Global Index of Fishing Intensity (FI)

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SEDAR 103: US Caribbean Application of Alternate Assessment Methods

Summary

The global index of fishing intensity (FI) uses catch (landings), fishing effort, primary production (PP) and trophic level (TL) of all species to produce four indicators, one of which is a composite index of fishing pressure, which can be a potential indicator of ecosystem overfishing (EOF). These indices were designed for data poor situations in developing countries, and can use any input data but rely on global datasets. However, this method does indeed depend on coarse global datasets, has an uncertain robustness, and granularity is unclear at more local scales below national levels. This index may not tie directly to actionable steps but can be a good diagnostic tool.

I. Introduction

Overfishing has severe social, economic, and environmental ramifications. Eliminating global overfishing is one of the United Nations' Sustainable Development Goals (SDGs). The SDGs require effective policy and progress monitoring. However, current indicators are issue-specific and cannot be utilized to measure fisheries efficacy holistically. A comprehensive index that takes into account the inputs, outputs, and ecological implications of fisheries has been developed (Ye and Link 2023). These components are then merged to form a single composite fishing index that evaluates both total fishing pressure on the ecosystem and historical patterns. One can delineate if ecosystem overfishing is occurring, or not (Link and Watson 2019; Fig. 1).

The global index of fishing intensity (FI)

- Combines three main indicators to assess status of fisheries ecosystem
- Is designed for relatively data-limited situations around the world
- But is unclear how much more FAO is going to utilize it

II. Method Description

Adapted from Ye and Link (2023):
The three aspects of a fishery production system are represented in Fig.2, together with illustrative but not exhaustive major features and associated fishery regulating approaches. Although the three metrics, input, output, and fishing-induced changes, have historically been fundamental to traditional fishery management, fishery regulation is frequently centered on a single aspect, such as catch, bycatch, or species of conservation concern (output), vessel number, season length, effort, and accessible areas (input), catch per unit effort (change in stock abundance), or habitat destruction (alteration to ecosystem). In contrast, this study examines the total performance of the three dimensions of fisheries.

Vessels, gear, labor, and fishing time are all examples of anthropogenic fishing inputs (Fig.2). In fisheries science, these inputs are usually standardized on their selectivity and efficiency to define input intensity. This is known as effective fishing effort, which is calculated by multiplying the quantity of engine power of fleets by the effective operational time. The larger the fishing effort, the greater the fishing intensity, which subsequently influences catch, habitats and environmental repercussions. To make fishing intensity comparable across ecosystems, however, fishing efforts must be standardized by ecosystem area as well. Following Ye and Carocci (2019), this paper defines input intensity (I^a) as the amount of fishing effort (*F*; kilowatt-days per year) expended per area of ecosystem (*A*; square kilometre) *i* during year *t*:

$$I_{it}^{a} = F_{it}/A_i \quad (1)$$

A fishery's primary output is catch, which includes all species, including targeted, unintentionally caught or discarded (Fig.2). The catch-to-biomass ratio is used in stock assessment to quantify fishing intensity at the output end. However, because biomass accessible to fishing is difficult to estimate, net primary production is used instead, and the ratio (also known as the Fogarty ratio; Link and Watson 2019) of total catches (*C*) to total net primary productivity (*P*) in an ecosystem is defined as an indicator that measures the output intensity (I^b) of ecosystem *i* at year *t*:

$$I_{it}^{b} = C_{it}/P_i \quad (2)$$

Fishing alters the species composition, predator-prey relationships, fish habitats, and the ecosystem's structure and function (Fig.2). Changes in the environment and climate may have an effect on the species caught by fisheries. All of these changes are complicated and difficult to quantify, but they will affect both the mean trophic level of the catch and the environment. As a result, trophic changes have been frequently employed to evaluate the effects of fishing on aquatic ecosystems and the resulting changes in biodiversity. We use changes in the mean trophic level (*L*) of fish species caught relative to mean trophic level in 1970 as a proxy indicator of fishing impacts (I^c) on ecosystem *i* at year *t* in this paper

$$I_{it}^{c} = 1 - L_{it}/L_{i1970} \tag{3}$$

The mean trophic level is a complicated statistic that is influenced by a variety of factors, including changes in species composition caused by the environment, as well as interspecific predation and competition. The trophic level of captures may temporarily increase if fishing fleets extend to deeper waters where species with high trophic levels are less fished and if technological advancements make high-trophic-level species more catchable. In this study, the region-based mean trophic level, which can correct for such bias, was used.

There are numerous potential indicators of ecosystem pressure in literature[39]. However, the majority of them necessitate extensive modeling, observations, or data, and the majority of those may be irrelevant to the vast majority of marine ecosystems. Despite the fact that it does not fully reflect changes in all trophic levels of a marine ecosystem in response to fishing influence, mean trophic level has been a popular proxy indicator used to examine fishing impacts on aquatic ecosystems and the resulting changes in biodiversity. We believe that, despite the imperfect nature of the data, we should begin addressing real-world policy concerns with the best available information and continue to enhance it as technology and knowledge evolve.

The three indicators assess three different aspects of fishing. I^a measures fishing by the amount of effort expended on a unit area, I^b quantifies the amount of removed catches in relation to primary productivity, and I^c is concerned with changes in mean catch trophic levels – a proxy indicator of fishing-induced ecosystem changes. Any indicator with a higher value means a greater impact on the ecosystem. As a result, the three indicators collectively assess the overall intensity or pressure of fishing in each area.

The three indicators use different scales and units of measurement. Normalization is required when multiple indicators are utilized to create a composite indicator in order for them to be comparable and represented in the same units. This study employs the min-max normalization method as shown below:

$$SI_{it}^{j} = Smin^{j} + \frac{I_{it}^{j} - min^{j}(I_{it})}{max^{j}(I_{it}) - min^{j}(I_{it})}(Smax^{j} - Smin^{j}) \tag{4}$$

where SI_{it}^{j} is the Standardized Indicator *j* for Ecosystem *i* at Year *t*, $max^{j}(I_{it})$ and $min^{j}(I_{it})$ are the maximum and minimum values; $Smax^{j}$ and $Smin^{j}$ are the maximum and minimum standardized values of Indicator *j*, which can be set according to the needs of the specific study. They were chosen for clarity in this study so that all *SI*s are on a scale of 1 (*Smin*) to 100 (*Smax*) and thus comparable across indicators.

I^a and I^b are heavily skewed downward, with many small values and few large ones. As a result, arithmetic means are insufficient to describe the "central tendency," and we instead use the geometric mean. In contrast, because I^c has a more normal distribution, arithmetic means are used. When it comes to calculating global trends, another unique aspect of global research is the enormous variation in the scale of fisheries between countries. The average catch of an EEZ over the study period was used to calculate its weight, ensuring that each country is represented in proportion to the size of its fishery[85]. As a result, in this study, weighted geometric means are used for I^a and I^b and weighted arithmetic means for I^c, as shown bellow:

$$SI_t^j = \prod_{i=1}^n I_{it}^{j\ W_i} = \exp\left(\frac{\sum_{i=1}^n W_i ln\left(I_{it}^j\right)}{\sum_{i=1}^n W_i}\right) \text{ for } j{=}a \text{ and } j{=}b \tag{5}$$

with standard deviation:

$$\sigma_t^j = exp\left(\sqrt{\left(\frac{\sum_{i=1}^n W_i\left(ln\left(I_{it}^j\right)-ln\left(I_{it}^j\right)\right)^2}{\sum_{i=1}^n W_i}\right)}\right) \tag{6}$$

and

$$SI_t^j = \frac{\sum_{i=1}^n W_i I_{it}^j}{\sum_{i=1}^n W_i} \text{ for } j{=}c \tag{7}$$

with standard deviation:

$$\sigma_t^j = \frac{\sum_{i=1}^n W_i(I_{it}^j - SI_t^j)^2}{\sum_{i=1}^n W_i} \tag{8}$$

where

$$W_i = \frac{\bar{C}_i}{\sum_i \bar{C}_i}$$

where $\bar{C}_i$ is the annual average of fish landings over the study period, indicating the size of fisheries in ecosystem *i*.

After normalization, we derived a composite fishing index (*FI*) using their geometric mean

$$FI_t = \left(\prod_{j=a}^c SI_t^j\right)^{1/3} \tag{9}$$

and its standard deviation [86] is

$$\sigma_t = \exp\left(\sqrt{\left(\sum_{j=a}^c {\sigma^2}_t^j + \sum_j \sum_{j\neq k} Cov(ln(I_t^j), ln(I_t^k)\right)/9}\right) \tag{10}$$

In *FI*, geometric aggregation is used to address concerns about interaction and compensability. It considers the disparities in achievement across multiple indicators. Any indicator's poor performance is directly reflected, although not fully compensated for, in the composite index value.

To ensure consistency and easy comparison with other global research, we developed these indicators for each of the key 130 EEZ/FAO statistical area ecosystems, then aggregated them by continent and developed or developing countries, following the customary approach of the international community. This classification of countries as developed or developing is based on the Human Development Index. This definition, however, may not be universally accepted.

A. Data Input

- Catch (landings)
- Fishing effort
- Primary production
- Trophic level of all species

B. Analyses/Data Outputs

- Four indicators, the latter a composite index fish pressure

C. Implications for Management

- This serves as a Potential Indicator of EOF
- Can be used as an ELRP
- Provides broader context

D. Caveats

- depends on coarse global datasets
- robustness uncertain
- granularity unclear at more local scales below national levels
- may not tie directly to actionable steps
- good diagnostic

III. Applications of the Method

- Global consideration, Ye & Link 2023
- Fig. 3 show the four indices globally, and how they have changed over the past seven decades.

- These can be calculated, and are available, for major LME-level zones as well. For example, these are show for all the major continents (Fig. 4) and developed vs. non developed countries (Fig. 5).
- This is compared to the fisheries sustainability index (FSI) in Fig. 6, which shows that this is a good match that captures the dynamics of all the stocks in a region.

IV. Discussion

This is provided for SEDAR 103 to demonstrate global approaches to the challenges facing Caribbean Islands wrt EBFM. We do not necessarily recommend that it be adopted, executed or employed for the US Caribbean territorial waters. Rather, that it be kept in mind as other suites of approaches being considered, particularly by other Caribbean nations working with International organizations like FAO. At the least, it can provide some context as a suite of four indicators to evaluate fisheries performance, but may pose some challenges to being used in an actionable context.

V. References

Link, J.S., Watson, R.A. 2019. Global ecosystem overfishing: Clear delineation within real limits to production. Science Advances 5(6). doi: 10.1126/sciadv.aav0474

Ye, Y. & Carocci, F. 2019. Control mechanisms and ecosystem-based management of fishery production. *Fish and Fisheries* **20**, 15–24.

Ye, Y., Link, J.S. 2023. A composite fishing index to support the monitoring and sustainable management of world fisheries. Sci Rep 13, 10571. doi:10.1038/s41598-023-37048-6

VI. Tables and Figures

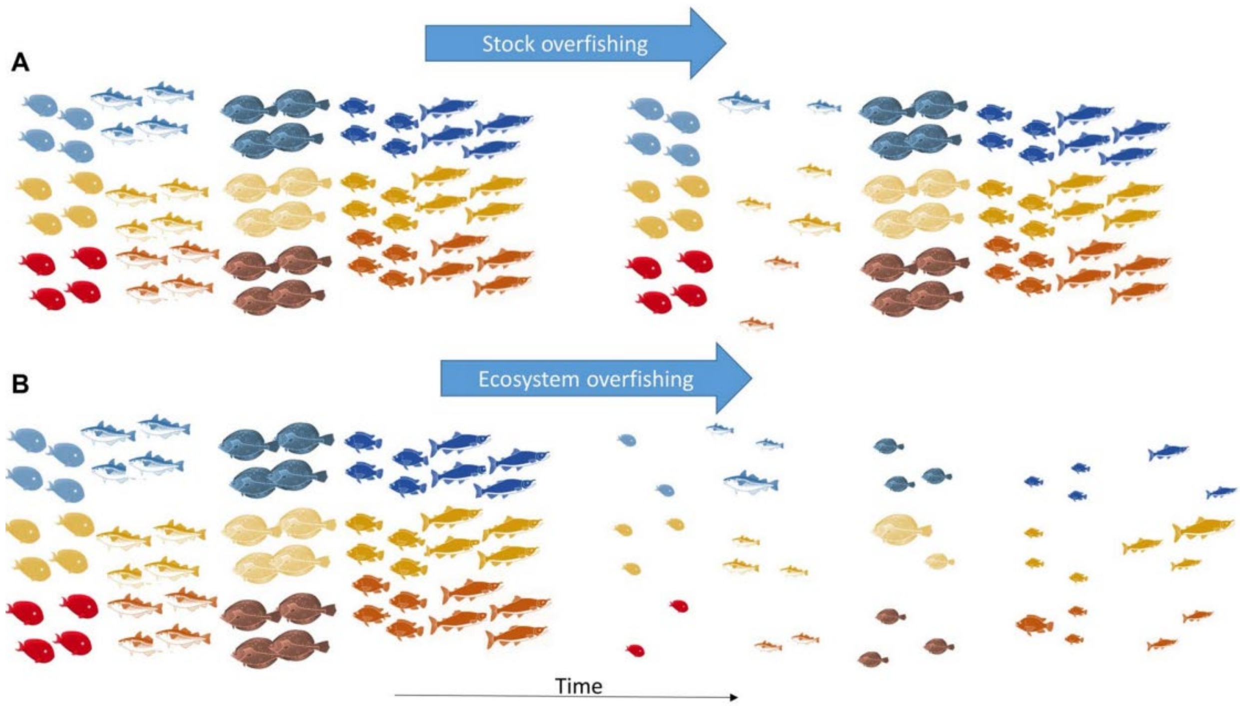

Figure 1. (A) Schematic of population overfishing. While a population is experiencing overfishing, the abundance and biomass (here as the number of fish icons) and fish size declines over time, along with many other facets related to population and fleet dynamics. (B) Schematic of EOF. Analogous to population overfishing, EOF is the result of continued fishing pressure on multiple populations, leading to sequential depletion across populations in an ecosystem over time. (Link and Watson 2019).

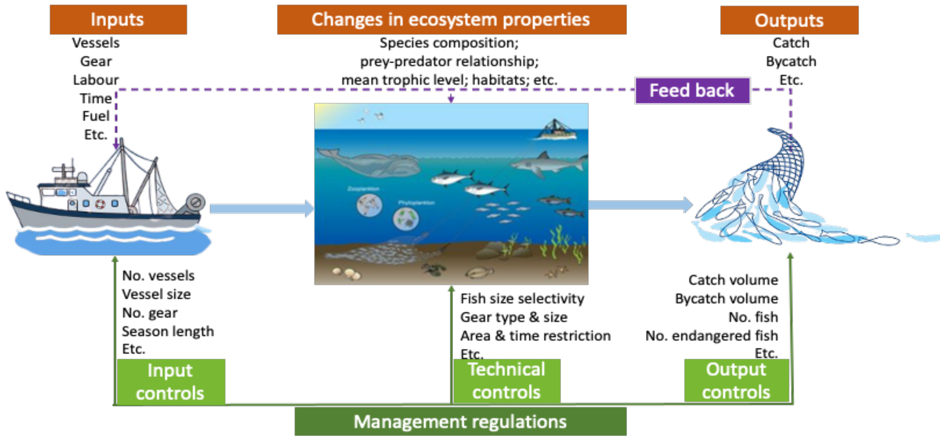

Fig. 2. A diagram depicting a fishing system that includes inputs, outputs, and changes in the ecosystem's features, as well as various control techniques extensively used in fishery management.

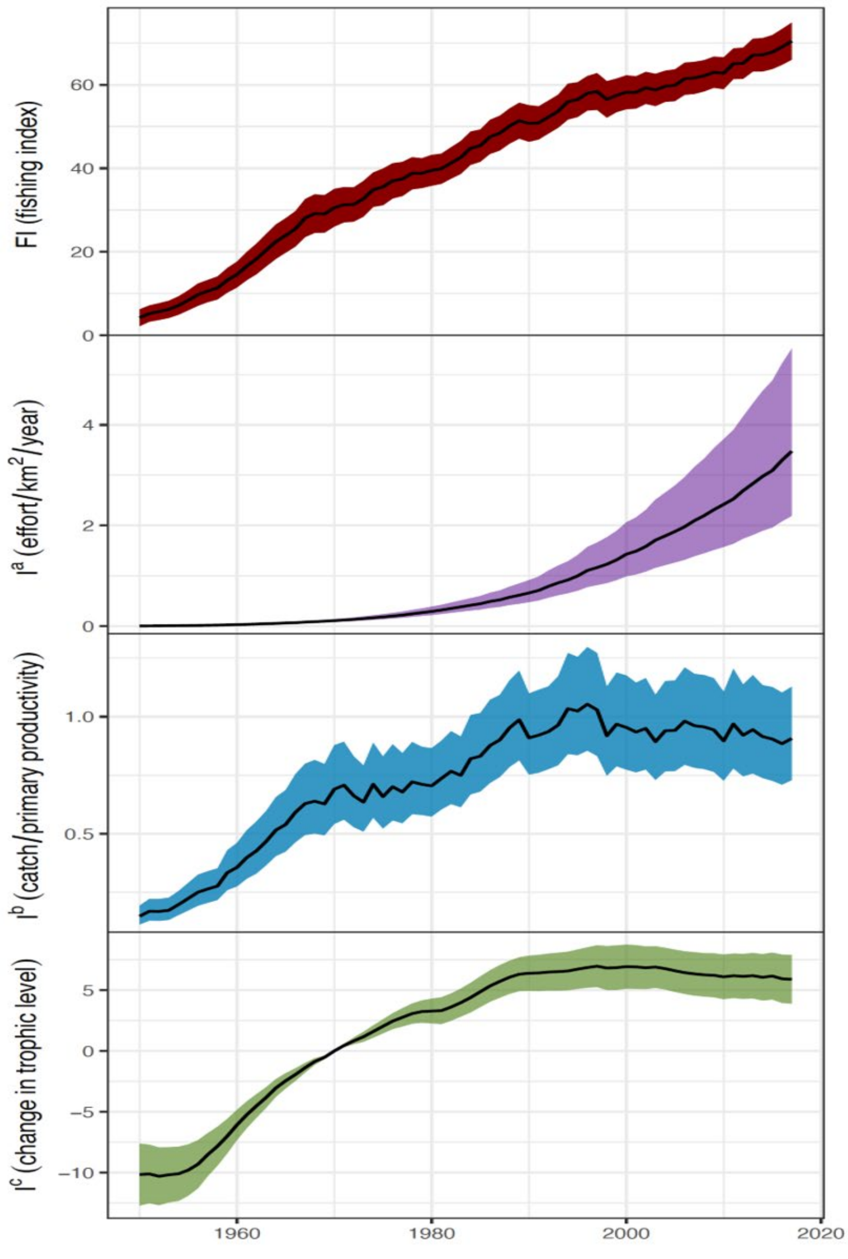

Figure 3. The global fishing index and three component indicators of fisheries from 1950 to 2017. The lines are geometric means weighted by EEZ's average annual catches over the study period (equation 6) and the shadows are 95% confidence intervals. FI=the global index of fishing intensity; Ia=fishing effort per unit of area (kilowatt days/km2 per year); Ib=ratio (‰) of catch to primary productivity; and Ic=change in mean trophic level (percent) relative to 1970. (Ye and Link 2023)

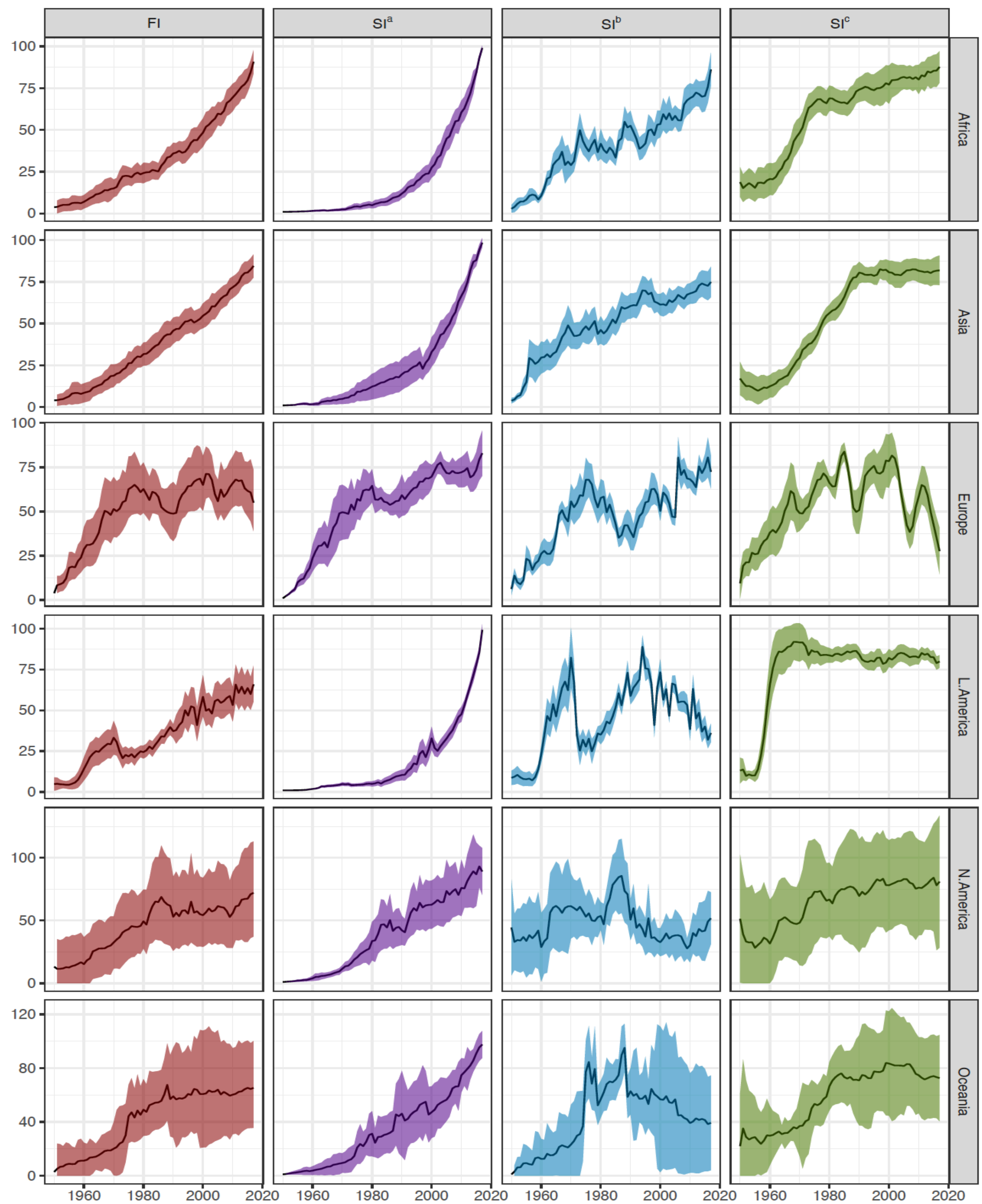

Figure 4. *The estimated fishing index and three component indicators by continent. FI=the global index of fishing intensity; SI^a=standardized (see equation 6) input indicator; SI^b=standardized output indicator; and SI^c=standardized fishing impact indicator. Shaded areas indicate 95% confidence bands. (Ye and Link 2023)*

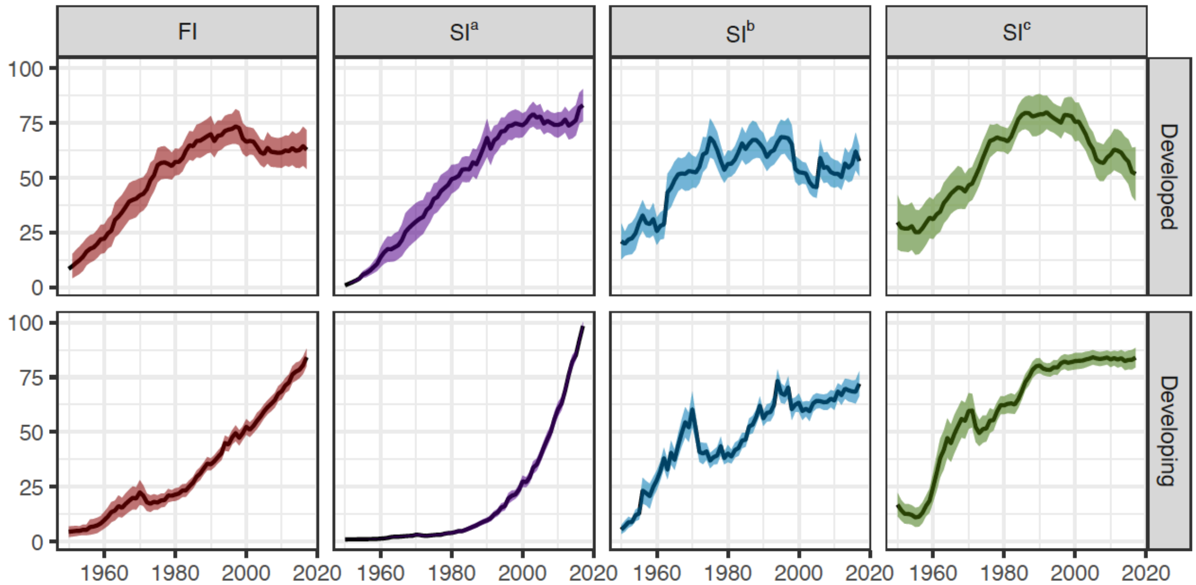

Figure 5. The estimated fishing index and three component indicators for the developed and developing countries. FI=the global index of fishing intensity; SI^a=standardized (see equation 6) input indicator; SI^b=standardized output indicator; and SI^c=standardized fishing impact indicator. Shaded areas indicate 95% confidence intervals. (Ye and Link 2023)

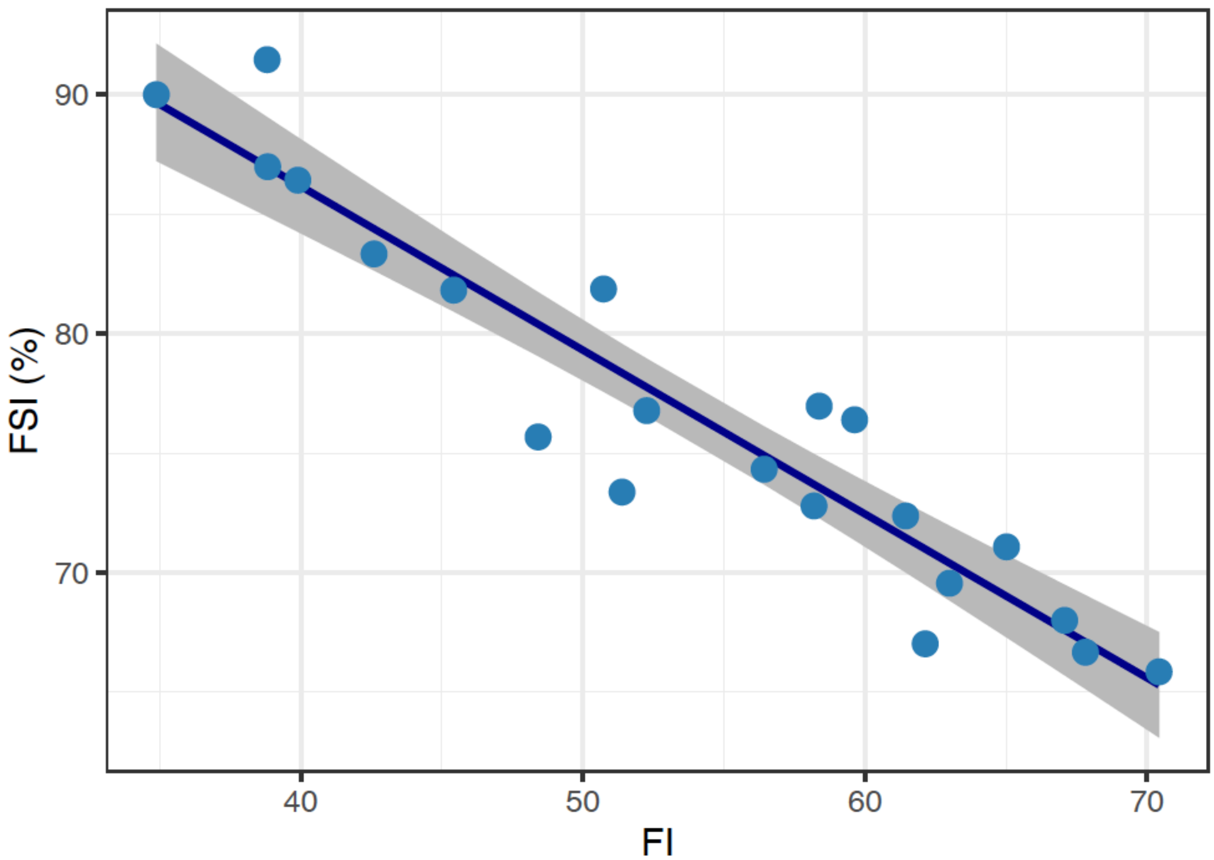

Figure 6. The relationship between the sustainability of fish stocks (FSI) and the fishing index (FI) from 1950 to 2017. The dots indicate data points, while the line is a linear model fit to the data with the shadows representing 95% confidence intervals. (Ye and Link 2023)

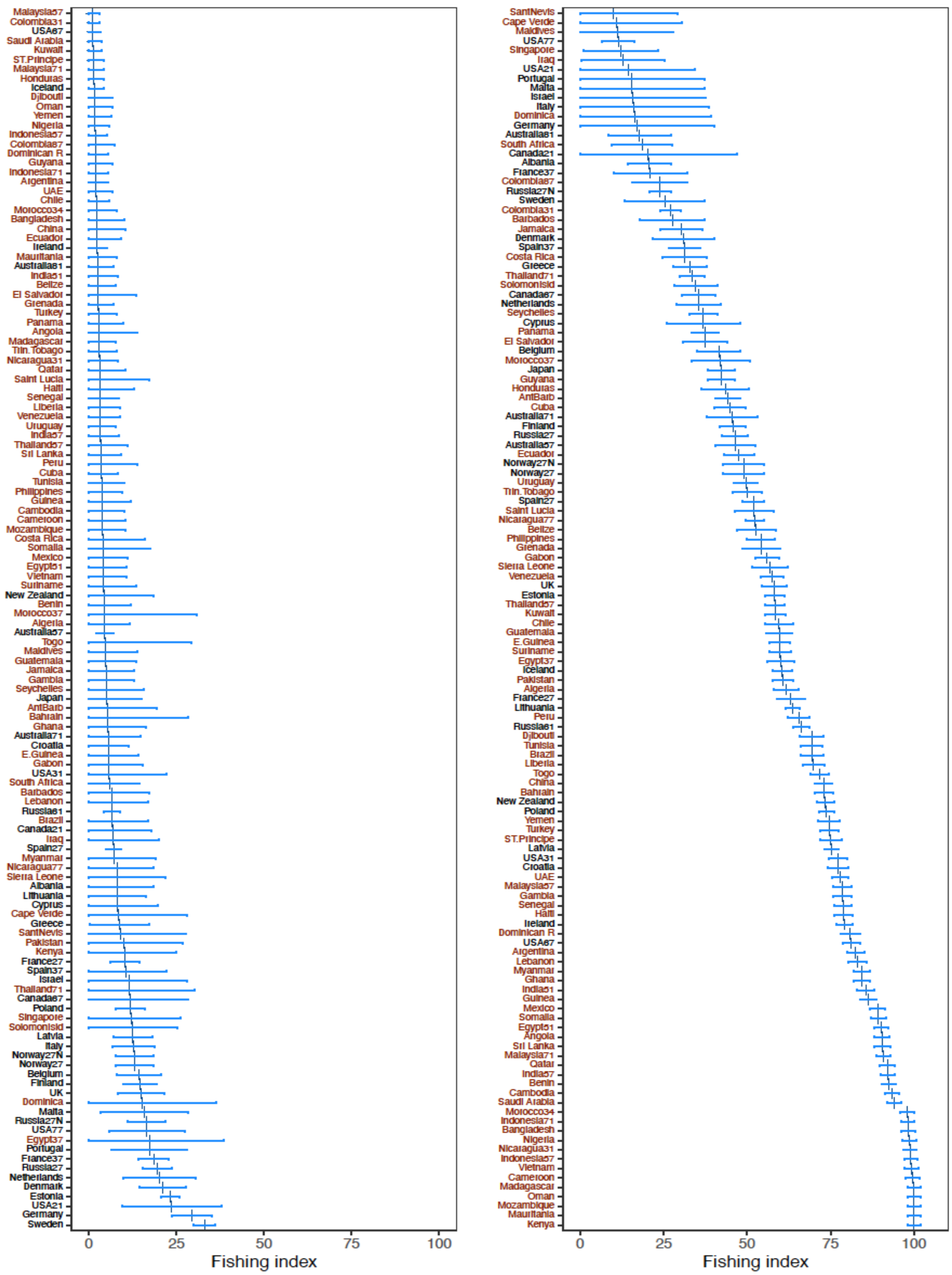

Figure 6. Comparison of fishing index estimations by EEZ-Areas in 1955 (left panel) and 2017 (right panel). Countries in black and brown are developed and developing nations, respectively. Vertical lines denote a EEZ's mean of fishing index (FI), while bars indicate 95% confidence intervals. (Ye and Link 2023)