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An index to assess the health and benefits of the global ocean

Benjamin S. Halpern[1,2], Catherine Longo[1], Darren Hardy[1], Karen L. McLeod[3], Jameal F. Samhouri[4], Steven K. Katona[5], Kristin Kleisner[6], Sarah E. Lester[7,8], Jennifer O'Leary[1], Marla Ranelletti[1], Andrew A. Rosenberg[5], Courtney Scarborough[1], Elizabeth R. Selig[5], Benjamin D. Best[9], Daniel R. Brumbaugh[10], F. Stuart Chapin[11], Larry B. Crowder[12], Kendra L. Daly[13], Scott C. Doney[14], Cristiane Elfes[15,16], Michael J. Fogarty[17], Steven D. Gaines[8], Kelsey I. Jacobsen[8], Leah Bunce Karrer[5], Heather 9663255Lea17h259Bun18ce2t9b0344lbb Heather Lea 1.9768102.6708576.0566Tm14Tj0 Hea988r866361.5999n18ce252r13umba17ugh9

[6]Sea Around Us Project, Fisheries Centre, University of British Columbia, Vancouver, British Colombia V6T 1Z4, Canada.[7]Marine Science Institute, University of California, Santa Barbara, California 93106, USA. [8]Bren School of Environmental Science and Management, University of California, Santa Barbara, California 93106, USA. [9]Nicholas School of the Environment, Duke University, Durham, North Carolina 27708, USA.[10] Center for Biodiversity and Conservation, American Museum of Natural History, New ork, New ork 10024, USA. [11] Institute of Arctic Biology, University of Alaska, Fairbanks, Alaska 99775, USA. [12] Center for Ocean Solutions and Hopkins Marine Station, Stanford University, Monterey, California 93940, USA.[13] College of Marine Science, University of South Florida, St Petersburg, Florida 33705, USA. [14] Department of Marine Chemistry and Geochemistry, oods Hole Oceanographic Institution, oods Hole, Massachusetts 02543, USA. [15] Department of

framework to assess ocean health and motivate better data collection to strengthen future iterations of the index.

Germany scored highly (index 5 73) because eight goals performed well (excepting •food provision• and •tourism and recreation•). Our approach to scoring ocean health departs from a purely protectionist one that would aim to maintain natural systems with minimal human impact. The index credits sustainable non-extractive and extractive use, except in places where such uses are prohibited (for example, no-take reserves), as well as preservationist goals.

Third, the index allows transparent assessment of how societal values influence perspectives on ocean health. Although we weighted goals equally to avoid presuming societal values, we recognize that people value ocean benefits differently. To evaluate potential consequences of unequal weighting, we calculated index scores for four potential weighting schemes that approximate preservationist, non-extractive use, extractive use, and strongly extractive use value sets (see Supplementary Information for further details). Resulting global index scores ranged from 56 to 67 across value sets (Fig. 4 and Supplementary Table 30; country-level average maximum difference 6 standard error (s.e.) 5 7.1 6 0.2). For a few countries, most notably Romania, Russia, French Guiana, Micronesia and Denmark, changing weights created important differences, altering index scores by up to 27 (Supplementary Table 30). Monte Carlo simulations of thousands of possible value sets produced similar results (index 5 60.1 6 0.003 (s.e.); min 5 50; max 5 70; Supplementary Fig. 5 and Supplementary Table 30). The preservationist perspective produced the highest index score, primarily because extraction-based goals generally scored low whereas non-extractive goals scored higher. Because goal weights can influence index scores, it is critical to determine societal values (weights) before index calculation. Choosing a single unequal weighting scheme for this global analysis would not have been appropriate as these weights will vary by country, region and community.

Exploring the index

Variation among country-level index and individual goal scores offers novel insights into causes and consequences of different levels of ocean health (Fig. 5). Index scores had a largely unimodal distribution, which is expected in composite indices[27]. No country scored above 86 and most scored below 70. •Natural products•, •carbon storage• and •coastal protection• drove variation among countries because of flatter distributions and greater range in values, whereas •food provision• and •tourism and recreation• most influenced overall index scores because of their consistently low values (Supplementary Table 31 and Supplementary Information). •Tourism and recreation• in particular proved difficult to model given limited data, such that scores for this goal are probably artificially low for many countries. •Biodiversity• scores may seem surprisingly high, but this result accurately reflects that relatively few known marine species risk extinction (see http://www.iucnredlist.org) and that the reference point for this goal is not pristine abundance but instead stable populations of all species (see Supplementary Information). Diving deeper into the index, current status is the main driver of individual goal scores, but with scores notably reduced by negative trends for •biodiversity• and •carbon storage• due to decreasing species status and increasing habitat loss, and by pressures greater than resilience for •tourism and recreation• and •coastal livelihoods and economies• (Fig. 6 and Supplementary Information).

Countries with identical or similar scores provide examples of how multiple paths exist for achieving any given index score. For example, the United States and United Kingdom scored 63 and 62, respectively, but6328 could significantly improve ocean health by addressing multiple goals. More effective and comprehensive protection of coastal areas and species, as is being pursued under the Convention on Biological Diversity Aichi Biodiversity Targets for 2020 (ref. 29), would directly benefit •sense of place• and •biodiversity• goals, and indirectly benefit most other goals by increasing ecological resilience and thus the likelihood of future goal delivery[30] Efforts to promote coastal livelihoods, environmentally sensitive urbanization of the coastal zone and improved sanitation infrastructure would improve •coastal livelihoods and economies•, •tourism and recreation•, and •clean water• goals. Simulating specific management scenarios could provide guidance on which actions would have the greatest impact.

Sustainability into the future

Sustainable delivery of each goal is foundational to our definition of a healthy ocean and approach to modelling the index. The status of many goals incorporates a penalty for pursuing a goal in a way that hampers its future delivery, whereas the •likely future state• augments scores for goals expected to improve in the near-term future (see Supplementary Information). About half of the goals are getting

Global-scale analyses are useful for global comparisons but tend to be locally imprecise because of inherent challenges in using available global data sets. Future finer-scale applications will allow full exploration of how to best use and refine the index. By calling attention to specific data layers (and gaps), the index can stimulate better measurements, more focused management and, hopefully, accelerate progress towards a healthier ocean.

Developing the index required many assumptions and compromises (see Supplementary Information); here we elaborate on three. First, we limited the index to ten constituent goals primarily for parsimony and ease of communication while maintaining a structure complementary to other ecosystem benefit typologies such as in the Millennium Ecosystem Assessment[18]. We recognize that this structure significantly influences our results. Second, gaps existed in many data sets that we used, requiring proxies or models to fill those gaps (see Supplementary Information). For example, international arrivals data provide a modest proxy for coastal tourism (•tourism and recreation• goal) and undervalue the goal in nations with significant domestic tourism. Likewise, no global data exist for important stressors such as illegal fishing, habitat loss rates and point-source pollution. By identifying these data gaps, the index can help motivate future data collection. In other cases, we had to forgo better quality, region-specific data to maintain global consistency. Future iterations of the index, including those at finer geographic scales, can incorporate new data as available. Better data will in turn allow for construction of improved models that show greater fidelity to each goal•s intent, but may also cause scores to chan8eevcbu(eas)1213(n8e8iu(e-1.137tind3uis)-36k9hes)1is dats(se)-es,6(ter)-315(dats)-ecd irh-2-ec2(ocean.)]TJ 0.99

$$I = \sum_{i=1}^{N} \alpha_i I_i$$

where α_i is the goal-specific weight ($\sum \alpha_i = 1$; default is $\alpha_i = 1/N$) (see Supplementary Information) and I_i is the average value of present and likely future status $I_i = (x_i + \hat{x}_{i,F})/2$, for each goal i. The present status of goal i (x_i) is its present status value (X_i) relative to a reference point ($X_{i,R}$) uniquely chosen for each goal following guiding principles (see Supplementary Information and ref. 34), and rescaled 0…100. The likely future status ($\hat{x}_{i,F}$) is a function of present status (x_i), recent (5 year) trend (T_i), pressures (p_i), and factors that promote resilience (r_i), such that

$$\hat{x}_{i,F} = (1 + \delta)^{-1}[1 + \beta T_i + (1 - \beta)(r_i - p_i)]\, x_i$$

where the discount rate $\delta = 0$ and the weighting term $\beta = 0.67$, giving trend twice the importance of the difference between resilience and pressures in determining likely future state (see Supplementary Information). We tested the sensitivity of results to assumptions about δ and β and found minimal differences for near-term timeframes (see Supplementary Information). Assessment of the likely future status captures whether the present status is likely to persist, improve or decline in the near-term future, based on current status (x_i) and trends, and is therefore an indication rather than prediction of the near-term future. Ecological pressures fall into five broad categories—pollution, habitat destruction, species introductions, fishing and climate change—and are weighted equally to social pressures (such as poverty, political instability and corruption), with resilience measures such as international treaties and ecological resilience included when they address pressures relevant to a particular goal (see Supplementary Information). The inclusion of these factors ensures that the index is responsive to changes that are reflected more slowly in the current state.

and any associated references are available in the online version of the paper.

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We measured ocean health as a function of ten widely held public goals (see Supplementary Information for further details) for what the ocean can provide have specific consequences for goals, we assessed and ranked separately each ecological stressor within these categories.

To account for the cumulative effect of stressors, we summed the weighted intensities of each stressor within a pressure category (p_k) and divided by the maximum weighted intensity that could be achieved by the worst stressor (max = 3.0) such that:

$$p_k = \frac{\sum_{i}^{M} w_i s_i}{3} \quad (8)$$

where w_i is the stressor-specific sensitivity weights (from Supplementary Table 25) and s_i is the data-derived intensity of the associated stressor (which is scaled 0…1). If $p_k > 100$, we set the value equal to 100. This formulation assumes