6.D(2)
153rd SSC

EMBARGOED UNTIL 2:00 PM ET THURSDAY 22 AUGUST 2024

INSIGHTS

PERSPECTIVES

FISHERIES

Taking stock of global fisheries

Current stock assessment models overestimate productivity and recovery trajectory

By **Rainer Froese**[1] and **Daniel Pauly**[2]

Marine fish populations or "stocks" are subject to fishing pressure along the world's coastlines by local fishers and further offshore by industrial fleets, whose huge capacity is capable of decimating the fish that they target. Fishing operations are therefore typically constrained by catch limits derived from stock assessments—i.e., reports on the condition of a fish stock and its estimated future abundance. Theoretically, catch limits should ensure sustainability by not exceeding the productive ability of fish populations and by allowing depleted stocks to rebuild. In reality, the fraction of overfished stocks continues to increase, and reported global catches stagnate despite increasing fishing effort, implying that fish abundance is declining (*1*). On page 860 of this issue, Edgar *et al.* (*2*) report a likely explanation for the apparent inability of standard stock assessment models to provide sound catch limits. Their findings underscore the importance of accurate stock estimates for sustainable fisheries management.

For 230 fish stocks, including most of the world's largest fisheries, Edgar *et al.* compared stock sizes reported by scientists to fisheries managers at the time of historical stock assessments ("last biomass") with updated estimates modeled for the same year in the most recent stock assessments. These latter estimates should be the most accurate because they are based on the longest time series of data. The authors found that hindsight historical last biomass estimates were more or less accurate for sustainably fished stocks. For stocks that were overfished, however, historical biomass estimates were substantially overestimated compared with more recent assessments. Moreover, rising

[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, 24148 Kiel, Germany. [2]Sea Around Us, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada. Email: rfroese@geomar.de; d.pauly@oceans.ubc.ca

Fishing boats set off to the East China Sea after a 3-month fishing moratorium. Overfished stocks are on the rise globally, suggesting that management advice is not sufficiently conservative.

trends in biomass reported for overfished stocks were often inaccurate, resulting in so-called phantom recoveries for stocks where actual biomass was fluctuating at a low amount or even declining. In other words, overfished stocks that were in urgent need of catch reduction and rebuilding were instead displayed by models as increasing in biomass. These phantom recoveries progressed across assessments as updated stock assessments became available. On the basis of these data, fishery managers could reasonably conclude, albeit incorrectly, that the stock was recovering and able to support even higher catch levels.

Edgar *et al.* further examined the consequences of their findings for global assessments of fishery sustainability. For each stock, they estimated the likely error in each most recent assessment to determine the proportion of overfished versus sustainable stocks globally. Their results indicate that 29% of the stocks classified by the Food and Agriculture Organization of the United Nations as "maximally sustainably fished" instead cross the threshold for categorization as "overfished" (*1*). Within the overfished category, the authors estimate that the number of collapsed stocks (those that are smaller than 10% of previous maximum biomass) is likely 85% larger than currently recognized. Successive phantom recoveries may have also misled a number of other prominent studies (*3*) proposing improving fish stock status globally.

Given the importance of fish as food and livelihood for a growing human population, as well as the importance of functioning marine ecosystems for carbon capture in the face of climate change, the apparent global failure of applied fisheries science to correctly advise managers is troubling. Where does the observed bias in stock assessments come from? Given its persistence over decades and ongoing presence (*2*), why was it not detected earlier? In cases where the strong bias in most recent biomass estimates was known (*4*), why was that knowledge not used to correct the last biomass estimates downward or at least to drastically increase their range of uncertainty?

State-of-the-art stock assessments use complex models that can include more than 40 different parameters related to fish life history, catch details, fishing effort, and management controls (*5*). These multiple variables make stock assessments unnecessarily complex, with outputs that are essentially irreproducible except by a few experts with access to the original model, data, and settings (*6*). Moreover, several of the required input parameters are typically unknown or difficult to estimate and are instead set by modelers to arbitrary values that have worked in the past. Such practices may strongly restrict results to modelers' expectations (*2*, *7*, *8*).

But the main reason for the overestimation of recent biomass is the tendency of standard models to overestimate productivity at depleted stock levels. That tendency is apparent at the low range of biomass (typically between 20 and 40% of maximum biomass) predicted as sufficient to support maximum sustainable catches (*9*). This prediction was recently tested by comparing the modeled biomass required to support a certain catch with observed records of catch and biomass for nearly 100 global stocks (*10*). Although the predictions of a simple, two-parameter model (*10*, *11*) correctly traced the highest density of observed data points, a widely used multiparameter model (*5*) failed to trace the highest density of points overall and especially at depleted stock sizes. In other words, either by design or by the chosen settings, the sophisticated multiequation model fared worse compared with the simple model based only on the S-shaped curve of population increase.

The findings of Edgar *et al.* underscore how systematic bias in stock estimates can lead to management advice that is not sufficiently conservative to sustain productive fish populations. Efforts on several fronts are needed to improve the accuracy of stock assessment models that serve as the backbone of effective fisheries management. Critically, national and regional agencies responsible for performing fish stock assessments must remove any observed bias in their recent biomass estimations in depleted stocks. Returning to simpler and ultimately more realistic assessment models rooted in ecology may also be prudent (*9*). Proper use of the precautionary principle is additionally advised: In the face of strong doubt about model outcomes, the lower confidence limit is used rather than the mean or the median. As well, managers need to be aware of the difficulties and limits of predicting the status of an invisible resource and should apply their own common sense when repeatedly confronted with phantom recoveries of a depleted resource.

The principles of ecosystem-based sustainable fishing are straightforward and not difficult: take out less than is regrown; let fish grow and reproduce before capture; use fishing gears with low impact on the environment and on other species; provide refuge or no-take areas as reservoirs of genetic diversity; and maintain functional food webs by reduced fishing of forage species, such as anchovies, sardines, herring, or krill (*12*–*14*). Four of these five principles can be applied without knowledge of last biomass. ■

REFERENCES AND NOTES

1. FAO, *The State of World Fisheries and Aquaculture 2024 – Blue Transformation in Action* (FAO, 2024).
2. G. J. Edgar *et al.*, *Science* **385**, 860 (2024).
3. R. Hilborn *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **117**, 2218 (2020).
4. ICES, Sole (*Solea solea*) in Subarea 4 (North Sea), ICES Advice: Recurrent Advice, Report (2021); https://doi.org/10.17895/ices.advice.7859.
5. R. D. Methot Jr., C. R. Wetzel, *Fish. Res.* **142**, 86 (2013).
6. E. Thompson, *Escape from Model Land: How Mathematical Models Can Lead Us Astray and What We Can Do About It* (Basic Books, 2022).
7. M. Mangel *et al.*, *Can. J. Fish. Aquat. Sci.* **70**, 930 (2013).
8. E. A. Fulton, *Fish Fish.* **22**, 428 (2021).
9. D. Pauly, R. Froese, *ICES J. Mar. Sci.* **78**, 2204 (2021).
10. R. Froese *et al.*, *Acta Ichthyol. Piscat.* **53**, 173 (2023).
11. M. B. Schaefer, *Inter-Am. Trop. Tuna Comm. Bull.* **1**, 23 (1954).
12. R. Froese, H. Winker, D. Gascuel, U. R. Sumaila, D. Pauly, *Fish Fish.* **17**, 785 (2016).
13. G. J. Edgar, T. J. Ward, R. D. Stuart-Smith, *Aquat. Conserv.* **28**, 1337 (2018).
14. E. K. Pikitch *et al.*, *Science* **305**, 346 (2004).

10.1126/science.adr5487