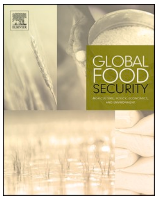
Global Food Security 32 (2022) 100598

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs



Food security challenged by declining efficiencies of artisanal fishing fleets: A global country-level analysis

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ARTICLE INFO

Keywords:
Technical efficiency
Fisheries
Global change
Data envelopment analysis
Sustainable development

ABSTRACT

Global capture fisheries are a vital global food provisioning to help end hunger and malnutrition. To ensure that global seafood supply sustainably supports a growing population, many initiatives within the UN Sustainable-Development-Goals seek to balance management with efficient resource use. Here we examine changes for 150 countries that represent over 98% of global catch for the 1950–2014 period by analysing multiple fleet outputs relative to inputs (such as vessel power) using data envelopment analysis. We show that country specific technical efficiency has declined at rates of $-3\%\,_{yr}^{-1}$ for artisanal and industrial fleets in 44 and 49 countries respectively. Recent global artisanal fleet (2010–2014 average) declines of $-0.2\%_{yr}^{-1}$ show losses that translates to ~71400t posing serious implications for sustainable food security and vulnerable livelihoods in the face of climate change.

1. Introduction

The United Nations Sustainable Development Goals (SDG) and Blue Growth initiatives (Burgess et al., 2016) provide targets to build resilience in coastal communities, minimise the impacts of climate change disruption, provide poverty alleviation for the poorest and most vulnerable, and promote the sustainable management of marine resources ensuring support for food security. For example, population growth, wealth or global change—mediated by climate (Blasiak et al., 2017), could be detrimental for the physical well-being, dietary and food preferences for many people (Golden et al., 2016), and could seriously influence the nutritional status and food security of many populations (Arnason et al., 2009). For many regions of the world—particularly developing countries who depend on small-scale fisheries—threats to food security are worsening due to the acceleration of fishing effort (Ye and Gutierrez, 2017). However, fishing data are often unreliable and the sustainability of fisheries is still highly uncertain (Meissa and Gascuel, 2014; Tidd et al., 2018).

The increasing number of larger, more efficient fishing vessels, the development of techniques for better storage and preservation of seafood, and the improvement of transport networks for their distribution (with 40% of seafood volume traded globally) (FAO, 2014) have facilitated the ever-increasing demand for fish. Often there are too many vessels harvesting depleted stocks (Rousseau et al., 2019) in part due to subsidies (Sumalia et al., 2021) and to limited governance (Ye and Gutierrez, 2017), which can put fisheries on a downward trajectory, posing greater risks to external shocks, and potentially leading to sudden declines or long-term collapse in production or increases in the price of fish products (Gephart et al., 2017). In turn, these can threaten the stability of fisheries production, biodiversity of fisheries and thus food security, especially in climate vulnerable countries (Blasiak et al., 2017).

To land a given volume of fish, a certain amount of fishing effort, labour and capital inputs (capacity) is required. When too much fishing effort is applied there is not only excessive pressure on the stock but there is said to be an excess of fishing capacity which represents economic waste and underutilized fishing effort and low fishing efficiency (FAO, 2013). Low fishing efficiency can arise because of excess capacity due to changes in engine power, gear, information technology and fishing effort (e.g. days at sea or number of vessels) (Pascoe and Herrero, 2004). Simply, fishing efficiency is a general term that is related to an econometric term known as 'technical efficiency', which represents what is caught, relative to what could be caught given the available means. It should be noted that technical efficiency is not a useful catch rate (e.g. catch per unit effort) statistic for making inferences of relative

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https://doi.org/10.1016/j.gfs.2021.100598
Received 17 June 2021; Received in revised form 2 November 2021; Accepted 24 November 2021

changes of stock size for fisheries stock assessment purposes. This is because technical efficiency is affected by economics, in that fish are targeted at their lowest cost and is not a particularly good indicator of stock biomass status. It can be high or low, effectively irrespective of stock levels, as it can be influenced by, for example, a combination of fishing skill and technological change over time (Hilborn and Waters, 1992).

Historically marine capture fisheries production rose as technology increased (Watson and Tidd, 2018). This is dependent on both the availability of fish and the efficiency of methods used to catch them. Present day advances - including new technologies, e.g. acoustic devices, fish aggregation devices (FADs), satellite maps and global positioning systems (GPS) - allow vessels to travel further into the high seas and to fish deeper. Comparing the same physical attributes (e.g. kW power) of a vessel and their subsequent catches from the past (including the number of days) to what is required to catch the same amount nowadays will indicate how efficiency has changed. However, it is unclear whether fisheries efficiencies in different regions are becoming more or less efficient, and importantly whether this is likely to continue into the future. Resolving this question is important, as it has implications for food security, since lower efficiencies are associated with higher fishing costs. For example, with global marine catches in 2012 approximately 90 million tonnes and artisanal catches representing 34 million tonnes (World Bank, 2012), a small year on year percentage change in efficiency could have a significant effect, regionally and globally. To illustrate, a ± 0.05% yearly change within the artisanal sector could translate into a 17,000 tonnes per year loss or gain. Given that a global annual average of 20 kg of fish per person is consumed (FAO, 2016), any small percentage loss in efficiency and hence catches could affect the dietary needs of many.

Here we focus on country-level rate of changes in global fisheries production efficiency with the aim of comparing industrial and artisanal fleet trends, for both developing and developed countries and identifying potential risks posed to the most climate vulnerable countries. To do this we used a data envelopment analysis (DEA) (Farrell, 1957) approach and global database on multiple fleets catch and effort (Rousseau et al., 2019; Anticamara et al., 2011; Watson et al., 2013; Bell et al., 2016) spanning from 1950 to 2014. With biomass estimates lacking for most of the world's oceans, we cannot attribute these changes to declining fish production or other socio-economic factors, instead we analyzed country specific relative fishing efficiencies (catch relative to inputs for 150 countries) and catch diversity indices (Shannon Wiener index) through time. Keeping track of relative indicators of fishing efficiency will help promote and maintain economic performance and diversity of fisheries resources by keeping fishing effort at bay.

2. Materials and methods

2.1. Data

The catch (Watson, 2016) and capacity databases for global fishing activity produced by (Rousseau et al., 2019, Anticamara et al., 2011; Watson et al., 2013; Bell et al., 2016) were used in this study (see also supplementary text of compilation sources). A combination of databases (e.g. FAO, EU fleet register), scientific and grey literature were used to develop a time series of the number of motorised marine fishing vessels, total days at sea and their engine power (see also supplementary text for summary of compilation sources), as per (Rousseau et al., 2019). Missing power data was inferred by comparing countries with similar sociocultural background and economic development for all countries for the years 1950 and 2014 (it should be noted that there are unpowered artisanal/small-scale effort that is large in some countries but not included in this analysis). The capacity database contains information on an aggregated number of active vessels and kW power by year and country. The catch database contains catch (t), year and country. Additionally, we used a time series of Gross Domestic Product (GDP) time series data and climate vulnerability indices described by (Blasiak et al., 2017) to explain relationships between climate vulnerability and the potential of the country to change.

2.2. Data envelopment analysis (DEA)

Efficiency is a broad term in the context of environmental science and thus has different definitions. Here, the concept of efficiency we adopted is the one widely used in resource economics, that measures of the input(s) a system requires to achieve a specified set of output(s). Although catch-per-unit effort (CPUE) is often used to analyse trends in fisheries production this is most often based on a single output (catch) relative to a single variable (effort - e.g. kW days) (see Rousseau et al., 2019). It is also worth noting that CPUE can also be split between fleets and standardised. In contrast, approaches used in resource economics have focused on total system-level inputs and outputs. DEA is a preferred method among fisheries economists as it can deal with aggregation and multi species fisheries and multiple inputs and outputs (FAO, 2008; Oliveira et al., 2010). An output-oriented DEA-approach (bias-corrected – see supplementary text) was used to measure country efficiency. The DEA method measures efficiency by comparing each individual production unit. We used a year as the production unit within a country's time series to compare against all other years given a set of input and output variables (Cooper et al., 2000). The algorithm compares observations from those production units relative to a 'production frontier'. The production units situated on the frontier are assigned an efficiency score (θ) of 1, and the subsequent units within that optimal frontier <1 (representing distances from the frontier). For example, an efficiency score of 0.75 implies that a 'year' production unit could in theory increase its outputs (its catch per unit effort, CPUE) by 33% (1/0.75) while keeping inputs the same if it performed as well as its best-performing peers (see Coelli et al., 1998).

Here, the DEA was calculated on an inter-temporal design (Färe et al., 1996) to estimate relative changes in technical efficiencies capacity utilization assuming the inputs (units are similar, i.e. number of vessels, kW and days) and outputs are similar (catch in tonnes). DEA optimizes on each year to get the best fit for that year's performance relative to all other years in the time series, thus assuming efficiency is embodied within the inputs and the ability to catch fish. We appreciate that this approach is simplistic based on global landings and fleet capacity estimates for each country but its intention is to show the likely evolution and direction of production efficiencies over time.

2.3. Fisheries input variables

In our analysis, the number of vessels and kW power by year (spanning the 1950–2014 period) by country were used to represent the fixed input, i.e. a country's 'capital stock' (the total physical capital existing in the fishery at any moment of time) (Tidd et al., 2016). We analyzed artisanal and industrial sectors separately. To model properly for revenue-maximising behaviour, vessel level species and size composition data are needed, since price per unit weight varies by both species and size class. As vessel-specific economic or biological data were not available for global fleets, days at sea by year and country and sectors were used as a proxy to represent variable input measures (i.e. reflecting inputs dependent upon the level of fishing effort – number of boats). (See also supplementary text).

2.4. Fisheries output variables

Annual catch in tonnes of molluscs (freshwater and marine separate units), crustaceans (freshwater and marine separate units), marine fish (e.g. demersal fish), small pelagic fish (e.g. anchoveta), large pelagics (e.g. tunas), mixed pelagics, elasmobranchs (e.g. sharks, skates and rays), diadromous (e.g. salmons and trouts) and other (e.g. carps, aquatic plants and miscellaneous seafood products) – are the catch output levels by sector. Like other statistical techniques, DEA also has stability issues in terms of degrees of freedom. Degrees of freedom increase with an increase in the number of production units, in our case the variable year. Therefore, when selecting the variables it is important to ensure that sample sizes are sufficient, that is: Number of observations $\geq$ MAX {m $\times$ k, 3 (m + k)} where m = number of outputs, k = number of inputs. This means that the minimum number of production units (observations) is the product either of the inputs and outputs or 3 times the sum of the inputs and outputs, whichever is larger. The outputs in our analysis were aggregated to the level of detail described above rather than the potential of >70 species combinations to circumvent problems with degrees of freedom issues.

2.5. *Technical efficiency (TE)*

The output-oriented distance function, where relative efficiency is calculated, is given as (Färe et al., 1989, 1993), see also (Tidd et al., 2016):

Max. θ, zsubject to,

$$\begin{aligned} &\theta y_{j,m} \leq \sum_{j=1}^{J} z_j y_{j,m} \ \forall\, m, \\ &\sum_{j=1}^{J} z_j x_{j,n} \leq x_{j,n} \quad \forall\, n, \\ &z_j \geq 0 \ \forall\, j, \end{aligned} \tag{1}$$

The efficiency score θ, $(\theta \geq 1)$, determines how much production of each year (j) can increase for a given quantity (n) of fixed (number of boats and kW power) and variable inputs (days at sea), $(x_{j,n})$, to give the feasible quantity (m), of outputs (see section 'Output variables' above) $(y_{j,m})$, in an efficient combination (maximum productivity) where (z_j) weighting factors measure the optimal linear combination of frontier observations that give the optimal performance of the unit in question (Tidd et al., 2016). Years which are the most technically efficient operate along the frontier boundary (θ) and have a value of 1. Those that are less efficient operate within it and have a value < 1. Technical efficiency (Eq. (2)) of a year is:

$$TE = \frac{1}{\theta} \tag{2}$$

When calculating technical efficiency within the DEA, assumptions must be made about the 'returns to scale' as this affects the efficiency score θ. We assumed variable returns to scale (VRS) $z_j = 1$, the change in output can be greater, equal to, or less than the change in input which is the general approach adopted in fisheries economics. Constant return to scale CRS (which can be explained as an increase in input that causes a proportional change in output) is said to overestimate capacity output and underestimate capacity utilization while VRS (can be explained as an increase that does not cause a proportional change in output) is generally a more conservative estimate of capacity output and of capacity utilization (see Cooper et al., 2000).

2.6. *Calculation of global (or regional) trend in technical efficiency*

Calculated global trends in technical efficiency by year (see above), for each country and sector were weighted by that country's reported total catch and an overall mean weighted technical efficiency computed.

$$TE_{y,\,s} = \frac{\sum TE_{y,\,s,c} L_{y,\,s,c}}{\sum L_{y,\,s}} \tag{3}$$

Here L is the catch in tonnes, y is the year, s is sector and c is the country.

2.7. *Relating diversity to food supply and stability in the context of climate change*

We graphically present potential risks posed to countries using the well-known Shannon Wiener diversity index applied to country specific catches to represent food supply and stability. The diversity index relates as a weighted measure overtime of the richness of species (food) by their distribution evenness and therefore depicts changes in relative abundance of each food within a given supply of food. (see supplementary material). We calculated the % rate of change in efficiencies versus the % rate change in Shannon Index through time by country for the most vulnerable countries (106) in relation to their index of climate vulnerability to visualize the risk to countries. (Estimates based on country Economic Exclusive Zone sea surface temperature anomalies, relative to 1900–1950, and a range of country specific socio-economics) and GDP (Some countries were omitted due to lack of vulnerability score, GDP (2010–2014 ~ average) or lack of early years catch by species information) as a wider indicator of adaptive capacity through time. For example, the higher the GDP the more a country is able to adapt to the consequences of climate change due to having greater resources at their disposal.

3. Results

3.1. *Current status of global fisheries efficiency*

The global fishing efficiency year on year percentage rate of change decreased for many of the countries considered. Strongest declines were for mid-latitude artisanal fisheries (Fig. 1A) at a rate of up to −3% per annum (calculated using a rate equation over 64 years for average

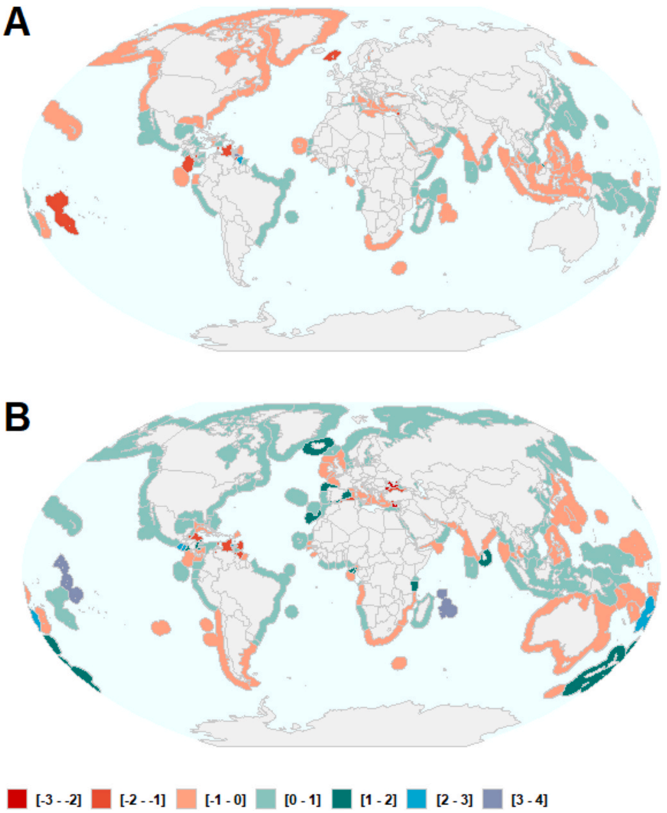

Fig. 1. Global fishing efficiency indicators as percentage year on year change for data between 1950 and 2014 for each country's A) artisanal fleets, B) industrial fleets (EEZs with no colour represent missing data). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

technical efficiency). These modest global changes reflect increased fishing effort to harvest the same volume of fish and thus could translate into lower profits. Conversely for the industrial fleet (Fig. 1B) we find that many northern hemisphere countries fishing efficiency has increased at a rate of up +2% per year and for many countries in the western pacific region an increase of up to +4% can be observed. These patterns reflect continual efficiency increases i.e. less fishing inputs to catch the same volume of fish.

Understanding the changes in technical efficiency is important for food security (and food insecurity). Many countries catch different quantities of seafood, therefore weighting the technical efficiency by the actual catch of the country can provide an instrument to identify trends and changes in the global time series.

The reported catch weighted mean of technical efficiency temporal trends by sector, artisanal and industrial, are shown in Fig. 2A and C. Despite a fall in efficiency estimates for the artisanal sector from 1980 to 2000 (excess capacity), a steep increase was observed around the turn of the century followed by a period of stability and then a decline in recent years. The industrial sector however shows less variation. Fig. 2B shows an overall global average increase in efficiency for artisanal fleets (+0.04% per year per year – calculated mean across years), while for the industrial (Fig. 2D) an increase year on year of +0.08% is observed. Despite the increases for both sectors, the 5-year average up to the year 2014 has a calculated decline in efficiency for the artisanal sector of −0.2% in contrast to the +0.3% increase for the industrial sector.

3.2. *Regional variability in fishing efficiencies through time*

Substantial temporal trends over the 1950–2014 period were evident for technical efficiencies (catch weighted mean), across regions, and across artisanal and industrial sectors (temporal trend - Fig. 3A) and percentage year on year change with fitted loess smoother (Fig. 3B). While many regions showed small changes in efficiency, other regions showed larger increases in efficiencies through time, most notably in South America and Oceania, where we observed a +0.7 and + 0.84% per year increase in technical efficiency for the industrial sectors respectively (Fig. 3Bf and Fig. 3Bl). These changes may reflect the large anchovetta, horse mackerel, sardines fisheries operating in the eastern Pacific Ocean, and tuna fisheries in the western Pacific Ocean, which have undergone an accelerated expansion of their fisheries since the 1980s driven by the high demand and increases in pelagic catch compositions. This effect may have been inflated by phenomena such as *El Niño* for instance, which influence warmer water masses, the preferred habitat of some tunas, and contributed to higher catch rates. While cooler masses are the preferred habit for anchovetta and the other species that are influenced by the *La Niña* phenomena.

For Oceania, recently there has also been a large increase in efficiency year on year for the artisanal sector of ~+2.65% (Fig. 3Bk) and an observed decline in the industrial sector of +0.17% relative to 64-year average of +0.84% (Fig. 3Bl). In contrast, efficiency trends have increased at a rate of ~+1% for both sectors in South America (Fig. 3Be and Fig 3Bf). It is also notable that Oceania and South America have a high degree of year-to-year variability in efficiencies i.e. less stability, and this variability could potentially pose a risk to food securities especially for some of the poorer countries in these regions that rely on fish for nutrition, dietary needs and employment.

The African and Asian region show the steepest declines most recently for the artisanal sectors (−0.2 and −0.44%) (Fig. 3Bg and Fig. 3Bi). The North American region shows the least variation in efficiency over the period of ~ +0.04 and + 0.03% for artisanal and industrial, although in the most recent years increases have been observed for both sectors of +0.26 and + 0.5% respectively (Fig. 3Bc and Fig. 3Bd).

European technical efficiencies decreased on average by over −0.09% per year for the artisanal sector during the 1950–2014 study period (Fig 3Ba), with larger increases of +0.21% per year for their industrial sector (Fig. 3Bb). However, the European 5-year average depicts larger increases for both artisanal and industrial sectors of +0.51%

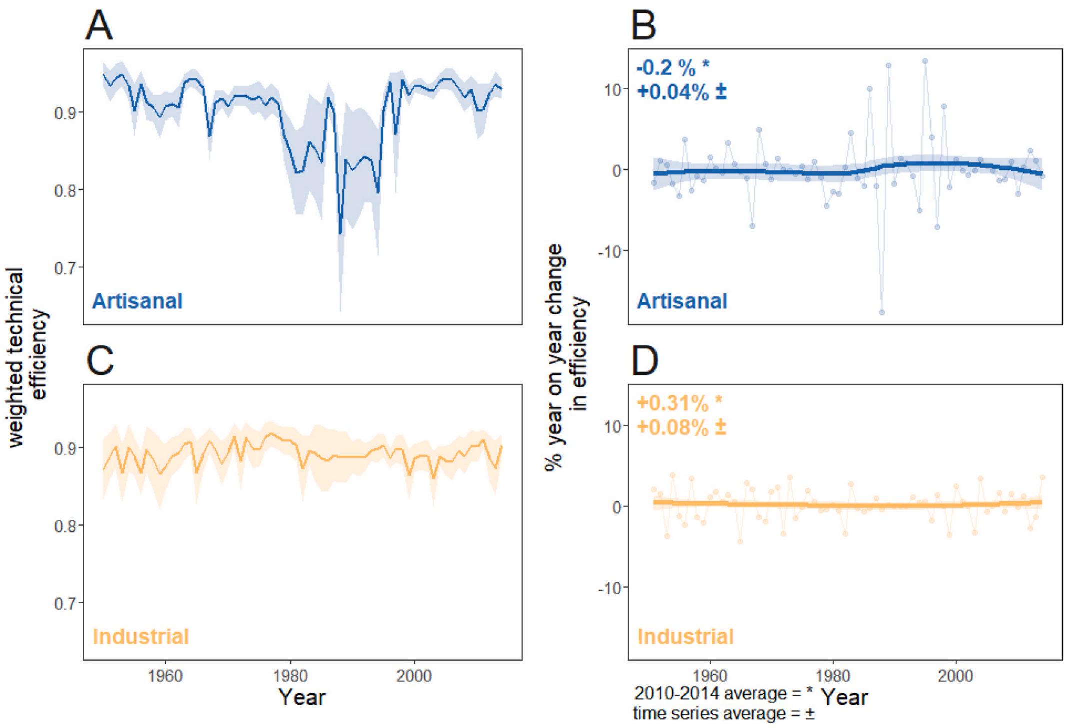

Fig. 2. A) Artisanal (blue) and C) Industrial fleets (yellow) global catch weighted technical efficiency time series. Artisanal (blue) B) and D) Industrial fleets (yellow) loess model predictions and observed points, % year on year change in technical efficiency for global sectors (reported catch weighted mean of technical efficiency) (error ribbon depict technical efficiency catch weighted mean standard errors). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

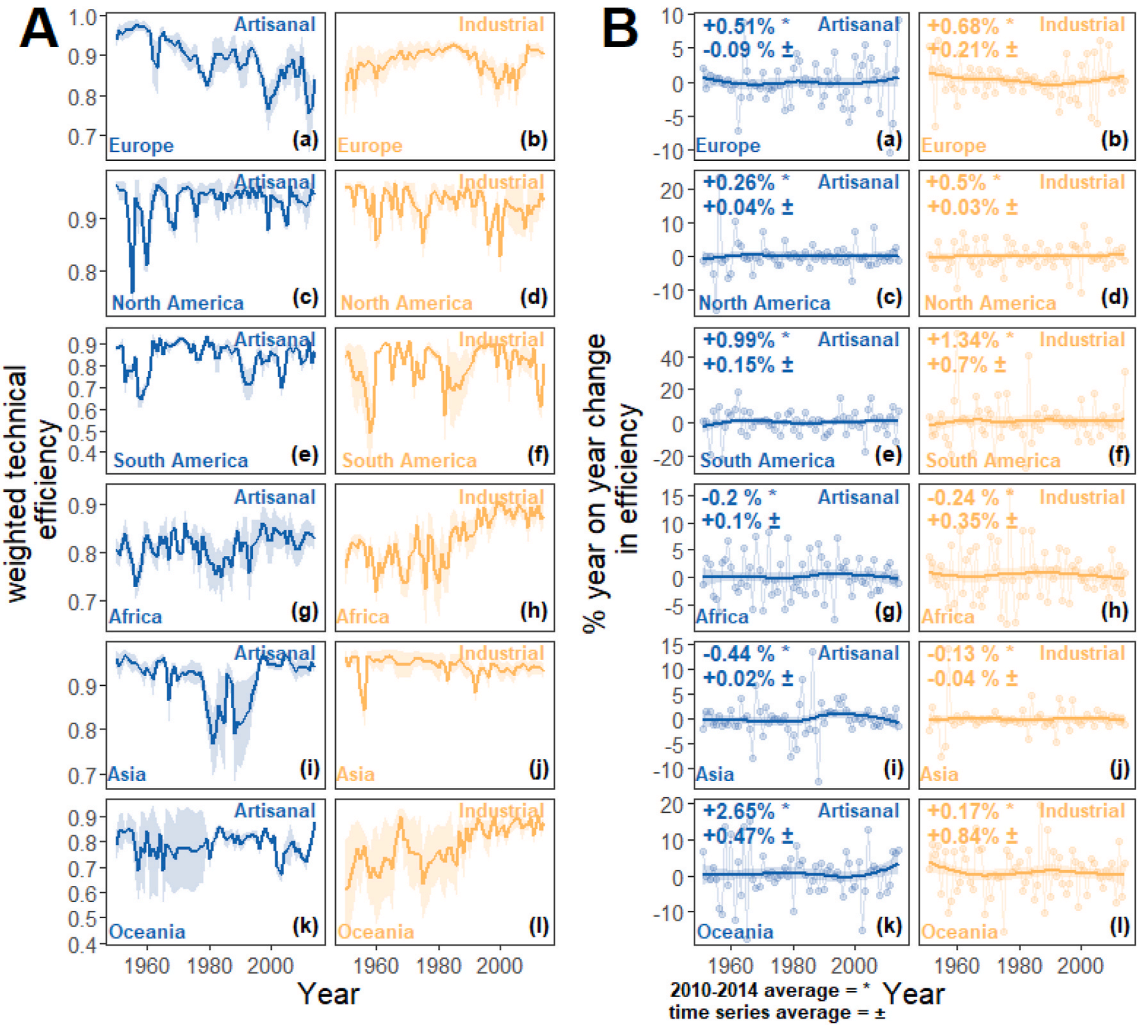

Fig. 3. A) Regional technical efficiencies. Artisanal = blue, Industrial = yellow line. Technical efficiency by year (reported catch weighted mean of technical efficiency) for artisanal and industrial fleets (technical efficiency/catch weighted standard errors). B) % year on year change in regional variation of technical efficiencies – Loess model predictions (line) and observed points. (a, b) Europe, (c, d) North America, (e, f) South America, (g, h) Africa, (i, j) Asia, (k, l) Oceania). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and +0.68% respectively (Fig. 3Ba and Fig. 3Bb).

3.3. Changes in country-level efficiencies in the context of climate change

The long-term profitability of fishing activity is influenced by changes in economic efficiency through time coupled with climate vulnerability. Under these conditions, countries need to alter the balance between the diversity of species caught as well as approach Maximum Economic Yield (MEY, proxy for technical efficiency) to achieve the highest efficiencies. Simultaneously, climate change poses additional risks for fisheries and may limit the possibilities for countries to achieve such efficiencies, now and into the future, given major changes in species redistributions and productivity.

The relationship between the rate of change in technical efficiency and the rate of change in the catch diversity index is shown in Fig. 4. High scores of both technical efficiencies (a mean of industrial and artisanal sectors due to some artisanal fleet countries having limited time series) and catch diversity fall in the top right-hand corner. The size of the circles (each country) represents climate vulnerabilities and the colour is approximate GDP (2010–2014). This reveals how well countries have diversified their catch portfolio. A higher technical efficiency score and a higher diversity of the target species reveal how well countries have diversified their catch portfolios. I.e. fishers are

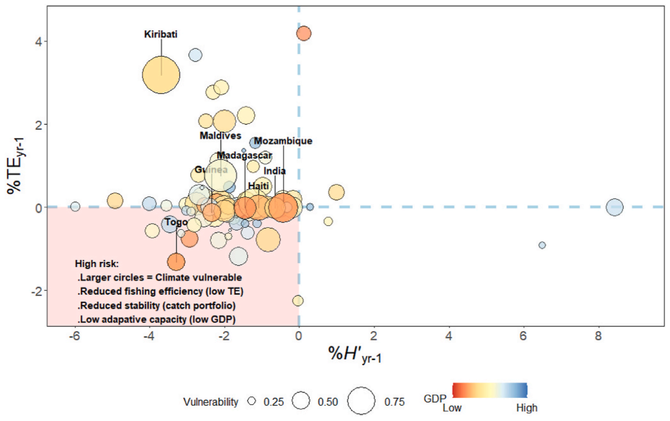

Fig. 4. Average across all sectors % rate of change in Shannon's diversity H' index (based on reported catch) versus average across all sectors % rate of change in technical efficiencies for a selection of the most vulnerable countries (n = 106) to climate change – Extreme region of concern labelled within the figure situated on the bottom left.

balancing fishing effort with fishing opportunities.

Forty three countries are found to be in the bottom left hand corner which represents an area of multiple risks especially to those who are the most vulnerable to climate change (and low adaptive capacity to climate threats i.e. low GDP) to declines in fishing efficiency and catch portfolios which tend to stabilize food supply. Simply, with falling efficiencies comes the threat of excess fishing effort, costs implications and smaller catches, and thus food supply. Furthermore, the threat in this region of Fig. 4 is further increased by the loss and species diversity of the catch giving fishers less of a portfolio of fishing opportunities to cushion the effects of target species losses. These losses could be due to regional species loss from overfishing, climate change and/or result from a change of targeting of a more lucratively priced species (e.g. tunas in Oceania and western Africa) or lower-value reduction fisheries (fishmeal and fish oil in Asia and South America). Notably, some of these countries are also strongly affected by climate change (Fig. 4), and do not have the adaptive capacity (due to low GDP) to manage, or the ability to adjust to change in order to cope with climate related threats, e.g. Mozambique, Madagascar, Togo and Guinea. Thus, support to facilitate swift management for some of these most vulnerable countries.

The top left-hand corner of Fig. 4 also represents an area with poor catch diversity, but these countries have high technical efficiencies. The majority of these countries ($n = 58$) have a higher GDP and thus have a higher adaptive capacity to climate change compared to the countries found in the high-risk region. Nevertheless, these countries (e.g. Kiribati and The Maldives) will have to balance their increased fishing efficiency with future fishing opportunities in order to prevent themselves falling into the high risk quadrant.

4. Discussion

Our analysis of global fisheries at the regional and country scales has revealed high variability in fishing efficiencies globally and falling catch diversity in many regions and countries. Many artisanal fleets have had to increase their fishing effort, meaning their efficiencies are falling year on year (up to −3%, Fig. 1A). Globally this translates into a fall in efficiency for the artisanal sector of −0.2% per year (average for the 2010–2014), which in turn translates into a ~71,400 tonnes loss in catch globally. All of this highlights excess capacity that is likely to be symptomatic of management issues and highlights major challenges for meeting food and nutritional security needs (Golden et al., 2016).

This is especially exacerbated in regions of the world even more so in poor countries where the impacts of climate change are already affecting ecosystems and our health. With falling efficiencies fishing costs rise, and as such are passed on to the consumer and thus raises wider concerns with respect to the vulnerabilities worldwide to hunger, in terms of what we need now to produce enough food, and in the future without threatening global and regional biodiversity.

One of the biggest causes of excess capacity are government grants or subsidies, which are a serious threat to marine capture stocks that encourage wasteful fishing practices in already overcapitalized fisheries and maintain effort (Meissa et al., 2014), even when stocks decline (Sumaila et al., 2019). Fisheries managers have attempted to limit excess fishing capacity by introducing some form of regulated access to the finite and sometimes diminishing resources (Pauly et al., 2002; Peterman et al., 2004; Mora et al., 2009; Beddington et al., 2007; Worm et al., 2009). While the global catches have declined since the middle of the 1990's (Worm et al., 2009) it is apparent that global fishing effort has not (Rousseau et al., 2019; Bell et al., 2016), suggesting excessive levels of capacity in some regions, and difficulties for any beneficial economic stability.

Fishing efficiency for some industrial fishing countries have increased at a rate of up to +2–4% per annum (Fig. 1B). This concurs with a recent study by (Palomares and Pauly, 2019), which (based on information assembled from 51 independent studies) empirically estimated technical efficiency 'creep' between +2 and 4% for some countries. The increase in efficiency seen in these industrial fleets may potentially due to fishers seeking new opportunities in the high seas to compensate for local abundance losses in their previous fishing grounds, or uptake of advanced fishing technology (Watson and Tidd, 2018), fisher skill and decommissioning of inefficient vessels due to their rising costs associated with aging vessels.

However, with efficiency gains, falling catch diversity can be of major concern and may worsen adaptive capacity of resilience of fishers to climate change (Young et al., 2019; Robinson et al., 2020), with widespread implications for the economic productivity and social wellbeing in regions where seafood becomes scarcer (Blanchard et al., 2017). In some cases, optimising catch diversification (Robinson et al., 2020) (catch portfolios) may be impossible due to shifting stocks (e.g. due to species' redistribution, declines in local abundance and/or sizes), subsidies and political power. The knock-on effect can result in increased costs and variable fish prices (relating to fish species and size). Disentangling exogenous factors that are influencing these efficiencies are needed to further understand the ecological, social and economic dimensions of sustainability of these changes and for informing management.

The sustainability of fisheries nationally and internationally requires integrated indicators and knowledge of global fisheries capacity to meet international targets in the face of climate change. Importantly our results highlight that global fleet capacity reduction is urgently needed to meet sustainability goals and targets by 2030. Implementation of proactive fisheries management, preventing IUU (Illegal, Unreported and Unregulated) fishing, eradicating harmful subsidies, and climate adaptation measures will further help achieve sustainable fisheries (Sumaila et al., 2019). Having identified the nations that have falling efficiencies and are vulnerable to climate change, a more detailed country and regional specific analysis is required to unpack the specific details and test different climatic (extreme events and fluctuations), and economic conditions and to analyse their effects on shortfalls in fisheries production. Integrating the above information at a detailed scale would not only give a better insight of how to improve environmental sustainability but would equally support understanding of economic as well as social sustainability and thus potential trade-offs.

With the global demand in food rising due to population growth and land based production raising environmental and health concerns, marine resources will become increasingly important to the nutritional needs of many (Costello et al., 2020; Golden et al., 2021; Gephart et al., 2021; Naylor et al., 2021). Thus, swift action will be necessary and challenging, particularly in regions where falling fishing efficiencies, catch stability and climate change are negatively affecting seafood security.

Funding

ERC Starting Grant project CLOCK (Grant Agreement n.679,812).

Author contributions

Conception and design: A.T., J.L.B., R.W.
Analysis and interpretation of data: A.T., J.L.B, R.W., E.O.
Acquisition of data: A.T., R.W. and Y.R.
Modelling: A.T.
Writing, reviewing and/or revision of the paper: A.T., J.L.B., R.W., Y. R. & E.O.

Conflicts of interest

The authors declare no competing interests.

Data and materials availability

We used the R package 'Benchmarking' for our analyses. Original fishing effort data found here: https://figshare.com/articles/dataset/vessel_effort_csv/12905930 and catch data are found here: https://doi.org/10.25959/5c522cadbea37.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The research conducted here has received funding from the European Research Council under the European Union's Horizon 2020 research and innovation program.

Funding for open access charge: Universidade de Vigo/CISUG.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gfs.2021.100598.

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