

Is the ocean food provision index biased?

ARISING FROM B. S. Halpern *et al.* *Nature* **488**, 615–620 (2012)

How close to maximum sustainable food provision is current seafood harvest from the world’s oceans? Halpern *et al.*¹ suggest that the answer is 25% from a global index of food provision, part of their multifaceted index of ocean health. Rigorous methods used for management, however, demonstrate that their food provision index is uncorrelated with actual food provision, and that global ocean food provision is in the range of 71–95%. Their results stem from an uncertain method of estimating maximum sustainable yield (MSY), and we believe that this approach should be avoided as a measure of food provision. There is a Reply to this Brief Communication Arising by Halpern, B. S. *et al.* *Nature* **495**, <http://dx.doi.org/10.1038/nature11975> (2013).

The first indication that the Halpern *et al.*¹ food provision index may be unreliable comes from examining the scores of individual countries whose fisheries performance is well understood. It is widely acknowledged that fisheries in New Zealand and the USA are well managed^{2,3} whereas those in Europe are not^{3,4}. However, New Zealand has an index value of 16% and the USA 25%, whereas Europe includes four of the six highest values, topped by France (87%) and Spain (60%).

We tested the reliability of their index in a number of ways. Crudely, their index should be about the same as dividing global catches by global MSY. Recent estimates of global MSY are 83–99 million t (ref. 5), 89.5–100.9 million t (ref. 6) and 85–110 million t (ref. 7), which are similar to older estimates that are often rounded to 100 million t (refs 8, 9). Dividing current catch of 78.6 million t (ref. 10) by MSY yields estimates for current food provision of 71–95%.

The underlying basis for the Halpern *et al.*¹ food provision index (setting aside modifications for trends, pressures and taxonomic

groupings) involves comparing current catches to estimated multi-species MSY as estimated from a regression of MSY against maximum catch (see Fig. 1 for details). This regression is highly uncertain: the ratio of their predicted MSY to actual MSY spans a 50-fold range (95% CI, 0.10–5.02). This is why MSY is normally estimated from biomass data using stock assessments. Stock assessment estimates can be used to ground-truth the Halpern *et al.* catch-based estimates of MSY. For example, when their method is applied to all assessed tuna and billfish fisheries, their predicted MSY is lower than assessment MSY values for the 29 (out of 36) largest fisheries, and summed predicted MSY is only 41% of summed biomass-estimated MSY. When these estimates are fed into their rule for calculating food provision (which is zero when catches exceed $1.5 \times$ MSY), their food provision index for tuna and billfish species is 0%. By contrast, the MSY estimates from the assessments used to manage these tuna and billfish species result in an estimate of food provision of 94% (summed catches divided by summed MSY).

For a more rigorous examination, we compared sustainable yield at a given biomass level to MSY, both from a Pella–Tomlinson model (Methods). We applied this model to a compilation of 234 fisheries stock assessments^{11,12} for which we have reliable estimates of catch, biomass and MSY. For these well-studied fisheries, covering 20–25% of global catch, food provision is 86% (median), or 75% (weighted by maximum catch). Notably, food provision estimates from these fisheries are uncorrelated with the Halpern *et al.*¹ estimates (Fig. 2,

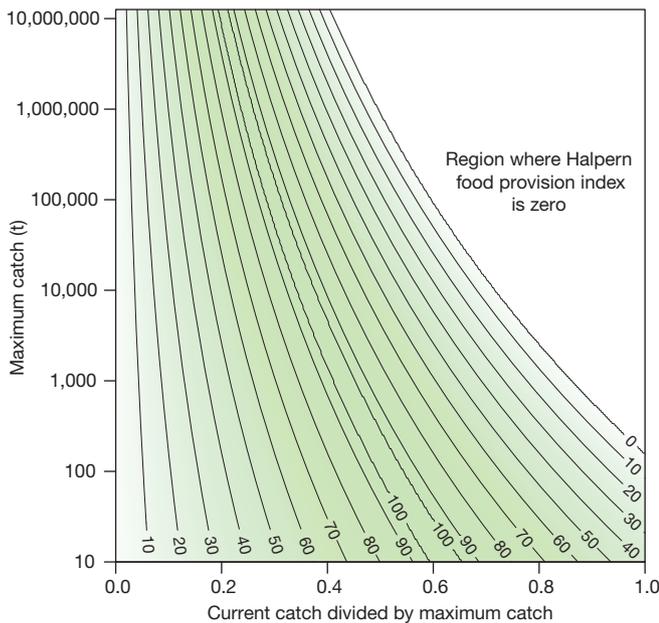


Figure 1 | Contours of the Halpern *et al.*¹ food provision index (0–100%) in relation to current catch and maximum catch (C_{max}). The Halpern index is 100% when catch is between 71% and 79% of assumed MSY, and 0% when catch is either zero or greater than 150% of assumed MSY. MSY is assumed to equal $C_{max}^{0.92}$, based on a highly uncertain relation between MSY and C_{max} . For large fisheries, the food provision index is zero whenever current catches are more than 50% of maximum catches.

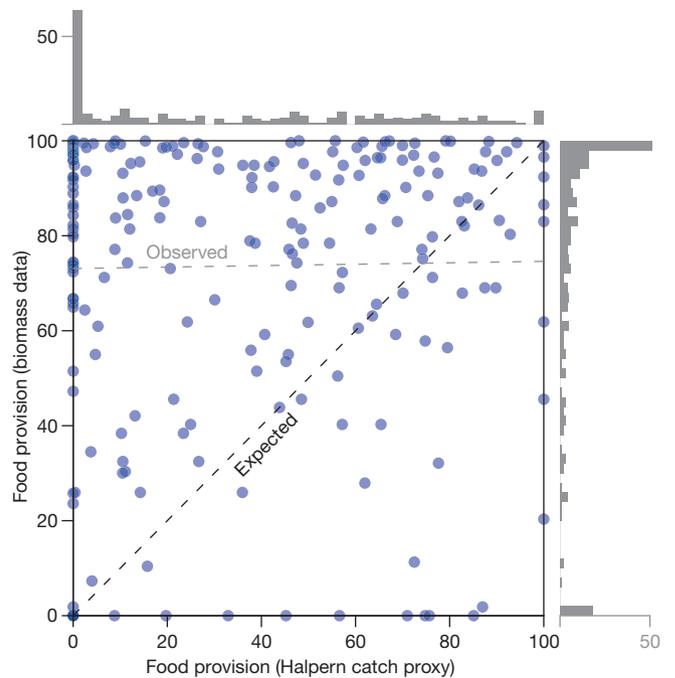


Figure 2 | Food provision indices (percentages) estimated using the Halpern *et al.*¹ proxy, compared to food provision based on biomass data for 234 fisheries comprising 20–25% of global catch (circles, see Methods for details). The two indices should be tightly correlated and fall on the 1:1 ‘expected’ line, but are uncorrelated (‘observed’ line, $y = 0.015x + 73.1$, $R^2 = 0.0003$). Grey histograms indicate the total number of fisheries at each value for the food provision values, with a peak at 0% for the Halpern *et al.*¹ proxy and at 100% for the index based on biomass data.

BRIEF COMMUNICATIONS ARISING

$R^2 = 0.0003$). Furthermore, for fisheries with a food provision index of 0% from Halpern *et al.*¹, actual food provision averages 73%. As the Halpern food provision index is uncorrelated with food provision estimates based on well-studied fisheries in many regions of the world¹¹, we see little value in applying it to data-poor fisheries on a country-by-country basis.

The same rigorous method can be applied to Food and Agriculture Organization of the United Nations (FAO) status reports¹⁰, which covered 70% of global catches in 2009. Re-sampling fisheries from FAO ranges for overexploited fisheries, fully exploited fisheries and underexploited fisheries³ and estimating food provision using the Pella–Tomlinson model yields a mean food provision index of 82% (95% CI, 81–84%).

Thus, food provision from oceanic fisheries is consistently estimated to be in the range of 71–95% by a wide variety of methods, which is far from the 25% estimated by Halpern *et al.*¹. In conclusion, Halpern *et al.*¹ believe that it must be possible to extract MSY and food provision estimates from a simple function of current catch and maximum catch. Such approaches in other guises are similarly flawed^{12–15}.

Methods

Sustainable yield from fisheries as a function of population size can be represented by a Pella–Tomlinson curve¹⁶. From this curve, food provision is the ratio of sustainable yield to MSY, and can be written as a function of current biomass (B) relative to biomass producing MSY (B_{MSY}) plus a parameter (z) that governs the shape of the curve:

food provision =

$$100 \times \max \left\{ 0, \frac{z^{z/(z-1)}}{z-1} \left(\left(\frac{1}{z} \right)^{1/(z-1)} \frac{B}{B_{\text{MSY}}} - \left[\left(\frac{1}{z} \right)^{1/(z-1)} \frac{B}{B_{\text{MSY}}} \right]^z \right) \right\}$$

Setting $z = 1.188$ ensures that B_{MSY} occurs at 40% of unexploited biomass, which is the mean from 147 fisheries¹⁶. This food provision index is 0% when biomass is zero or greater than $2.5 \times B_{\text{MSY}}$, and 100% when biomass equals B_{MSY} .

This project was partly funded by Cooperative Agreement NA09OAR4320075 between the Joint Institute for Marine and Atmospheric Research (JIMAR) and the National Oceanic and Atmospheric Administration (NOAA). The views expressed herein are those of the authors and do not necessarily reflect the views of the NOAA or any of its subdivisions.

Trevor A. Branch¹, Daniel J. Hively¹ & Ray Hilborn¹

¹School of Aquatic & Fishery Sciences, Box 355020, University of Washington, Seattle, Washington 98195, USA.
email: tbranch@uw.edu

Received 31 October 2012; accepted 28 January 2013.

1. Halpern, B. S. *et al.* An index to assess the health and benefits of the global ocean. *Nature* **488**, 615–620 (2012).
2. Pauly, D. *Focusing One's Microscope: Daniel Pauly on the State of Global Fisheries* <http://blog.nature.org/2011/01/daniel-pauly-fish-stock-global-world-fisheries/> (2011).
3. Worm, B. *et al.* Rebuilding global fisheries. *Science* **325**, 578–585 (2009).
4. Froese, R. & Proelß, A. Rebuilding fish stocks no later than 2015: will Europe meet the deadline? *Fish Fish.* **11**, 194–202 (2010).
5. Sumaila, U. R. *et al.* Benefits of rebuilding global marine fisheries outweigh costs. *PLoS ONE* **7**, e40542 (2012).
6. Arnason, R., Kelleher, K. & Willmann, R. *The Sunken Billions. The Economic Justification for Fisheries Reform.* (World Bank and FAO, 2008).
7. Costello, C. *et al.* Status and solutions for the world's unassessed fisheries. *Science* **338**, 517–520 (2012).
8. Ryther, J. Photosynthesis and fish production in the sea. *Science* **166**, 72–76 (1969).
9. Pauly, D. One hundred million tonnes of fish, and fisheries research. *Fish. Res.* **25**, 25–38 (1996).
10. FAO. *The State of World Fisheries and Aquaculture 2012* (Food and Agriculture Organization of the United Nations, 2012).
11. Ricard, D., Minto, C., Baum, J. K. & Jensen, O. P. Examining the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. *Fish Fish.* **13**, 380–398 (2012).
12. Branch, T. A., Jensen, O. P., Ricard, D., Ye, Y. & Hilborn, R. Contrasting global trends in marine fishery status obtained from catches and from stock assessments. *Conserv. Biol.* **25**, 777–786 (2011).
13. Daan, N., Gislason, H., Pope, J. G. & Rice, J. C. Apocalypse in world fisheries? The reports of their death are greatly exaggerated. *ICES J. Mar. Sci.* **68**, 1375–1378 (2011).
14. Carruthers, T. R., Walters, C. J. & McAllister, M. K. Evaluating methods that classify fisheries stock status using only fisheries catch data. *Fish. Res.* **119–120**, 66–79 (2012).
15. Hilborn, R. & Branch, T. A. Does catch reflect abundance? No, it is misleading. *Nature* **494**, 303–306 (2013).
16. Thorson, J. T., Cope, J. M., Branch, T. A. & Jensen, O. P. Spawning biomass reference points for exploited marine fishes, incorporating taxonomic and body size information. *Can. J. Fish. Aquat. Sci.* **69**, 1556–1568 (2012).

Author Contributions T.A.B. designed the study, T.A.B. and D.J.H. analysed the data, and T.A.B. and R.H. discussed the results and wrote the paper together.

Competing Financial Interests Declared none.

doi:10.1038/nature11974

BRIEF COMMUNICATIONS ARISING

Halpern *et al.* reply

REPLYING TO T. A. Branch, D. J. Hively & R. Hilborn. *Nature* 495, <http://dx.doi.org/10.1038/nature11974> (2013)

Branch *et al.*¹ suggest that the fisheries component of our ocean health and benefits index² is 'biased'. We contend that our approach is no more biased than their alternative, and that our method improves on theirs in three fundamental ways: it provides a score for every country, accounts for thousands of data-poor stocks, and incorporates sustainability more comprehensively.

Our global score is an area-weighted country average of a multi-dimensional assessment of sustainable food provision, fundamentally different from what Branch *et al.*¹ interpret it to be, which undermines comparisons to their global estimate. They incorrectly state that our index should be roughly equivalent to dividing global catch by global maximum sustainable yield (MSY), and incorrectly interpret a score of 100 in our index as $B = B_{MSY}$. They focus on single-stock biomass harvested relative to single-stock MSY, as in their Fig. 1, and assume that they know true MSY values. We used a multispecies reference point (mMSY) with a precautionary buffer that penalizes countries both above and below this value, and our focus was on fisheries within exclusive economic zone (EEZ) scales. Branch *et al.*¹ focused on a single global assessment (of current status only), leading to a relatively small number of the largest fish stocks worldwide driving their interpretation. We chose to use catch data, available for all countries and most stocks, acknowledging the associated limitations and uncertainty of those data. Although their approach may be useful for assessments of global biomass production, and we agree it is preferable to use abundance estimates and other indicators rather than catch data when possible, reliance on such data precludes country-level assessments at the global scale.

By focusing their analysis on a geographically restricted data set of exclusively large commercial species (<5% of all stocks in the world), they assume that small stocks, and the many interactions they have with large stocks, do not matter for understanding sustainability, and that the many data-poor stocks are irrelevant to understanding food provision. Data-poor stocks represent ~80% of all fisheries biomass and the vast majority of stocks in most countries. These stocks are in worse condition than assessed stocks, and getting worse³. Their selection of tuna and billfish as a counter example to our results focuses on an outlier; these large pelagic stocks are not representative of most fisheries within EEZs (that is, bottom-dwelling species or those taken in small-scale fisheries) or most unassessed stocks. Therefore, it is reasonable to assume that unassessed stocks would lower fisheries index scores, and for our comprehensive assessment to differ from the narrower one of Branch *et al.*¹

Because of these key differences, strong correlations between our methods should not necessarily be expected. In addition, assessments

made using best available data in individual countries should generate different outcomes compared with a global assessment where the focus is on using globally available and comparable data. We know that many country-specific scores will change as we improve the underlying data and our ability to predict sustainable yield of stocks around the world. Our index was explicitly designed as a framework that can ingest the best scientific information as it becomes available, whether as better data or improved approaches to measuring a goal, and in fact, we are doing just that as we apply the index at regional scales. Authors from both papers are currently collaborating with the Food and Agriculture Organization of the United Nations to examine how to improve methodologies for estimating fisheries exploitation status globally. We look forward to incorporating those results and improved data in future iterations of the index.

This Reply is written by the subset of authors that developed the fisheries component of the ocean health and benefits index² relevant to the discussion in Branch *et al.*¹.

Benjamin S. Halpern^{1,2}, Steven D. Gaines³, Kristin Kleisner⁴, Catherine Longo¹, Daniel Pauly⁴, Andrew A. Rosenberg⁵, Jameal F. Samhouri⁶ & Dirk Zeller⁴

¹National Center for Ecological Analysis and Synthesis, 735 State Street, Suite 300, Santa Barbara, California 93101, USA.

²Center for Marine Assessment and Planning, University of California, Santa Barbara, California 93106, USA.
email: halpern@nceas.ucsb.edu

³Bren School of Environmental Science and Management, University of California, Santa Barbara, California 93106, USA.

⁴Sea Around Us Project, Fisheries Centre, 2202 Main Hall, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada.

⁵Union of Concerned Scientists, 2 Brattle Square, Cambridge, Massachusetts 02138, USA.

⁶Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E, Seattle, Washington 98112-2097, USA.

1. Branch, T. A., Hively, D. J. & Hilborn, R. Is the ocean food provision index biased? *Nature* 495, <http://dx.doi.org/10.1038/nature11974> (2013).
2. Halpern, B. S. *et al.* An index to assess the health and benefits of the global ocean. *Nature* 488, 615–620 (2012).
3. Costello, C. *et al.* Status and solutions for the world's unassessed fisheries. *Science* 338, 517–520 (2012).

doi:10.1038/nature11975