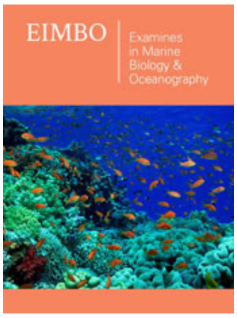
Crimson Publishers
Wings to the Research

Research Article

Status and Potential Production of the Main World Fisheries

ISSN: 2578-031X



Ernesto A Chávez* and Alejandra Chávez-Hidalgo

Interdisciplinary Center for Marine Sciences, Mexico

Abstract

Status of exploitation of the main world fisheries is analyzed under the premise that they are not over exploited. Unfortunately, sustainability in many fisheries has not been achieved. The Fishing mortality is usually referred to the Maximum Sustainable Yield (MSY) and is being adopted as a target in many fisheries; which is the threshold of overexploitation, fisheries often face the risks of being overfished. In many cases, the MSY is overpassed, or the stocks are under the condition of overexploitation of recruits, and consequently current yields and stock biomasses are quite below their MSY. The perspective suggests that world fish production will fall into depletion if no action is taken to ensure exploiting the stocks in a sustainable way. Findings suggest that nine out of the ten most important word fisheries examined are overexploiting their juvenile stages. Results suggest that the main fish stocks still withstand further catch rise by increasing the age of first catch, and their potential contribution to the overall yield may grow, from the current 22.9Mt to 84.4Mt. In reference to the world human population, this means a potential increase of up to 12.5Kg per capita annually, almost four times higher than current yields.

Keywords: Stock assessment; Optimum yield; Pelagic fisheries; Potential world production; World fisheries; Potential yields; MSY; Overfishing

***Corresponding author:** Ernesto A Chávez, Interdisciplinary Center for Marine Sciences, IPN. Av. IPN s/n, Col. Playa Palo de Santa Rita, La Paz, BCS, Mexico 23096

Submission: May 28, 2025
Published: July 23, 2025

Volume 7 - Issue 4

How to cite this article: Ernesto A Chávez* and Alejandra Chávez-Hidalgo. Status and Potential Production of the Main World Fisheries. Examines Mar Biol Oceanogr. 7(4). EIMBO. 000670. 2025. DOI: 10.31031/EIMBO.2025.07.000670

Introduction

Within all challenges faced by the society, in the context of a human population boom [1], a growing environmental pollution and a warming world, the future of fisheries is burdened by political trends and ruling economic and social factors [2-6]. The development of fisheries is urged by the need to feed a growing human population and the consequences of the depletion of exploited stocks, motivated by economic interests and constrained by their finite biomasses. Economic factors, social factors, and the dynamics of fisheries, face each other multiple interacting problems, apart from the climate variability, but they have their own dynamics [7], and this complicates the possibility of finding isolated and independent solutions. Aquaculture seems to offer a light of hope for humankind by helping to solve the problem of producing food from the aquatic environment. However, it is not a permanent solution. There are certain trends in fishery development which in practice, may contribute to a future that can help fisheries to become truly sustainable [8,9], such as reduction of discharges, reduction of large vessels, improvement of management measures, increased involvement participation of the eco-labeling of fishery products, reduction of subsides and illegal fishing, relative price stability and certification of many fisheries, among others. All these factors open a window of hope that allows to expect that sustainability of fisheries may become a reality, rather than a utopia, leading to accept that significant changes in fisheries management are needed to protect global marine ecosystems. The problem of doing accurate assessments becomes critical by perceiving that more and more stocks are over exploited every day, leading to economic crisis of fishers depending on their resources. Fisheries scientists and managers are concerned by the problem of assessing the exploited stocks as well as devising accurate scenarios for their optimum management. Therefore, the goal of this paper, is to assess the main world fisheries to know their status of exploitation and to suggest changes in the fishing intensity and in the age of first catch to improve yields.

Materials and Methods

An age structured simulation model was used, named FISMO, for FIsheries Simulation MOdel [10,11]. Here, catch and population parameter values are input data and fifteen-year catch data series; it was developed in Excel as template. The variables used as reference to test fishing scenarios are the age of first catch (tc), maturity age (tm), and the fishing mortality (F). The model allows identification of quantitative scenarios and optimizes the adoption of exploitation strategies; when it is fitted to each fishery, allows assessing observed and recorded yields with absolute coincidence between both variables, and a zero deviance between the catch data series and the simulated one, which is achieved by suppressing the use of fishing effort data in the stock assessment process. Catch values are decomposed into age structure, and the series can be simulated beyond the last year of recorded data, aided by the stock-recruitment model by Beverton & Holt [12], and keeping constant a certain F value. It allows testing the stock response by changing the F and tc, as well as devising many exploitation scenarios addressed to optimize yield, profits, and social benefits.

Selected fisheries

FAO [13] world fisheries statistics were the basis to select the most important catch records, and they are a consistent source of information [14]. Each statistical zone was examined, and the ten most important fisheries were selected according to their yield ranks. Fisheries whose landings were at least 220,000metric tons (t) or more are included in this analysis, as shown in Table 1. Data suggest that the main stocks are declining or at least remain stable; by contrast, on examining the whole scheme, two unidentified groups of species appear, mostly tropical, suggesting an increasing demand for food from the sea. Each stock examined was assessed with the simulation model. Sustainable Yields (SY) were determined with the current tc and these values were compared to the optimum MSY value estimated as a function of tc at the optimum F value. The difference between current SY and optimum MSY was evaluated as an unexploited potential yield of each stock.

The Maximum Sustainable Yield (MSY), can be understood as the largest annual harvest that a fish stock can produce in the long term [15-19] and it was deeply rooted in Ecology [20]. MSY is important to understand for everyone involved in fisheries management, as is the alternative concept of MEY, the Maximum Economic Yield [16]. In this paper, The MSY concept was used as a reference to which fisheries should be addressed as a fisheries target. In those cases where economic data are available, the Maximum Economic Yield (MEY) would be preferable, because it is attained at an F value lower than the one required for the former one and the profits are higher than at the MSY. In this paper, economic values were not used and therefore our goal is the reference point which is advised as fisheries target.

The MSY is understood as the largest annual harvest that a fishstock can produce in the long term [15-19] and it was deeply rooted in Ecology [20]. MSY is important to understand for everyone involved in fisheries management, as is the alternative concept of MEY, the Maximum Economic Yield [16]. In this paper, The MSY concept was used as a reference to which fisheries should be addressed as a fisheries target. In those cases where economic data are available, the Maximum Economic Yield (MEY) would be preferable, because it is attained at an F value lower than the one required for the former one and the profits are higher than at the MSY. In this paper, economic values were not used and therefore our goal is the reference point which is advised as fisheries target.

The reference made here to the MSY or to the optimum yield as management options, is given in the first case, to the yield under the scenario of overexploited stocks, which the current and normal case, described in a red line. In the second case, a reference is made as result of simulation of the stocks, and assuming that a value of F=0.9 is the maximum yield, which in fact it is not, should be seen as a precautionary value, is an underestimation of the MSY value because there are other factors like competition, predation, and other food web factors not explicitly considered here, that determined to assign the value of F=0.9 and equivalent to the MSY, and for a reason of convenience, this value is assigned as the MSY to be pursued as a target of a fishery which is examined in this paper. For details, the reader should examine the papers by FAO [21].

Current yields

Source data proceed from the FAO [13] catch statistical records over a series of seventy years up to 2022, providing the first approach to diagnose the condition of every fishery and detection of fish production of the main world fisheries. A rough estimation of the harvest equivalent to the MY of the world fisheries was previously made [22]. Recorded and simulated catch, as well as the estimated biomass of every stock examined, were evaluated in each case for the last fifteen years of records.

An examination of the main world fisheries catches, whose parameter values are presented in Table 1, stimulated the interest to evaluate their maximum potential yield under the hypothesis that they are under the condition of over exploitation of recruits [11]. Here, it is evident that three fisheries, the Peruvian anchovy, the south American pilchard, and the Chilean jack mackerel, display a consistent decline. Three other fisheries, the Atlantic herring, the Alaska Pollock, and the Atlantic cod show an apparent response to the climate variability. Four others, the Chub mackerel, the Skipjack tuna, the European pilchard, and the Gulf menhaden, display a relative stability. There are only two fisheries, the Alaska pollock and the European pilchard, which show a consistent growing trend at least through the last twenty years. The stock biomass seems to be not affected very much by the exploitation in four fisheries, the Peruvian anchovy, the Chub mackerel, the Skipjack tuna, and the Gulf menhaden. Total catch represents 44% of the world fish production, extracted from FAO [13].

Table 1: Population parameter values of the ten main components of the world fisheries analyzed in this paper and chosen for simulation (Data from Froese and Pauly 2023).

Common Name	Scientific Name	von	Bertalanffy	Growth	Parameters			Rel. W - L	
		K	L∞	W	-to	tm	tc	a	b
Alaska pollock	*Gadus chalcogrammus*	0.29	64	1,685	0.13	3	1	0.0104	2.88
Atlantic cod	*Gadus morhua*	0.4	110	13,637	0.3	1	1	0.0081	3.05
Atlantic herring	*Clupea harengus*	0.3	31	168	0.02	2	1	0.012	2.78
Chilean jack mackerel	*Trachurus murphyi*	0.1	85	4,502	1.4	5	2	0.0213	2.757
European pilchard	*Sardina pilchardus*	0.2	20	62	0.2	5	2	0.0052	3.14
Gulf menhaden	*Brevoortia patronus*	0.4	24	124	1.01	2	1	0.0051	3.18
Pacific chub Mackerel	*Scomber japonicus*	0.22	52	1,493	0.66	3	1	0.007	3.11
Peruvian anchovy	*Engraulis ringens*	0.44	19	661	0.5	2	2	0.117	2.95
Skipjack tuna	*Katsuwonus pelamis*	0.47	92	22,506	0.26	1	2	0.0044	3.413
South American pilchard	*Sardinops sagax*	0.45	31	206	0.17	1	1	0.0049	3.1

K=Growth rate; L∞=Asymptotic length (cm); W=Asymptotic weight (g); -to=Initial age, when length is equal to zero; tm=Maturity age (years); tc=Age of first catch; a and b=Parameter values of the length (L)-weight (W) relationship.

Alaska pollock=Abadejo de Alaska; Peruvian anchovy=Anchoveta peruana; Atlantic cod=Bacalao del Atlántico; Atlantic herring=Arenque del Atlántico; Skipjack tuna=Atún listado; California pilchard=Sardina de California; Chilean jack mackerel=Jurel chileno; Pacific chub mackerel=Caballa; European pilchard=Sardina europea; Gulf menhaden=Menhaden del Golfo.

The assessment of these fisheries allowed the possibility of simulating yield whose changes are a function of the age of first catch; then the chance of further increase in their biomasses and captures was tested. An obvious possibility for achieving an increase in the harvest of these fisheries could be by means of opening the mesh of fishing gears such that the age of first catch is at least the same as the age of first maturity in first place, then increasing the fishing mortality till the MSY was achieved. A fishery may reach many stages of SY even if it is overexploiting its juveniles; then if the turnover rate of its biomass is not declining, it could be maintained in a permanent condition of overexploitation for long time. However, this condition is not the best one; by contrary, the most convenient exploitation option at any population is achieved by giving the juveniles a chance to reach the age of maturity before being caught (Table 1).

Results

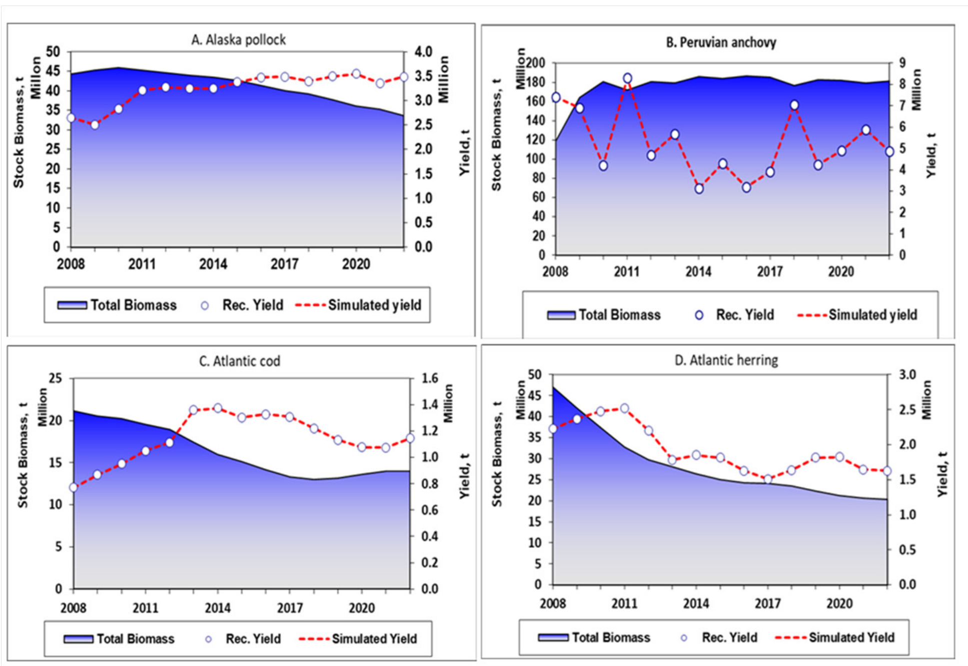


Figure 1(A-D): Recorded and simulated yield, and stock biomass as part of the fitting simulation process of the ten main stocks of the world fisheries. A. Alaska pollock; B. Peruvian anchovy; C. Atlantic cod; D. Atlantic herring.

Before describing results of each fishery chosen for assessment, it was necessary to show the results of the model, together with trends of biomass estimates (Figure 1A-J). In these figures, it is observed that the catch variability is more evident in the short-life stocks depending more on climate variability [23], as the Peruvian anchovy, the Chilean jack mackerel, the chub mackerel, the skip jack tuna, and the European pilchard. Despite that other stocks are still susceptible to the effect of climatic variability, their response in the catch statistics is not so evident. Assessments of other stocks deserving a comment are, the Atlantic herring, Atlantic cod, Chilean jack mackerel, and to some extent, the Gulf menhaden. In these cases, a high fishing pressure seems to have some effect reducing their biomasses; from high catch levels applied in some years, they display a decrease in the biomass later, meaning that the fishing mortality apparently is high enough to surpass the turnover rate of the stock [24,25]. This response ceases once the catch pressure is reduced, allowing restoration of the biomass. In the remaining cases: Alaska Pollock and Atlantic cod (Figure 1A, 1C), the fishing pressure apparently is not high enough as to provoke evident effect on the stock biomass. The same can be said for the chub mackerel, skip jack tuna, and the European pilchard (Figure 1E, 1H, 1I).

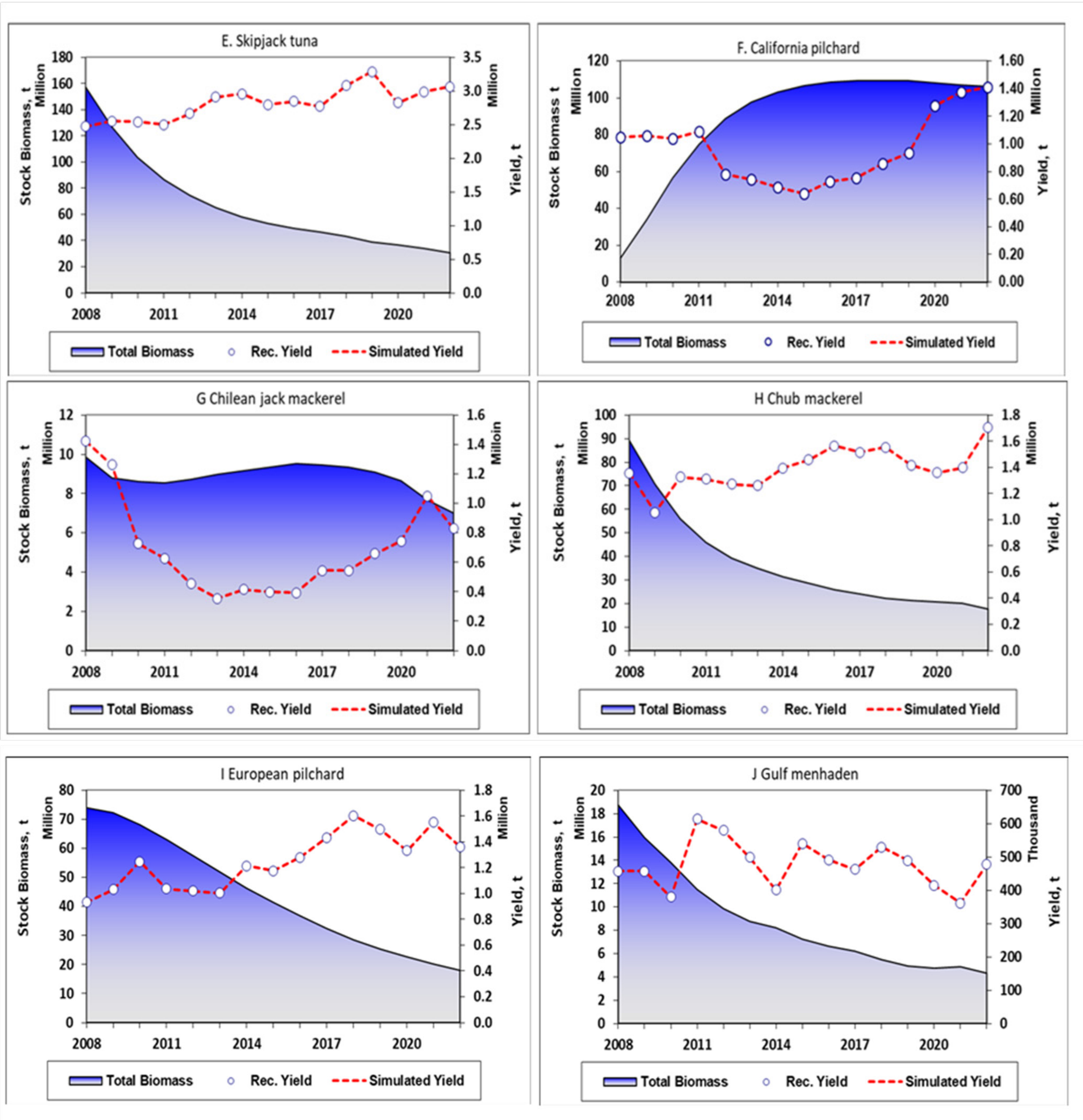


Figure 1(E-J): (continuation). E. Skipjack tuna, F. California pilchard; G. Chilean jack mackerel, H. Chub mackerel. I. European pilchard; J. Gulf menhaden.

Alaska pollock

The evaluation suggests that the fishery has been overexploiting juveniles severely (Figure 1A). When the age of first catch is changed from tc=1 to tc=6, a spectacular increase of yield is obtained, from 5Mt to 27Mt (Figure 2A). Bakun [26], states that since the late 1960's, catches of the Alaska Pollock have made up the majority of ISSCAAP Group 32 and dominating total captures. The graphic trend suggests that the fishery, despite having a rather constant yield through the last ten years, its stock biomass displays a decline through the same period, which may be consequence of a high fishing intensity in a condition which clearly corresponds to an overfishing of recruits, where the age of first catch is one year and the age of maturity is 3 years old.

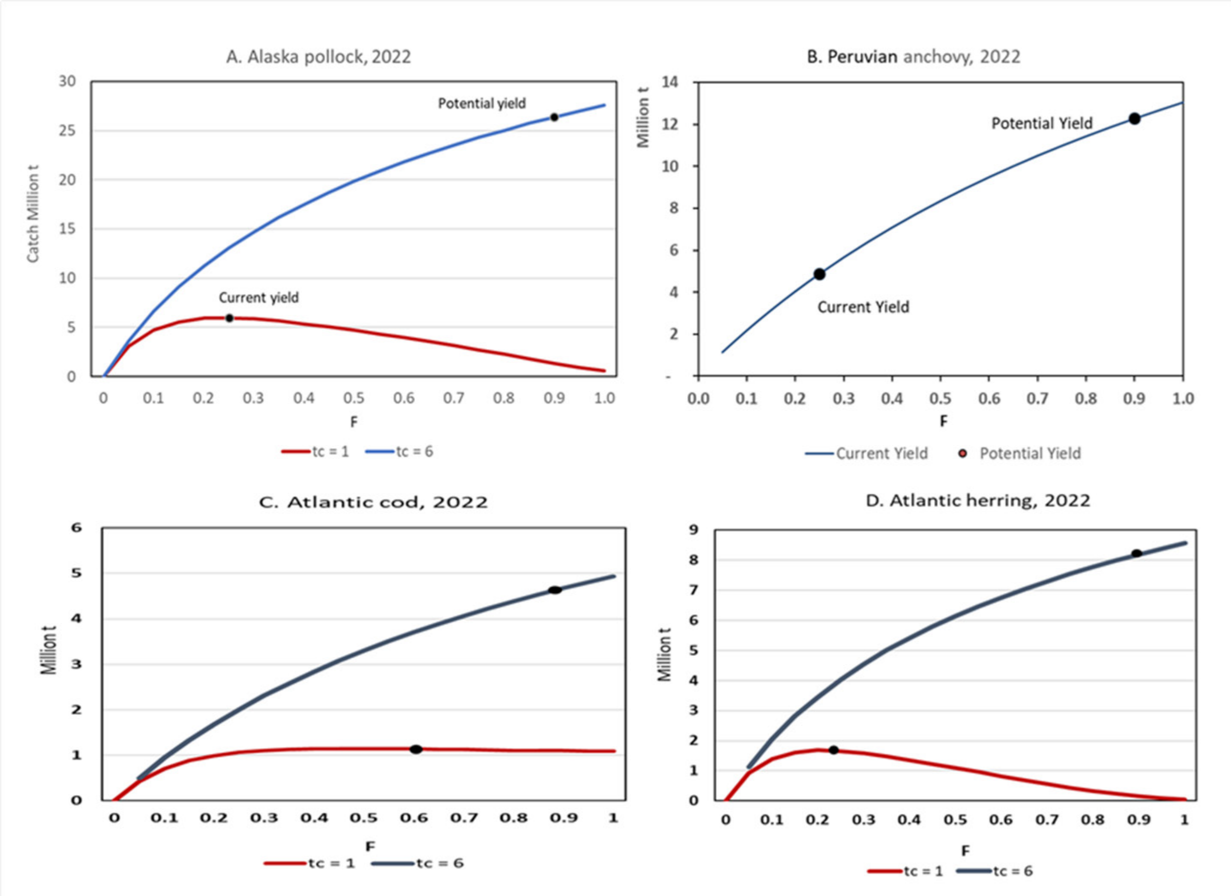


Figure 2(A-D): Current and potential yield of the ten most important world fisheries. The red lower line of each fishery describes the sustainable yield trend as a function of F and the current tc. The upper blue lines display potential yield at a larger tc value, excepting the Peruvian anchovy, where the fishery was simulated only with increase of F. The lower red lines describe the yield trend at current tc. In both cases, current yield is indicated by a dot; the dot on the blue line corresponds to F=0.9, evidencing the potential yield that could be harvested. A. Alaska pollock; B. Peruvian anchovy; C. Atlantic cod; D. Atlantic herring.

Peruvian anchovy

This is a short-lived species exploited in Peruvian waters and northern Chile. The catch in 2022 accounts to 4.9Mt; by far, the anchovy is the most abundant exploited stock amongst the world fisheries [13]. Climate variability, particularly El Niño event, has affected severely this population with dramatic impact in the economy depending on this fishery. The historical declining trend of stock biomass since the middle nineties (Figure 2B), indicates that nowadays the current fishing practice does not allow many possibilities of increasing yield soon [27]. However, based on these results, there is a possibility to increase the harvest up to 12.3Mt with little risk (Figure 2B). Unfortunately, given the short life span of this fish, there is no chance to increase the age of first catch without the risk of exceeding the catch of older age classes. The stock biomass displays rather constant values during the study period. Overfishing did play a major role in the collapse of the fishery of Peruvian anchovy in the early 1970's, but the "El Niño" 1972-73 was a primary cause of recruitment failure and stock decline [28]. It is suggested to increase fishing mortality from F=0.25 the current one, to F=0.9, in a precautionary recommendation, because of the high sensitivity of this stock to climate variability.

Atlantic cod

The 2022 catch recorded was 1.2Mt, and it corresponds to a ten-year series of high yields, after a period of low production when landings were below 0.8Mt (Figure 1C). The longevity of cod allowed to simulate catch with a tc=6 years, showing a significant increase in the stock biomass, with the possibility of catching up to 4.6Mt (Figure 2C). Shotton [29] mentions that cod is the most important member of its area and landings of this species literally peaked in 1968 at ~1.8Mt and then fell steeply to ~0.5Mt in 1978. There was a subsequent recovery during the period 1982 to 1989, followed by the collapse to the point of closing the fishery in Canada [30].

Atlantic herring

Catch recorded for 2022 was 1.7Mt, and the catch for the last fifteen years declines from 2.5Mt since the year 2010 by several causes [31]. The stock biomass also declines from 47Mt in 2008 to less than 20Mt in 2020 (Figure 1D). Both trends are a warning sign of the condition of this fishery. The longevity of this species allowed the possibility of simulating the fishery by choosing tc=6 years as the year to recommend further increasing its potential yield. If this age of first catch is adopted, the yield may increase significantly, from the current SY level, with a maximum of 1.6Mt, to at least 8.1Mt, as shown in Figure 2D. The species occupies estuarine and freshwater habitats at least for some part of its life cycle, which also appear to be under extreme stress [25].

Skipjack tuna

Catch records suggest that this is a healthy fishery, with tc=2 and tm=3, leading to slightly growing yields over the last fifteen years, and yields have been relatively stable oscillating around 3Mt (Figure 1E), [26]. However, its longevity allowed to simulate the fishery with tc=3 years; the resulting potential yield is 8.5Mt, with a net increase of 5.5Mt (Figure 2E).

California pilchard

Catch records of the last eight years indicate a sustained catch increase, from 0.65Mt to 1.4Mt in an apparent cyclic process. It is suspected that the age of first catch (tc=1), recorded in statistics, may be not the real one, because it is hard to explain how a stock overexploited for its juveniles, may display an increasing trend through the late 2015-2022 period (Figure 1F). The potential yield that can be obtained, shows that this fishery may increase from 1.4Mt recorded in 2022 with F=0.65 and tc=1, to 7.5Mt at F=0.9 and tc=4 years (Figure 2F).

Chilean jack mackerel

The exploitation of this fishery has evolved through a slow but consistent decline since 2012, passing from yields of 2Mt in 2005 to only 0.8Mt in 2022 (Figure 1G). This fishery showed a recovery from 2013 with 0.4Mt, to 0.8Mt in 2022. During the late nineties, this species was one of the major contributors to the overall increase in total regional production [26,32], despite a high fishing pressure [27] and strong dependence on climate variability [33]. Present catch with tc=2 is 0.8tm, implies a severe over exploitation of juveniles and something should be done soon to avoid a serious over exploitation problem of the fishery. Simulation with this long-lived fish allowed doing a wide range of tc trials, and in this case, a remarkable increase of potential yield showed the possibility of catching up to 4.9Mt with tc=8 (Figure 2G). This change in tc would permit attaining a more productive and sustainable fishery.

Chub mackerel

This species has sustained an important fishery in the USA [29], and on the Pacific NW as well (Hong et al. 2023). Catch records indicate that the chub mackerel displays a slight increase of about 700 thousand t through the last fifteen years. However, the stock has been overexploited for juveniles, describing a remarkable decrease of its stock biomass, with 88Mt in 2008 to only 17Mt in 2022; however, yield displayed a rather constant production, ranging from one to 1.4Mt in 2008 to 1.7Mt in 2022 (Figure 1H). Time trend of these two variables awakens the idea of a sudden decrease soon which can be caused by stock exhaustion and when there would be not enough recruits available to sustain a productive fishery as nowadays. On simulating the potential yield that could be harvested by changing the age of first catch, from tc=2 to tc=3, a potential yield of 4.5Mt could be obtained with F=0.9 (Figure 2H).

European pilchard

Catch and stock biomass trends of this species indicate a similar performance as the chub mackerel, thus it displays a decreasing trend of the stock biomass and a constant increase of yield, from one million t in 2008, of 1.4Mt in 2022 (Figure 1I). This means a similar perspective as the one described by the chub mackerel fishery, despite that the stock has been overexploited for juveniles with tc=2, and they get mature at tm=5. This is also a long-lived species, so the simulation with tc=3t, allowed finding a substantial increase of potential yield, from 1.7Mt to 4.4Mt (Figure 2I).

Gulf menhaden

According to catch records, the exploitation of this fishery evidence relatively constant yields in recent times, despite the Deep-sea Horizon oil spill in the year 2010 occurred near its fishing area, and there is a hypoxia zone existing near the output of the Mississippi river where it dwells [34]. Apart from this, the stock evidences the effect of overexploitation of juveniles, with a dramatic decrease in the numbers of one-year old recruits, declining from >13 billion during the year 2010, to just under 10 Billion recruits from the years 2019 to 2022; this 23 per cent decline should have a negative effect in the reproductive turnover of the population. Yields also showed a drop from nearly 600,000t in 2011 and 2012 to less than 500,000t in the years 2019-2022. Results of simulation support the idea that the catch could be substantially increased by exploiting adults only, this is, changing tc from 1 to 3 years. Under these circumstances, yield might increase from 478,000Mt (Figure 1J) to 1.18Mt (Figure 2J), approaching the condition of a sustainable fishery. Apparently, the hypoxia occurred in the summertime 1995 may have had a negative effect on the catch [35,36].

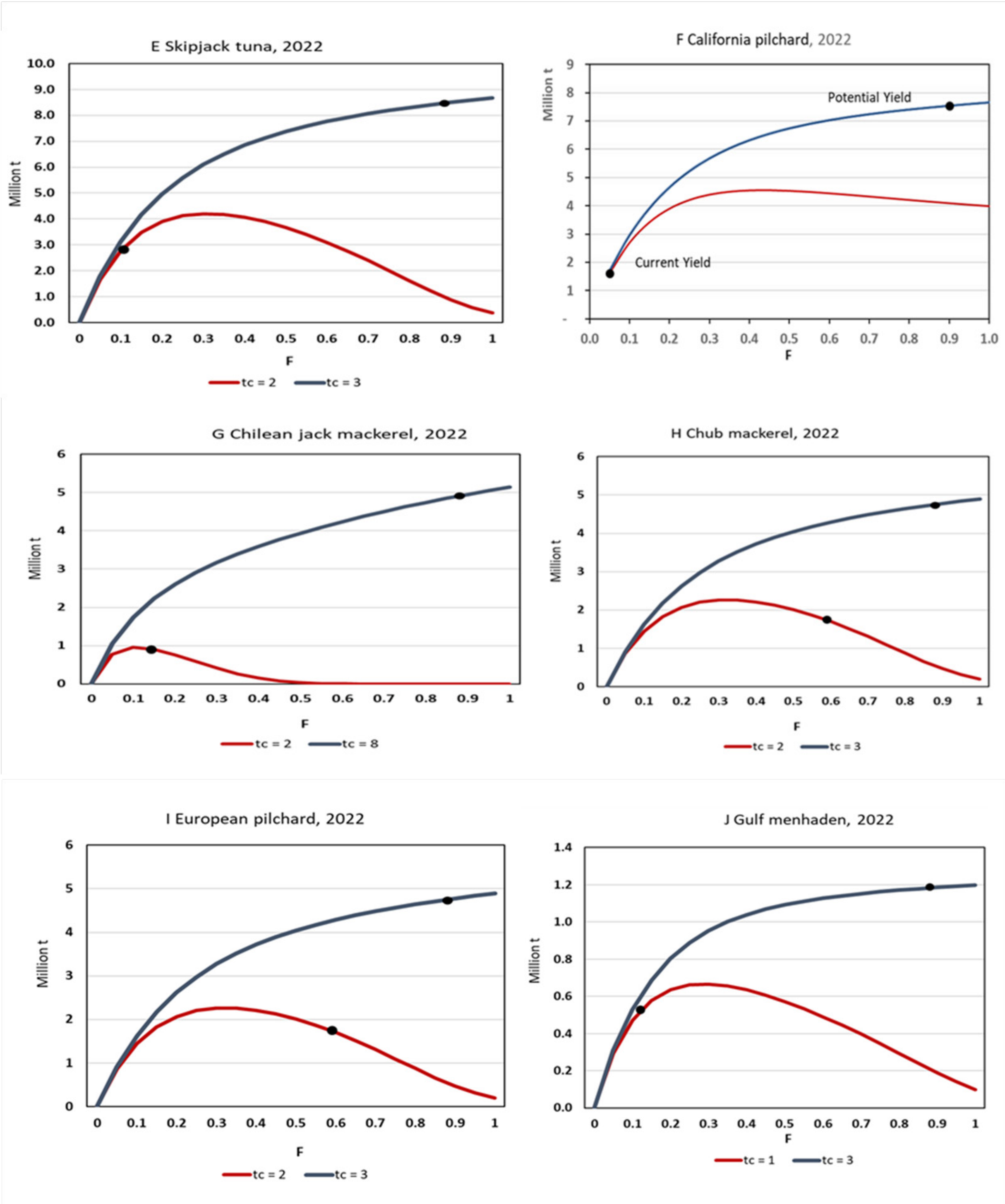


Figure 2(E-J): (continuation). E. Skipjack tuna, F. California pilchard; G. Chilean jack mackerel, H. Chub mackerel. I. European pilchard; J. Gulf menhaden.

Discussion

After describing the status and suggestions to increase yield of each one of the main world fisheries, it is pertinent to put their yield in a comparative context, allowing to make some recommendations addressed to exploit them sustainably [37]. After the former analysis of the ten main world fisheries, a general conclusion is derived, this is, all of them are over exploiting their juveniles, and to avoid more economic crisis caused by overfishing, it is necessary to exploit them only in their adult stages. This can be done by applying wider mesh openings in all these fisheries, after doing some previous selectivity tests to find the most suitable one at each stock. If the recommendations to enhance each fishery are adopted, it is expected that results could contribute to alleviate economic crises that occur more often in different parts of the world [3], and with a real chance to increase the marine food production in a significant way, apart from other simple guidelines for a quick diagnosis to ensure a sustainable exploitation in each case [37]. Concerning the fitting of recorded and simulated yields that have already been discussed previously, it is worth to mention that the perfect fitting between recorded and simulated yield presented in Figure 3, was achieved because the random fluctuation of catch data is attributed essentially to climate variability and fishing effort data, not much can be done with the climate and it effect on the fisheries, but respecting to fishing effort, the assessment was made through successive trials of F and by comparing its results between recorded and simulated yields year after year; this way, it was possible to make a very close approximation amongst recorded and simulated catch values over the catch data series. It was done this way because the fishing effort data were suppressed from the estimation process.

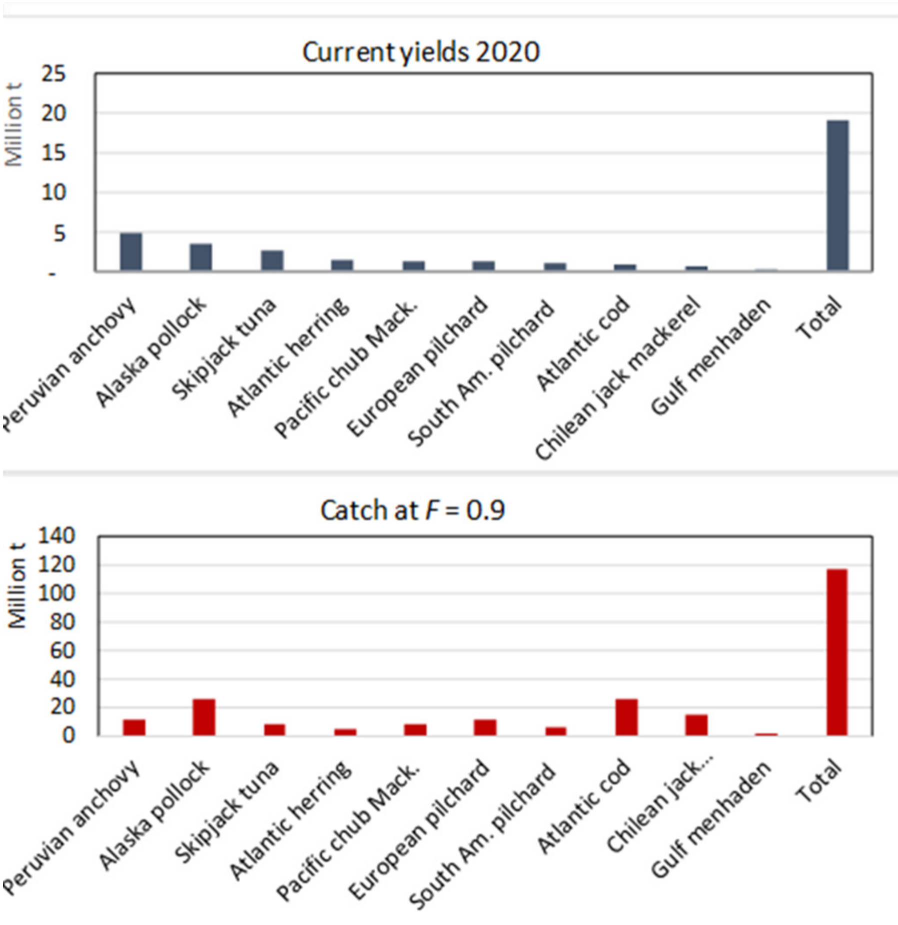


Figure 3: Landing records of the ten most important world fisheries. In both figures, the right-side column indicates the sum of harvest of all these fisheries. A. Upper figure. Recent yields (2022). After data from FAO (2023). B. Lower figure. Simulated potential yields at a precautionary fishing intensity (F=0.9).

Apart from possible changes in growth rate, natural mortality, and other population parameters, these changes in parameter values were not explicitly considered in the stock assessment, which were applied only to individual cohorts and therefore were separated from the random fluctuations of the stocks. The coefficient of variation of recorded catch was used to estimate a normalized random variation to the number of recruits, but this was omitted from the graphic outputs, where only deterministic catch trends are displayed. The use of only fifteen years of catch data was chosen with the deliberate purpose of minimizing the variance caused by the climate variability and its possible effect on recruitment. Therefore, the estimation of catch is based on the F as the only factor causing variability, because all data and population parameters are treated in the assessment as deterministic parameter values.

With the purpose of estimating the number of one-year old recruits each year, the Beverton & Holt [12] recruitment equation was used, such that in the data matrix of the numbers per age group and year, initial values were the recruit numbers estimated the previous year. Once the age of maturity was known, it was defined in the matrix of ages for the estimation of the number of adults, as a prerequisite for applying the recruitment equation. Yields for the year 2022 of the ten most important fisheries are shown in Figure 4. The bar on the right side of it represents the total catch of these ten stocks, which amounts to 22.8Mt. By contrast, the potential yield of each stock at a precautionary target, of F=0.9 (Figure 3B), here are considered as the MSY level, which suggests an impressive increase of potential yield, going from the current harvest up to 89.9Mt, this is, 3.9 times the volumes currently landed.

Potential increase in landing volumes correspond to a net increase of the world fish production of the order of 75.7Mt, as seen in Figure 4. These results imply the need that an international instance like FAO and other regional organizations, convince the fishing industry of each region and country involved in these fisheries, to consider the need of changing mesh openings. The recommendation suggests that in a period of no more than three years, all the fishing gears in use should adopt the use of the new mesh openings, such that the exploitation affects only adults. These recommendations may have profound implications to human society if the fish production is seen from the viewpoint of food per capita. Nowadays, world population is approaching to 7 billion people, and then if the current catch is distributed among all these people, the annual production per capita would be 2.7kg. However, if the potential yield estimated here is divided amongst all this population number, then we would have 16.7k. person-1; this is 6.2 times more food than nowadays. If the climate variability and errors in the estimation may incur in an overestimation of let say 50 per cent, even then, the potential increase in fish production would provide more than twice food than current yields.

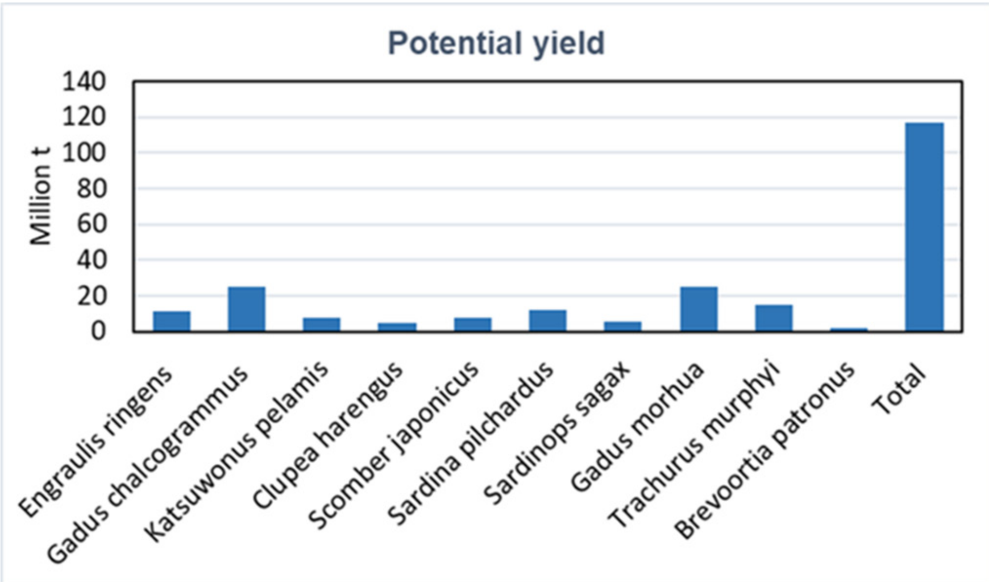


Figure 4: Net increase of potential fish production of the main exploited stocks, estimated by subtracting the potential yields at the FMSY=0.9 from the current ones recorded in 2022. It is remarkable to realize that the Atlantic cod and the Alaska Pollock are the most productive. Total net increase amounts to 67.0Mt.

Final comments

For years, current world fish production suggested a depressing perspective of an uncertain future, leading to an unexpected but wrong perspective of further fisheries development of overpopulated world [2,3,5,8,38-41]. This situation motivated the interest of evaluating the main world fisheries, taking care of the value of *FMSY*, which appeared robust to uncertainty concerning maturation and recruitment [42]. Here, the most abundant species are well represented [40], and statistics provide a useful guideline for an initial diagnosis of their status [43-45]. Results obtained in this assessment show an optimistic perspective. In 2011, the human world population was 7 billion (United Nations Population Fund, UNFPA). This means that fish production of the ten stocks assessed, of 22.8Mt, would be equivalent to 3.268kg per capita annually. There is an expectancy to feed 9 billion people for the year 2050 [1], urging the science for an accurate worldwide assessment and management [6,41,46]. In the likely case that these stocks could be exploited at their optimum yield, a further increase of their age of first catch would be required. This would allow further increase in their fishing intensities. The target would be set at the F=0.9 level, and a significant potential increase of yield, would allow increasing overall fish yields of these ten stocks, from 22.9 Mt to 89.9Mt. This means a net increase of 67Mt, equivalent to an increase to 12.5kg per capita per year, this is, almost four times the biomass provided by current yields Figure S-1. Unfortunately, most of this biomass is reduced into fishmeal, but results imply an optimistic perspective addressed to reduce famine of this hunger world, contributing to avert a worldwide fisheries disaster [5,39,40,45,47-51].

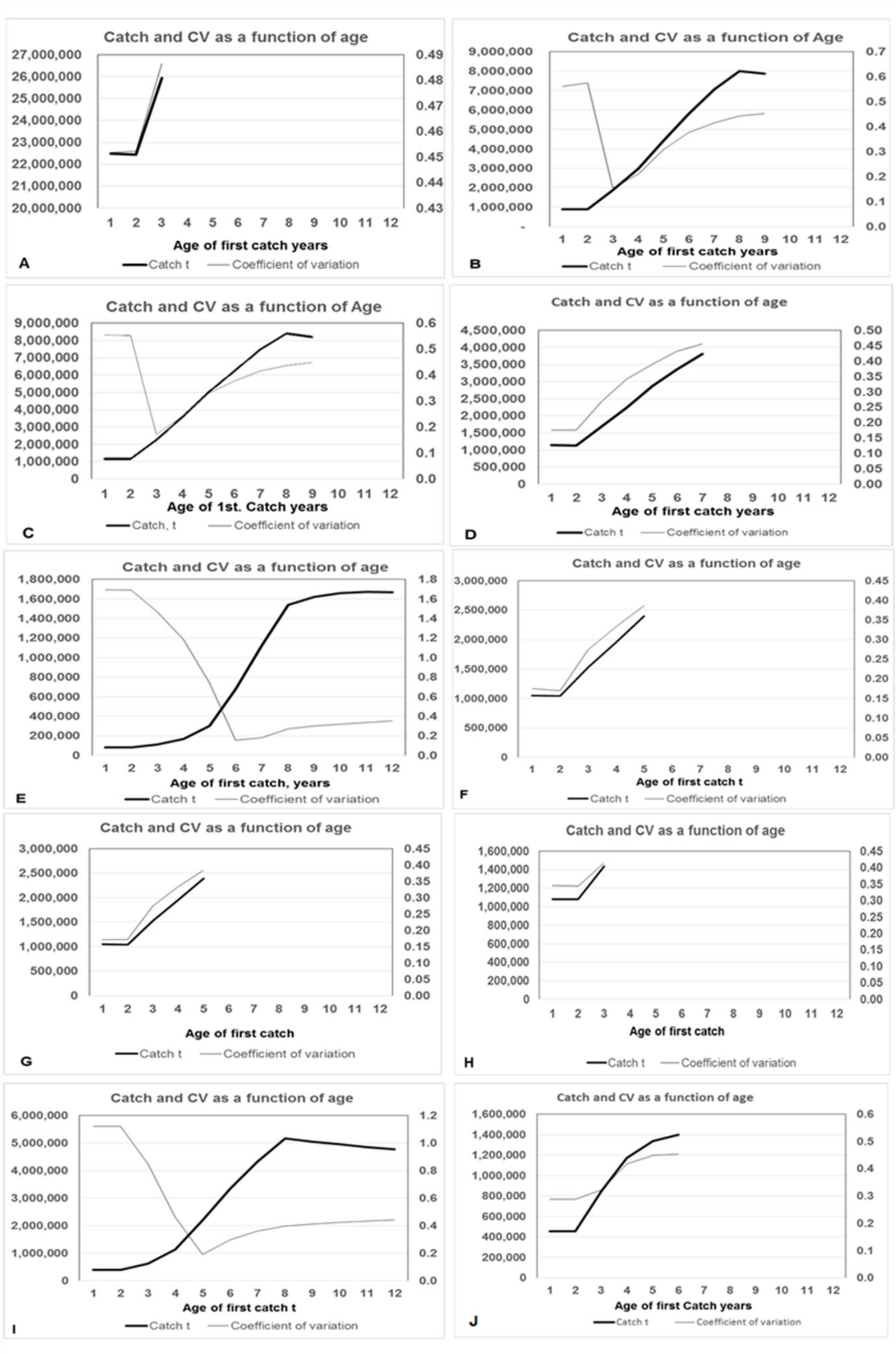


Figure S-1: Simulated potential catch (t) left side scale, and Coefficient of variation right side scale, as a function of the age of first catch in the ten main exploited stocks of world fisheries. A. Alaska pollock; B. Peruvian anchovy; C. Atlantic cod; D. Atlantic herring; E. Skipjack tuna, F. California pilchard; G. Chilean jack mackerel, H. Chub mackerel; I. European pilchard; J. Gulf menhaden.

Conclusion

a. The initial assumption that main world fisheries are exploited to their maximum capacity or are even overexploited, is confirmed.

b. It was detected that the main cause of depletion is overexploitation of juveniles. The exception may be the Peruvian anchovy, whose biomass is strongly dependent on climate variability.

c. However, results suggest that the main fish stocks still could withstand further catch increase by increasing their age at first catch and then the stock would support higher fishing pressure. Then, their potential contribution to the overall yield may imply a significant increase, from 22.9Mt to 89.9Mt, producing almost four times more biomass than current yields.

Supplementary Material

A macro was developed in the model that allows simulation of the catch and other variables, as function of the F and tc. By using this macro, it was possible to simulate the stock response as a function of these two variables. The simulation of all the harvesting scenarios tested was made after thirty years of simulating the stock performance, with the deliberate purpose of testing the model stability. Then with the application of the F or tc values of the last year catch, the model produced an output that allowed to provide consistent data useful for the purpose of decision making. To explore some statistical attributes supporting the fitting process in the simulation (Figure S1A-J), the performance of the catch as a function of tc and the Coefficient of variation (CV) also depending on the age of first catch, were examined and are displayed in Figure S1A-J. In these figures, the catch of each stock is displayed with a thicker line and the CV with a thinner line; the length of each line depends on the longevity of each stock, such that in short-lived species like the Peruvian anchovy and the skipjack tuna, only three age classes could be displayed. In others, like the Chilean jack mackerel and the European pilchard (Figure S1,E,I), their life spans are long enough that these two variables could be displayed on the whole scale of age. In the remaining stocks, with life spans longer than three years, the lines occupy longer lines than in the case of the last two stocks just mentioned.

By looking at the catch as a function of age, the trend in most cases is S shaped, with low values at low ages of first catch, then because of higher biomass is accumulated in the population, the lines show an increase that reaches a high level usually maintained at older ages. Only in the case of the Atlantic herring, Alaska Pollock, and the European pilchard (Figure S1,C,I), the biomass declines after the eighth year. The CV of catch, displayed as thin lines in Figure A1 A-J, was estimated for each age, starting from the smallest tc value until the last group of ages, or until the twelfth year in stocks with more longevity. Here, it was remarkable to see that in four stocks, the CV describes a V shaped line, where the minimum value lays at low ages, increasing on both sides of the age scale. In six stocks, the CV displays a low value and do not show a minimum. In most stocks, excepting two, the right side of the line displays an abrupt increase.

References

1. Béné C, Barange M, Subasinghe R, Pinstrup-Andersen P, Merino G, et al. (2015) Feeding 9 billion by 2050 – Putting fish back on the menu. Food Sec 7: 261-274.
2. Sharpless A, Evans S (2013) Feeding the world. The perfect protein: The fish lover's guide to saving the oceans and feeding the world. Editorial Rodale Books.
3. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515(7528): 518-522.
4. Hilborn R, Fulton EA, Green BS, Hartmann K, Tracey SR, et al. (2015) When a fishery is sustainable? Canadian Journal of Fisheries and Aquatic Sciences 72(9):
5. Carlsen L, Bruggemann R (2021) The 17 United Nations' sustainable development goals: A status by 2020. International Journal of Sustainable Development & World Ecology 29(3): 1-11.
6. Glaviano F, Esposito R, Cosmo AD, Esposito F, Gerevini L, et al. (2022) Management and sustainable exploitation of marine environments through smart monitoring and automation. Journal of Marine Science and Engineering 10(2): 297.
7. Grafton RQ, Kompas T, Hilborn RW (2007) Economics of overexploitation revisited. Science 318(5856): 1601.
8. Myers RA, Mertz G (1998) The limits of exploitation: A precautionary approach. Ecol App 8(1) 165-169.
9. Hilborn R (2007) Reinterpreting the state of fisheries and their management. Ecosystems 10: 1362-1369.
10. Chávez EA (2005) FISMO: A generalized fisheries simulation model. In: Kruse GH, VF Gallucci, DE Hay et al. (Eds.) Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program, University of Alaska Fairbanks, USA, pp: 659-681.
11. Chávez-Ortiz EA (2014) A numerical model for sustainable fisheries management. CICIMAR Oceánides 29(2): 45-56.
12. Beverton RJH, Holt SJ (1957) On the dynamics of exploited fish populations. Fish Invest Series, UK Ministry of Agriculture, Fisheries, and Food, UK, 2: 19.
13. FAO Fisheries and Aquaculture (2023) Statistics.
14. Froese R, Dirk Zeller, Kristin Kleisner, Daniel Pauly (2012) What catch can tell us about the status of global fisheries. Marine Biology 159: 1283-1292.
15. Maunder M (2008) Maximum sustainable yield. In: Jørgensen, Fath (Ed.), Encyclopedia of Ecology. Academic Press, USA.
16. Web Magazine Baltic Eye (2019) Stockholm University Baltic Sea Centre, Fisheries, Sweden.
17. Chávez EA (2020) Maximum sustainable yield, maximum economic yield and and sustainability in fisheries. J Aquac Mar Biol 9(1):15-17.
18. Gascuel D (2024) Chapter 4 - The long battle for fisheries management. In: Gascuel D (Ed.), Revolution in the seas. Academic Press. pp. 109-145.
19. Gillis DM, Koscielny J, Blanz B (2024) Maximum sustainable yield as a reference point in the presence of fishing effort that follows an ideal free distribution. Natural Resource Modeling 37(1): e12390.
20. Pauly D, Froese R (2021) MSY needs no epitaph—but it was abused. ICES Journal of Marine Science 78(6): 2204-2210.
21. FAO (1995) Precautionary approach to fisheries. (A scientific meeting organized by the Government of Sweden in cooperation with FAO). FAO Fisheries Technical Paper. No. 350, Part 1,2, Italy, pp. 52.
22. Chávez EA, A Chávez-Hidalgo (2013) Biomass from the Sea. In: Matovic MD (Ed.), Biomass now-sustainable growth and use. Biomass Chapter 21, Intechopen, pp: 511-522.
23. Chávez EA (2016) Effect of climate variability on fish stocks of the Northern Gulf of Mexico. Proceedings 68th Gulf Caribbean Fisheries Institute, pp. 456-466.
24. Froese R (2004) Keep it simple: Three indicators to deal with overfishing. Fish and Fisheries 5(1): 86-91.

25. Froese R, Henning Winker, Didier Gascuel, Sumaila UR, Daniel Pauly (2016) Minimizing the impact of fishing. Fish and Fisheries 17(3): 785-802.

26. Bakun A (1997) Review of the state of world fishery resources: Marine fisheries. 13. Northeast Pacific, FAO Fisheries. Circular 920: 1-173.

27. Gutiérrez M, Castillo R, Segura M, Peraltilla S, Flores M, et al. (2012) Trends in spatio-temporal distribution of Peruvian anchovy and other small pelagic fish biomass from 1966-2009. Latin American Journal of Aquatic Research 40: 633-648.

28. Csirke J (1997) Review of the state of world fishery resources: Marine fisheries. 15. Southeast Pacific. FAO Statistical Area 87, FAO Fisheries Circular 920 firm/c920, Italy.

29. Shotton R (1997) Review of the state of world fishery resources: Marine fisheries. 15. Southeast B. Regional reviews 1. Northwest Atlantic FAO statistical area 21, FAO Fisheries Circular, 920 firm/c920.

30. Pauly D, Christensen V, Guénette S, Pitcher TJ, Sumaila UR, et al. (2002) Towards sustainability in world fisheries. Nature 418(6898): 689-695.

31. Chagaris DD, Mahmoudi B, Muller-Karger F, Cooper W, Fischer K (2015) Temporal and spatial availability of Atlantic thread herring, *Opisthonema oglinum*, in relation to oceanographic drivers and fishery landings on the Florida Panhandle. Fisheries Oceanography 24(257): 257-273.

32. Dragon AC, Senina I, Hintzen NT, Lehodey P (2018) Modelling South Pacific jack mackerel spatial population dynamics and fisheries. Fisheries Oceanography 27(2): 97- 113.

33. Arcos DF, Cubillos LA, Núñez SP (2001) The jack mackerel fishery and El Niño 1997-98 effects off Chile. Progress in Oceanography 49(1-4): 597-617.

34. Chesney EJ, Baltz DM (2001) The effects of hypoxia on the northern Gulf of Mexico coastal ecosystem: A fisheries perspective. Chapter 17, Coastal and Estuarine Studies, The American Geophysical Union, 58.

35. Smith JW (2000) Distribution of catch in the Gulf Menhaden, Brevoortia patronus, purse seine fishery in the north Gulf of Mexico from logbook information: Are there relationships to the hypoxic zone? Coastal Hypoxia: Consequences for Living Resources and Ecosystems, Coastal and Estuarine Studies. American Geophysical Union, pp. 311-320.

36. Vaughan DS, Shertzer KW, Smith JW (2007) Gulf menhaden (*Brevoortia patronus*) in the US Gulf of Mexico: Fishery characteristics and biological reference points for management. Fisheries Research 83(2007): 263-275.

37. Froese R, Pauly D (Ed.), (2024) Fish Base.

38. Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F (1998) Fishing down marine food webs. Science 279(5352): 860-863.

39. Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. Nature 423: 280-283.

40. Pauly D, Reg Watson, Jackie Alder (2005) Global trends in world fisheries: Impacts on marine ecosystems and food security. Philosophical Transactions of the Royal Society, London, Buletin of the Biological Sciences 360(1453): 5-12.

41. Zhang S, Butt MJ (2023) Marine Scientific Research, New Marine Technologies and the Law of the Sea. In: Keyuan Zou, Anastasia Telesetsky (Eds.), The International Journal of Marine and Coastal Law 38(4): 839-842.

42. Ricouard A, Sigrid Lehuta, Stéphanie Mahévas (2023) Are maximum yields sustainable? Effect of intra-annual time scales on MSY, stability and resilience. Ecological Modeling 479(2023): 110321.

43. Pauly D, Christensen V (1995) Primary production required to sustain global fisheries. Nature 374: 255-257.

44. Chávez EA, Chávez-Hidalgo A (2013) Fisheries production of the Gulf of Mexico. Proceedings 65th Gulf Caribbean Fisheries Institute 2012: 87-94.

45. Worm B (2016) Averting a global fisheries disaster. PNAS 113(18): 4895-4897.

46. Hirokawa T, Thompson BS (2023) The influence of new sustainable fisheries policies on seafood company practices and consumer awareness in Japan. Marine Policy 157.

47. Jackson JBC, Kirby MX, Berger WH, Bjorndal KA, Botsford LW, et al. (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530): 629-637.

48. Baisre JA (2000) Chronicle of Cuban marine fisheries (1935-1995). Trend analysis and fisheries Potential. FAO Fisheries Technical Paper 394: 1-26.

49. Courtney M, Courtney J (2013) NOAA administration publishes misleading information on Gulf of Mexico “Dead Zone”.

50. Darnell RM (1967) Organic distribution relation to the estuarine ecosystem. In: Lauff GH (Ed.), Estuaries. AAAS 83: 376.

51. Olsen Z, Richard Fulford, Kevin Dillon, William Graham (2014) Trophic role of gulf menhaden Brevoortia patronus examined with carbon and nitrogen stable isotope analysis. Marine Ecology Progress Series 497: 215-227.