual speed of γ convergence showed somewhat less variation in that the fastest speed was the SSA region at -2.42%, while the slowest speed was the MENA region at -1.08%.

In short, the range of the speed of γ convergence by the four respective income subgroups was somewhat wider compared to the range of the speed for γ convergence for the five region subgroups. In contrast, the range of speed for σ convergence for the four income subgroups was much narrower compared to the range for the five regional subgroups.

In conclusion, all four income subgroups continued to increase their overfished FSS measures in the range of 4.0% (upper middle-income subgroup) to 2.6% (high income subgroup). All five regions also increased their FSS measures in the range of 4.54% (MENA region) to 2.16% (SSA region), contributing to the average FSS measure goal to reach excessively high 31.5% for the 131 countries by 2014. The annual speeds of declining σ convergence indicate that the dispersion of the FSS measures have substantially narrowed within the respective income and regional subgroups. At the same time, the annual speed of declining γ convergence also indicates that countries with lower FSS measures have continued to catch-up to countries with higher FSS measures and create ranking changes within the respective income and regional subgroups.

There are several policy implications based on the findings of this study. For the group of 131 countries, a global consensus needs to be developed to radically slow down the average growth rate of 3.22% experienced in the past. In addition, appropriate measures need to be developed to enforce the reduction in the future. Otherwise, a continuation of the past trend would mean that the 2014 average FSS index of 31.5% could double in just 22 years and could reach as high as 63.0%, which would be totally unacceptable. In other words, reducing the future growth rate needs to be drastic and effective.

Several scholars agree that the most effective way to decrease overfishing means reducing overcapacity of the world's fishing fleet [47-51], which places the most immediate pressure on fisheries since they play a key role in driving overexploitation. The total number of fishing vessels in the world in 2016 was estimated at about 4.6 million [52]. The fleet in Asia was the largest at 3.5 million vessels, representing about 75% of the global fleet, followed by Africa at 14%, and Latin America and the Caribbean at 6.4%. In Europe, the fleet capacity has continued to decline since 2000 through 2016. However, nearly all of the ships in this region are motorized vessels so their capacity for overfishing is greater.

Ye et al.'s comprehensive study [47] calculated a fishing effort index based on the number of docked vessels multiplied by technological improvement coefficients. The index revealed an increase from 0.4 million vessels in 1970 to 3.5 million in 2008 representing a ninefold increase over 40 years. Ye *et al.* [47] concluded that the global fishing effort should be reduced by 36% to 43% from the 2008 level if the 2002 World Summit on Sustainable Development (WSSD) goal is to be met. The WSSD goal states to "maintain or restore stocks to levels that can produce the maximum sustainable yield with the aim of achieving these goals for depleted stocks not later than 2015" [53]. They also concluded that the global fleet capacity needs to be reduced by the same percentages, which would mean the loss of employment for 12 to 15 million fishers. In addition, buybacks for excess fleet capacity would require US $76 to $355 billion. On the benefit side, meeting the WSSD goal would increase annual fishery production by 16.5 million tons, which would generate an annual rent of US $32 billion. In addition, biodiversity and marine ecosystems would greatly improve.

Implementing such a drastic reduction in fleet capacity to rebuild depleted fish stocks faces many obstacles. First, the difficulty of trading off short-term social and economic costs and pain for longer-term gains needs to be overcome. Second, recovery of a depleted stock may take years or even decades especially in cold temperature areas, even after fishing pressure is removed. National policies for rebuilding fish stocks may be outweighed by concerns about food security, employment, and lobbying by established interest groups. To have any chance of success, individual states need to integrate their rebuilding plans into their national political and economic decisions. Individual states need to learn [54] about the key elements of other cases of successful reduction of fleet capacity and rebuilding stocks in Australia [55], and in the U.S [5].

Since greater differences in all three output measures of the growth rate of FSS, as well as the speeds of both σ and γ convergence appear to be influenced more by the regional categorization, it would be useful to develop policy implications focused on specific regions. For example, the NA+ECA region requires special action to reduce both its fleet capacity and overfishing. The 2014 level of the FSS measure for the NA+ECA subgroup of 27 countries was excessively high at 38.1%. Although its growth rate of the FSS measure was the second lowest among the five regions, this region needs to adopt a radical reduction policy for its fleet capacity to reduce overfishing. Fortunately, most countries in this region are member states of the EU and thus are subject to the EUs Common Fisheries Policy (CFP) in their fishing activities.

A deep-rooted problem of fleet overcapacity has also been recognized as one of the key issues in the reform of the CFP. According to a study by Salomon *et al.* [56], the introduction on the possibility of transferable fishing concessions in the CFP could increase efficiency in the fisheries sector. In addition, subsidies from the European Maritime and Fisheries Fund for new vessel construction have ceased, and only capacity enhancing subsidies will be financed. For example, the fund will only subsidize replacing an old engine with a new one. However, none of these reform measures have directly translated into a reduction of fleet capacity. The reform measures in CFP seem to have been more successful in explicitly incorporating the concept of maximum sustainable yield (MSY) in setting of total allowable catches (TACs). The deadline for implementing this concept was postponed until 2020. Another reform measure dealt with the discard ban, which introduced an obligation to land all catches over time from 2015 to 2019 [56].

Other effective intervention policies need to be developed for the LAC region of 26 counties where the 2014 FSS measure reached the highest level at about 40.0%. This is in sharp contrast to all other regions where the projected fish production is either a small increase or a moderate decrease. The fact that the rapidly increasing speeds of both σ and γ convergence in the LAC region indicates that these 26 countries may have been engaged in very active competition to catch more fish and out-catch other countries. If left unchecked, the LAC region will soon reach the highest level of FSS ever experienced by any regional subgroup. Unfortunately, [52] indicates that this region's fish production is expected to increase from 10.2 million tonnes in 2016 to 12.01 million tonnes by 2030, which is a 17.7% increase. In particular, Chile is projected to increase fish production from 1.5 million tonnes in 2016 to 2.35 million tonnes representing a 56.7% increase. The remaining three major producing countries of Peru, Mexico, and Brazil are all projected to increase their production by 10% or more during this period. One of the major reasons for the expected increase in this region is to compensate for a relatively small volume of aquaculture production. For example, the proportion of aquaculture production of this region in 2016 to the total sum of fish and aquaculture production was only about 21%, compared to 46.8% for the world and 58.7% for Asia. It may be that a solution for overfished stocks for this region may come from a future emphasis on aquaculture production. In summary, the strongest interventional policy is recommended for the NA+ECA region, LAC region, as well as for the total group of 131 countries.

There are several limitations to this research including both theoretical and technical issues. One of the most serious limitations is the reliability and accuracy of the fish stock status data used for this research. Much work has been done to improve the quality of fish stock status data, but a substantial investment of resources and time are still needed to overcome the current shortcomings. In addition, conceptually, this research has not considered the various underlying causes for the declining fish stock population when deciding on the available options for improvement. Many future studies are needed to generate effective solutions to control the declining fish stock for individual countries, regions, and the world.

Despite of these limitations, the findings from this research clearly show that several income and regional subgroups of countries have reached crisis levels of overfished fish stock status. In addition, country differences in their fish stock status within respective income and regional subgroups have substantially narrowed. Thus, this paper offers examples of customized interventional policy recommendations for the total group of 131 countries as well as for respective regional subgroups of countries.

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