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

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The ocean plays a critical role in supporting human well-being, from providing food, livelihoods and recreational opportunities to regulating the global climate. Sustainable management aimed at maintaining the flow of a broad range of benefits from the ocean requires a comprehensive and quantitative method to measure and monitor the health of coupled human–ocean systems. We created an index comprising ten diverse public goals for a healthy coupled human–ocean system and calculated the index for every coastal country. Globally, the overall index score was 60 out of 100 (range 36–86), with developed countries generally performing better than developing countries, but with notable exceptions. Only 5% of countries scored higher than 70, whereas 32% scored lower than 50. The index provides a powerful tool to raise public awareness, direct resource management, improve policy and prioritize scientific research.

Human activities such as overfishing, coastal development and pollution have altered marine ecosystems and eroded their capacity to provide benefits now and in the future[1–3]. Yet people benefit directly or indirectly from these activities by extracting food, visiting coastal areas, making a living, or continuing centuries-old traditions. In a world with over seven billion people, nearly half of whom live near the coast[4], we urgently need new analytical approaches to guide how to balance multiple competing and potentially conflicting public goals[5,6] and connect human development with the ocean's capacity to sustain progress[7,8]. Assessments that neglect overall condition in favour of scrutiny of individual goals or stressors cannot adequately serve this role.

Recent initiatives, such as the US National Ocean Policy and EU (European Union) Maritime Strategy, emphasize using comprehensive ecosystem-based management to address the needs of both humans and nature[9,10]. Although such frameworks rely heavily on the concept of ocean health, few guidelines exist for how to measure it[10,11]. Indeed, even though ecosystem health is generally described as the well-being of coupled human–natural systems[12–18], most ecosystem assessments focus solely on the negative impacts of humans on nature[19]. Few synthetic measures exist to assess clearly and quantitatively the health of coupled ocean systems[20]. Without a framework to define and guide the measurement of ocean health, policy and management will resort to assessments that are less transparent, more subjective and that lack standardization across locations and through time[21,22].

Hundreds of specific indicators exist to measure various aspects of ocean condition[23]. A comprehensive index must simultaneously evaluate widely disparate metrics, allowing for an integrated assessment of changes in, for example, fish stocks, extinction risks, coastal jobs, water quality and habitat restoration. Building on and incorporating a wide range of existing indicators (see Supplementary Information for further details), we developed and implemented a systematic approach for measuring overall condition of marine ecosystems that treats nature and people as integrated parts of a healthy system. We thus provide a standardized, quantitative, transparent and scalable measure that can be used by scientists, managers, policy makers and the public to better understand, track and communicate ecosystem status and design strategic actions to improve overall ocean health. Each of ten goals (and their component parts) comprising the index (Fig. 1) can be considered separately or aggregated into an overall score for a region, country, or the entire ocean, and compared across these scales, provided that data sources are consistent. Although tracking individual components of health and benefits is useful[24,25], combining them into a synthetic measure using a concise set of indicators facilitates communication and allows direct comparison among management objectives. Here we provide a robust

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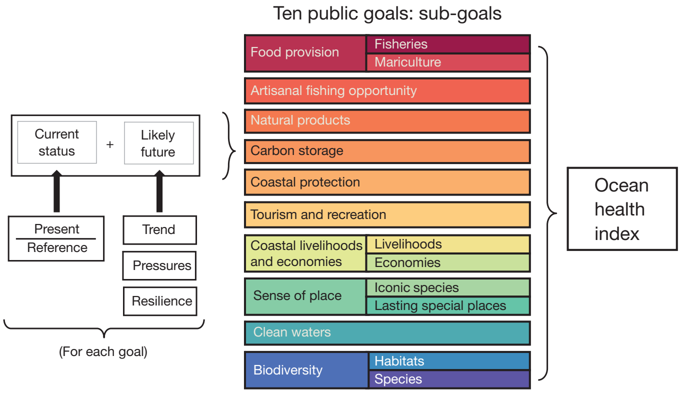

Figure 1 | Conceptual framework for calculating the index. Each dimension (status, trend, pressures and resilience) is derived from a wide range of data. Dimensions combine to indicate the current status and likely future condition for each of ten goals (see equations in Methods Summary and equations (1) and (4) in Methods). Colour scheme is also used in Figs 3–6.

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

In developing the index we addressed six major challenges (see Supplementary Information for further details): (1) identify a modest number of widely accepted goals to assess ocean health and benefits at any scale; (2) develop models that measure, with reasonable accuracy, how well each goal is achieved; (3) define robust reference points for each model; (4) incorporate sustainability into the index; (5) ensure that the index is responsive to real differences and changes in ocean health and benefits; and (6) allow flexibility to adapt to constraints (or future improvements) of data availability, quality and quantity. Although the index can be implemented at any scale, here we focus on global and exclusive economic zone (EEZ) scales.

State of the global ocean

The index score for the ocean within EEZ boundaries is 60 out of 100, providing an important benchmark and indicating substantial room for improvement throughout the index's portfolio of ten public goals (Fig. 1). Because EEZs include nearly all continental shelf area and produce the vast majority of food, natural resources, recreation, livelihoods and other benefits to humans[18], this assessment captures most of the concerns of the public, policy makers and resource managers. High seas areas may be added as data become available.

Index scores varied greatly by country, ranging from 36 to 86, with many West African, Middle Eastern and Central American countries scoring poorly, and parts of Northern Europe, Canada, Australia, Japan and various tropical island countries and uninhabited regions scoring highly (Fig. 2 and Supplementary Table 27). Of all EEZs, 32% had an index score <50 whereas only 5% had a score >70. Developed countries tended to score higher than developing countries; index scores are significantly correlated with the Human Development Index[26], an independent measure of development status ($r = 0.57$, $P < 0.0001$, $n = 141$; Supplementary Fig. 8). This is because developed countries tend to have stronger economies, better regulations and infrastructure to manage pressures, and greater capacity to pursue sustainable resource use. Yet some developed countries such as Poland and Singapore scored poorly (index score of 42 and 48, respectively), with low scores for several goals (Fig. 3), whereas developing countries like Suriname (index = 69) and Seychelles (index = 73) scored relatively well because many goals had very high scores (Supplementary Table 27). Individual goal scores varied markedly within and among countries, in turn driving index scores, as illustrated by the United States, China and Poland (Fig. 3).

Three key points affect the interpretation of index scores. First, results for individual goals may seem counterintuitive because we assessed ocean health through the lens of coupled human–natural systems. For example, extractive goals such as 'natural products' score best when harvest levels are high but sustainable, with inherent impacts on nature captured as pressures on other goals. Furthermore, a composite picture of ocean health across multiple goals may not match expectations based on the status of an individual goal. Many goals scored low globally, in particular 'food provision', 'natural products' and 'tourism and recreation' (all <50; Fig. 2 and Supplementary Table 27), whereas other goals scored higher (>75), including 'carbon storage', 'clean waters' and 'biodiversity'. Conclusions based on a single goal will deviate from those derived from the index's portfolio assessment. For example, Russia scored very low for 'food provision' and 'natural products' and very high for 'clean waters' and 'biodiversity', and had an overall index score of 67 (Fig. 3). Because detailed production function models currently do not exist for most goals, it is difficult to know if differences in goal scores are due to direct trade-offs among goals, poor management of low-scoring goals, poorer quality data for some goals, or reference points that are not directly comparable among goals. However, trade-offs probably occur among many goals, such that simultaneously achieving perfect scores on all goals would be difficult.

Second, the index represents the health of coupled human–natural systems. This portfolio includes goals that tend to be more highly valued by preservationists and non-extractive users—protecting places where biodiversity can flourish (existence value) and preserving a sense of place (cultural or aesthetic values)—and also those valued more highly by extractive users—providing food and natural resources. Jarvis Island, an uninhabited, relatively pristine location, received the highest score (index = 86) because many extraction-based goals are not applicable and the island is afforded a high level of protection, whereas

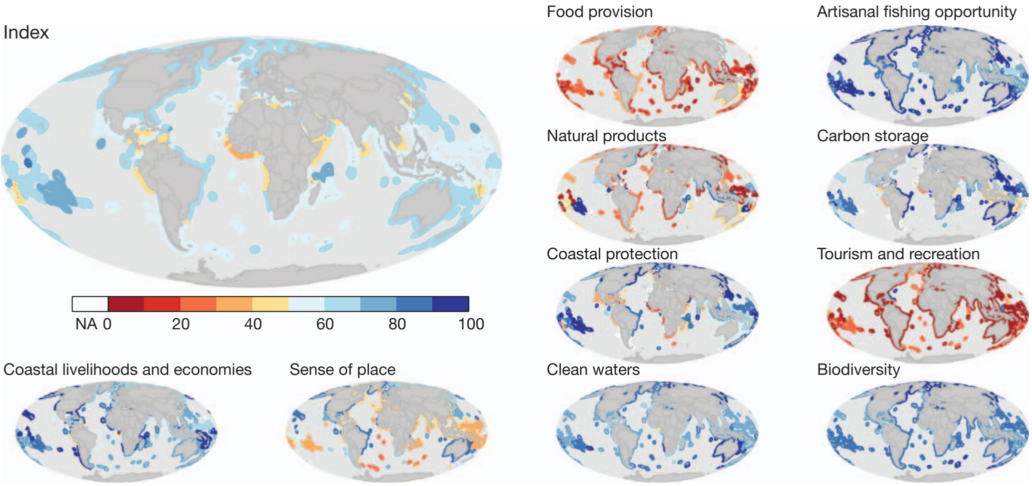

Figure 2 | Map of index and individual goal scores per country. All waters within 171 exclusive economic zones (EEZs), that is, up to 200 nautical miles, were assessed and are represented on the map. See Supplementary Table 24 for details and Supplementary Fig. 2 for sub-goal maps. NA, not available.

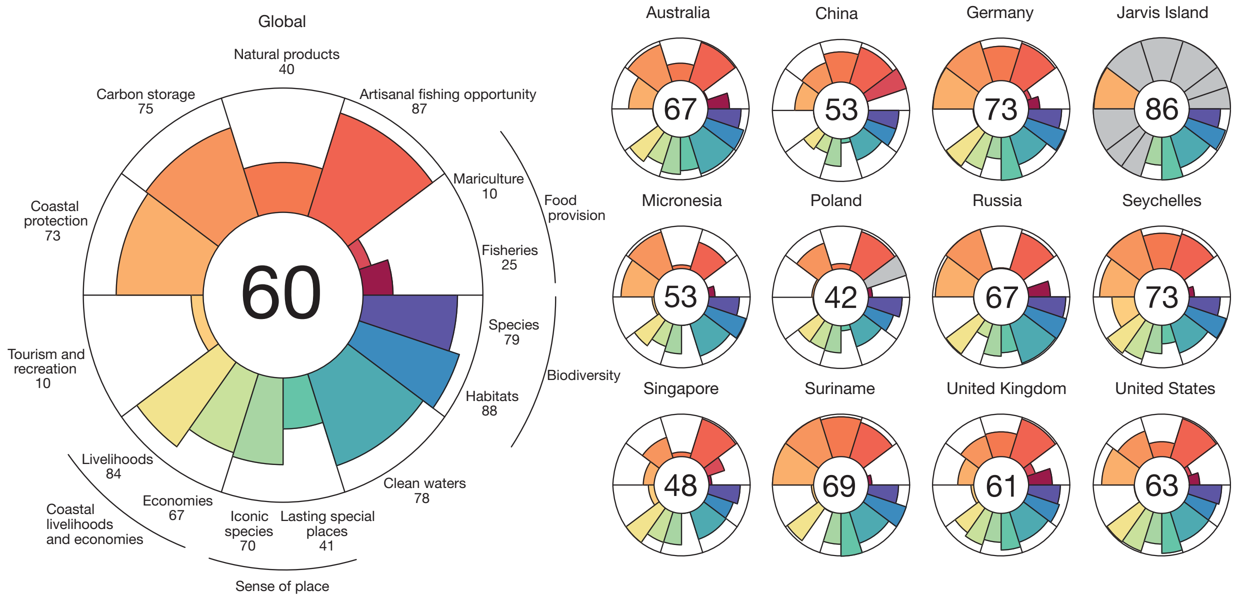

Figure 3 | Index scores (inside circle) and individual goal scores (coloured petals) for global area-weighted average of all countries and for several representative countries. The outer ring is the maximum possible score for each goal, and a goal's score and weight (relative contribution) are represented by the petal's length and width, respectively, except for 'food provision' sub-goals which are weighted by relative actual yield despite equal width of petals (see Supplementary Table 24 for per-country weights). All plots use equal weighting for all goals. Figures 3–6 use consistent goal-specific colour schemes. Grey indicates that a goal is not relevant to that reporting region.

Germany scored highly (index = 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 $\pm$ standard error (s.e.) $= 7.1 \pm 0.2$). 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 $= 60.1 \pm 0.003$ (s.e.); min = 50; max = 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, but the scores arose from very different individual goal scores. The United Kingdom scored substantially higher for 'food provision' and 'natural products' whereas the United States scored higher for 'coastal protection' and 'coastal livelihoods and economies' (Fig. 3 and Supplementary Table 27).

Comparing individual goal scores provides guidance for improving overall ocean health, both globally and nationally. Despite the successes of several developed countries in managing their fisheries[28], sustainable global food provision from wild-caught fisheries and mariculture is far below what could be delivered if wild stocks were more sustainably harvested and sustainable mariculture production was increased (country-level 'food provision' scores $= 15 \pm 1.2$ (s.e.); range = 0–72). Coastal habitat loss, which affects multiple goals ('carbon storage', 'coastal protection', and 'biodiversity'), also reduces index scores in many countries, particularly in West Africa, Central America and the Caribbean. Enhanced protection and restoration of mangroves, salt marshes, coral reefs and seagrass beds, for example,

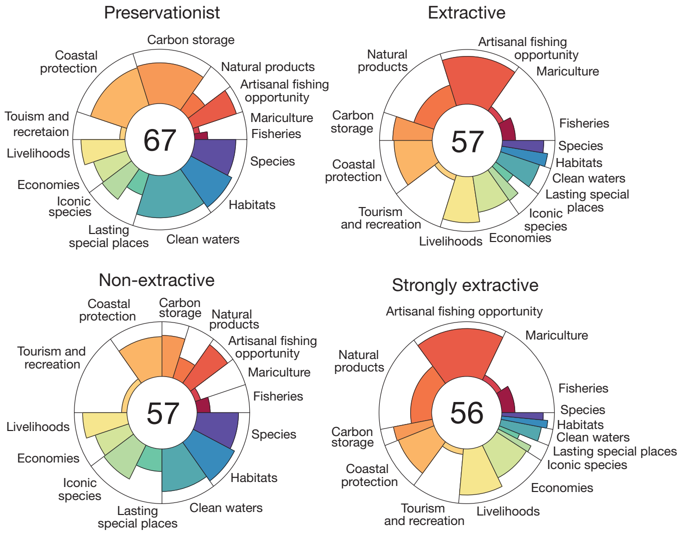

Figure 4 | Global index scores with goals weighted unequally based on four different potential value sets. Value sets are illustrative rather than prescriptive; labels for the value sets are approximations and should not be interpreted literally. See Supplementary Table 4 for weights used in each value set.

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 worse, on average, with negative trends, and pressures roughly equal to resilience (Fig. 6). This assessment could be overly optimistic if existing regulations are not being implemented effectively and existing pressures increase with time. Longer-term trends (>10 years) in goals for which sufficient data exist corroborate recent trends, showing that some sub-goals are broadly improving (for example, 'mariculture' and 'lasting special places') whereas the 'fisheries' sub-goal is declining (Supplementary Fig. 3). Neither method for capturing sustainability actually models future status of goals; such models would be complex and currently do not exist. Given sufficient data, however, both approaches provide meaningful indications of sustainability.

To measure resilience we relied on best available global measures, such as Worldwide Governance Indicators[31], that rarely incorporated information on the implementation or effectiveness of regulations, both key elements of good governance. Therefore, the index incorporates existence rather than outcome of resilience measures, and the projected future improvements are probably optimistic. Many sub-national regulations were not included in this analysis because of the need for globally consistent data. Future regional-scale assessments will incorporate more refined data on governance effectiveness.

A new frame of reference

The index produces results that may be surprising, as the approach deviates from the conventional view of humans as largely exogenous, negative drivers of change in oceans[32]. Humans undoubtedly have substantial negative impacts on the ocean, and index scores are negatively (albeit weakly) correlated with coastal human population ($r = -0.20$; $P = 0.01$; Supplementary Fig. 6) and cumulative impact scores[1] within each region ($r = -0.20$, $P = 0.009$; Supplementary Fig. 9). Yet the regional variation around these relationships shows that all possible combinations of population, impact and provision of benefits exist. Although focus on benefits to people is not new to management or science[18,33], it has yet to become the common currency of assessment.

The index draws from and builds on the ecosystem services perspective in two key ways. Most goals have direct analogues to ecosystem services, but a few do not, in particular the 'coastal livelihoods and economies' and 'artisanal fishing opportunity' goals, which are a function of multiple services and other socio-economic dynamics. Providing a consistent framework for including these highly relevant societal goals not captured by the services framework creates greater opportunity and utility for using the index in management settings. Second, the index represents an absolute measure of ocean health in that all goals are judged against reference points that describe what is possible or desirable in a particular place, whereas ecosystem service assessments typically quantify delivery of services without setting targets. We developed methods for setting reference points for each goal[34], with important implications for resulting goal scores (see Supplementary Information for further details), allowing for measurement of absolute state of ocean health and benefits.

Discussion

The index provides a robust, widely applicable tool for ongoing assessment of ocean health with respect to well-accepted societal goals and a key benchmark against which to compare future progress and inform comprehensive ocean policy. As with any indicator, the index assesses rather than models current and future conditions, and so it cannot predict the future. However, it can be used to simulate the consequences of a range of potential actions, providing a powerful tool to inform decisions about how to use or protect ocean ecosystems.

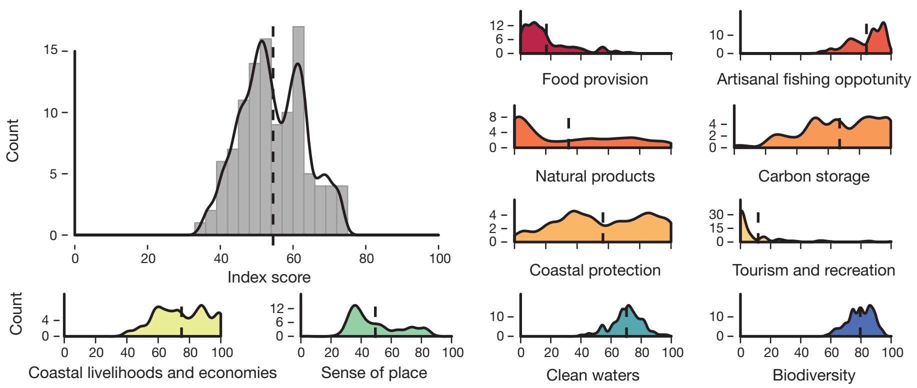

Figure 5 | Distribution of scores across countries for the index and each goal. Histogram plots are smoothed across five point bins; dashed vertical line is the arithmetic mean and so differs from the area-weighted mean in other figures. Note different scales on *y* axes.

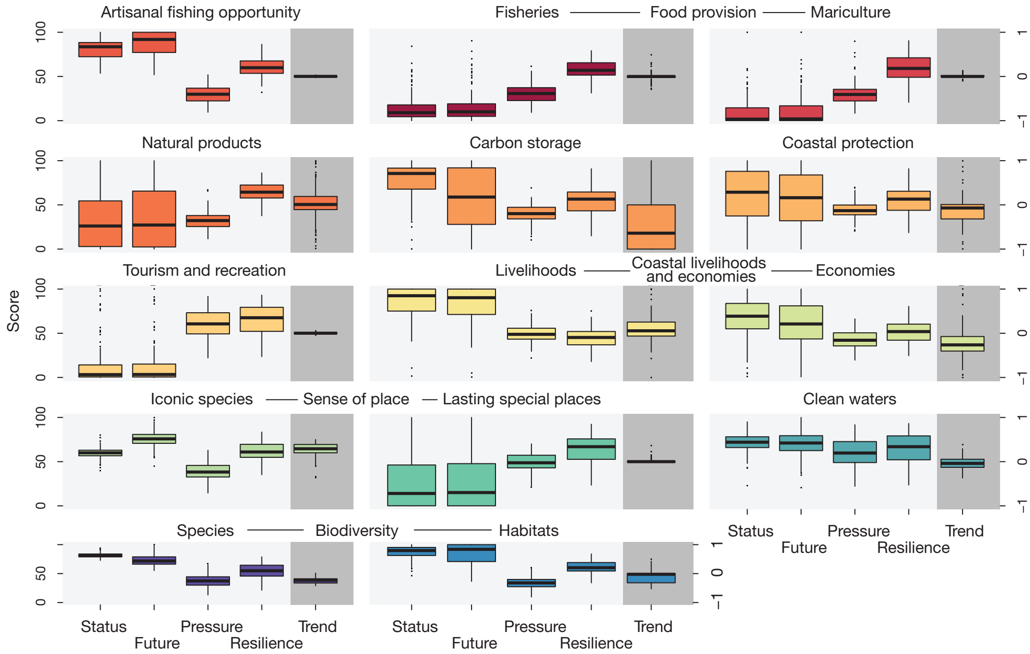

Figure 6 | Box and whisker plots for status, likely future state, pressures, resilience (light grey area), and trend (dark grey area) for country-level scores for each goal and sub-goal. Histograms are shown separately for each sub-goal. Note the different scale for trend (right *y* axis).

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 change simply because of improved data rather than a change in ocean health.

Finally, key knowledge gaps remain, particularly regarding reference points. The 'mariculture' sub-goal provides an example, where production data are available with appropriate global coverage but sustainability indicators are incomplete. More importantly, underlying production models do not exist to provide appropriate reference levels for any given location. We therefore had to assume that the best-scoring country (China) was the best possible case (that is, reference) and compare all other countries to it, depressing the score for many countries and lowering their 'food provision' scores, particularly if they had high mariculture production.

The composite nature of the index provides guidance on many potential avenues for improving ocean health that cut across multiple goals. In being both quantitative and comprehensive across sectors and goals, the index provides a mechanism for decision makers to evaluate and prioritize actions relative to particular goals given an awareness of potential trade-offs within the full portfolio of goals. More specifically, results indicate that better enforcement of marine protected areas or water quality laws would result in higher resilience scores, lower pressure scores, and ultimately improved status for multiple goals. More efficient use of existing natural and human resources would improve system resilience and therefore status scores (for example, see ref. 35), as would arise through more sustainable harvest of fisheries and mariculture production. Finally, investing in better data collection and reporting to allow more accurate calculation of the index would provide a mechanism for adaptive management, where individuals and institutions learn from their experiences to make more informed decisions. Although such recommendations are not novel from a sectoral perspective, the index offers new potential to leverage benefits from such actions across multiple sectoral goals.

The index allows clear and rapid communication of vast quantities of information. Resource managers, policy makers and the public typically gravitate towards specific issues. By demonstrating how and where these issues fit into a broader context, the index creates an important opportunity to transform the dialogue on how we manage our interactions with the ocean and meets a need unfulfilled by tracking single-sector outcomes. Indeed, pursuing options where several goals improve slightly may provide better outcomes than aiming to improve significantly a single goal, which could lead to inefficient or even unwanted outcomes[36]. We are currently implementing the index at regional scales in the United States, Brazil and Fiji and will regularly update the global assessment, allowing us to assess how the index responds to specific management actions and better understand and evaluate progress and trade-offs that emerge from individual management decisions. The transparency, comparability and target-driven quantitative assessments provided by the index are valuable to management at all scales, making the index an important tool for decision making from local to international levels.

METHODS SUMMARY

We define the index as the condition of ten widely accepted public goals for ocean ecosystems (Fig. 1 and Supplementary Information), which include but are not limited to established ecosystem services (for example, 'coastal livelihoods and economies' is not an ecosystem service)[18]. The index (I) score is the weighted sum of ten goal-specific index scores (I_i):

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

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 ($\sim$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.

Full Methods and any associated references are available in the online version of the paper at www.nature.com/nature.

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METHODS

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 to people (Fig. 1). The index therefore recognizes linkages between human societies and ocean ecosystems, and that people are part of coastal and ocean systems. Full details for how scores were calculated for the overall index and each goal, the data used in each case, and how each data layer was processed are provided in the Supplementary Information. Here we provide a summary of the general approach and models used, with details for model equations and parameters provided in Supplementary Table 33.

The objective (utility function) of the index is to maximize its value (I), where I is determined as a linear weighted sum of the scores for each of the public goal indices ($I_1, I_2, \ldots, I_{10}$) and the appropriate weights for each goal ($\alpha_1, \alpha_2, \ldots, \alpha_{10}$), such that:

$$I = \alpha_1 I_1 + \alpha_2 I_2 + \ldots \alpha_{10} I_{10} = \sum_{i=1}^{N} \alpha_i I_i \quad (1)$$

where $\sum \alpha_i = 1$. Each goal score, I_i, is a function of its present status x_i and an indication of its likely near-term future status $\hat{x}_{i,\mathrm{F}}$:

$$I_i = \frac{x_i + \hat{x}_{i,\mathrm{F}}}{2} \quad (2)$$

The present status of goal i, x_i, is its present value, X_i, relative to a reference point, $X_{i,\mathrm{R}}$, uniquely chosen for each goal and rescaled 0–100 such that:

$$x_i = \frac{X_i}{X_{i,\mathrm{R}}} \quad (3)$$

For goals, where exceeding the reference point is possible but not desirable because it is unsustainable, the calculation of the present state accounts for this.

The reference point, $X_{i,\mathrm{R}}$, can be determined in four potential ways, depending on the conceptual and data constraints for each goal[34]. Reference points can be estimated mechanistically using a production function (for example, maximum sustainable yield for fisheries), spatially by means of comparison with another region (for example, highest-ranked country represents the best possible known case), temporally using a past benchmark (for example, historical habitat extent), or in some cases via known (for example, zero pollution) or established (for example, 20% of waters set aside in marine protected areas) targets. Past benchmarks can either be a fixed point in time or a moving target (for example, 5 years before most current data).

For six of the ten goals, production (or delivery) of the goal involves activities by people that can negatively feed back on the potential of the goal to be realized (for example, overfishing ultimately reduces the total catch that is available). The six goals include 'food provision', 'artisanal fishing opportunity', 'natural products', 'tourism and recreation', 'coastal livelihoods and economies', and 'sense of place' (for example, visiting cultural sites can have a negative impact on them). This type of sustainability is built into the status assessment for the goals for which it can be assessed and assumed to be neutral in other goals (for example, 'sense of place') for which we currently do not have research or data to inform how this feedback works.

The estimate of a goal's likely near-term future status, $\hat{x}_{i,\mathrm{F}}$, is a function of four dimensions: present status; recent trend (over the past ~5 years) normalized to a reference value (T_i); current cumulative pressures to the goal (p_i); and social and ecological resilience to negative pressures (measured as a function of governance and social institutions in place to protect or regulate the system, and the ecological condition of locations; r_i). Trend is calculated as the slope of the change in status based on recent data. Whenever possible, trends were calculated as the slope of annual data over the previous 5 years; we included values from previous years and slopes calculated on as few as two data points (in very few cases) when faced with incomplete data sets. Because status values ranged from 0 to 100, trend primarily ranged from -1.0 to 1.0; we constrained values outside this range to these range end points because such steep slopes are usually a result of extremely unusual events or insufficient data.

The role of resilience and pressure dimensions is to improve our understanding of the likely near-term future condition by incorporating additional information beyond that provided by the recent trend, T_i. Our approach identifies those factors that negatively affect a goal as pressures and those that positively affect a goal as resilience (see 'Calculating pressures' and 'Calculating resilience' sections below). The recent trend captures the direction and rate of change based on conditions in the recent past. However, some pressure or resilience measures that were in existence in the past may have a cumulative effect that has not yet manifested itself (for example, for p: fishing pressure may have increasingly negative impacts as successive year classes of fish become increasingly less abundant; for r: establishment of a marine protected area may require a number of years before its benefits become apparent). In addition, the recent trend does not capture the effect of current levels of resilience (r) and pressures (p). The expectation of a likely future condition suggested by the trend will become more or less optimistic depending on the effects of r and p. If the effects are equal they cancel each other out.

Both r_i and p_i are scaled such that $0 \leq r_i, p_i \leq 100$, with 100 being the maximum value in both cases. The trend (T_i) is constrained to $-1.0 \leq T_i \leq 1.0$ (as noted above). The likely future status is then defined as:

$$\hat{x}_{i,\mathrm{F}} = (1+\delta)^{-1}[1 + \beta T_i + (1-\beta)(r_i - p_i)]x_i \quad (4)$$

where the discount rate (δ) is set to 0 initially. β represents the relative importance of trend versus resilience and pressure terms in determining the likely trajectory of the goal status into the future. We assume $\beta = 0.67$ based on the idea that the direct measure of trend is a better indicator of future (5 years) condition than indirect measures of pressure and resilience. This assumption makes trend twice as important; it is not possible to derive this weight empirically, and so we tested the sensitivity of the results to this assumption. Because we presume a roughly 5-year horizon for the likely future status, we assume $\delta = 0$; we tested the sensitivity of results to this assumption.

It is important to note that with high-resolution spatial and temporal data that perfectly measure all four dimensions within a goal, the likely future condition would approach the current status as current status approaches its maximum value. In other words, the likely future status cannot exceed the maximum possible value for status for each goal, which is 100 in nearly all cases. In reality, data are rarely perfect, creating potential situations where likely future condition exceeds 100. To address these cases, we implemented two rules that follow logical constraints. First, if current status = 100, then trend is set = 0.0, as any trend >0.0 in those cases must be due to incomplete or imperfect data. Second, given that $x_i^{\max}$ is equal to the maximum attainable status given realistic constraints, then if poor data quality or other practical constraints lead to $\hat{x}_{i,\mathrm{F}} > x_i^{\max}$ we set $\hat{x}_{i,\mathrm{F}} = x_i^{\max}$.

The maximum possible index value (U) is the sum of the maximum possible values for each goal indicator. Because this maximum value is the best possible value today and in the future, $r > p$ and $T = 0$, such that $x_i^{\max} = X_{i,\mathrm{R}}$ where the reference state has been normalized to 100. U is then:

$$U = \sum_{i=1}^{N} \alpha_i x_i^{\max} \quad (5)$$

We can therefore calculate the index (I):

$$\mathrm{I} = \frac{\sum_{i=1}^{N} \alpha_i I_i}{U} \quad (6)$$

This formulation also allows for assessments to be conducted using goals that are of interest/use for a particular location. For example, few extractive use public goals are relevant to or valued in uninhabited regions, so calculation of the index for these areas is based on a subset of goals. In this way, uninhabited areas that are pristine could score very highly, even though they are not delivering more direct market-based benefits to people.

Calculating pressures. To calculate pressures for each goal (p_i) we evaluate both ecological (p_{E}) and social pressures (p_{S}), such that:

$$p_i = \gamma(p_{\mathrm{E}}) + (1-\gamma)(p_{\mathrm{S}}) \quad (7)$$

where γ is the relative weight for ecological versus social pressures and is set equal to 0.5. At global scales, little evidence exists to support unequal weighting of ecological and social pressures for most goals; furthermore, unequal weighting would require unique values for each goal and there is currently no empirical work to guide such decisions. At local or regional scales there may be clear evidence for unequal weights per goal and γ should be adjusted accordingly.

We assessed five broad, globally relevant categories of ecological stressors: fishing pressure (p_{f}), habitat destruction (p_{hd}), climate change (including ocean acidification) (p_{c}), water pollution (p_{p}), and species introductions (invasive species and genetic escapes) (p_{sp}) (Supplementary Table 2). The five categories are intended to capture known pressures to the social–ecological system associated with each goal, that is, impacts that are assumed to significantly affect the ecological and social state of a system, and are derived from other systems of categorizing classes of stressors[1,37,38]. Because many ecological stressors within these categories 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 that any cumulative pressure load greater than the maximum intensity of the worst stressor is equivalent to maximum stressor intensity. The intensity data layers for stressors come from a wide range of sources (see Supplementary Table 23).

Overall ecological pressures (p_E) are then calculated as the weighted average of the pressure categories relevant to each goal, with weights set as the maximum rank in each pressure category (w_{i_max}), such that:

$$p_E = \frac{\sum_i^N (w_{k\_max} p_k)}{\sum w_{i\_max}} \quad (9)$$

Stressors that have no impact drop out rather than being assigned a rank of zero, which would affect the average score.

For social pressures, we primarily used data from the Worldwide Governance Indicators (WGI), a composite of hundreds of different measures that assesses in very broad but comprehensive terms the social structure and functioning of countries, scoring them along six component composite indicators: control of corruption, government effectiveness, political stability, regulatory quality, rule of law, voice and accountability. We averaged scores for all six components of the WGI and then rescaled them 0–100, with pressures then assessed as (1 − WGI). For the 'coastal livelihoods and economies' goal, we used one additional data layer to approximate social pressure: the global competitiveness index (GCI). If additional social pressure layers are identified for other goals in the future, they would be averaged with the WGI score in this same manner. Social pressures are therefore:

$$p_S = \frac{\sum_i^N z_i}{N} \quad (10)$$

where z_i are the social pressure measures specific to the goal (in most cases, only the WGI score). Unequal weighting may be appropriate in some cases but is difficult to assess currently. Finally, to combine the social and ecological pressures, we assumed that each should have the potential to contribute equally to the overall pressure score (as described in equation (7)).

Calculating resilience. To calculate resilience for each goal (r_i) we assess three types of measures: ecological integrity (Y_E), goal-specific regulations aimed at addressing ecological pressures (G), and social integrity (Y_S). The first two measures address ecological resilience whereas the third addresses social resilience. When all three aspects are relevant to a goal, resilience is calculated as:

$$r_i = \gamma\left(\frac{Y_E + G}{2}\right) + (1-\gamma)Y_S \quad (11)$$

where the three types of measures are all scaled 0–100, and γ is assumed to be 0.5. We chose $\gamma = 0.5$ so that the weight of resilience components that address ecological systems versus social systems were equivalent, based on the same rationale as for ecological pressures versus social pressures, with the intent, as best as possible, to have resilience measures directly matched with pressures.

Goal-specific regulations (G) are intended to describe the factors that set rules and regulations to address ecological pressures, and are measured as laws and other institutional measures related to a specific goal. Governance is a function of (1) institutional structures that address the intended objective; (2) a clear process for implementing the institution being in place; and (3) whether the institution has been effective at meeting stated objectives[39]. At global scales it is very difficult to assess these three elements; we usually only had information on whether institutions exist. However, in some cases we had detailed information on institutions that enabled us to assess whether they would contribute to effective management, and thus, increased ocean health. In those latter cases, we gave more weight to those measures. Specifically, we calculated G as a weighted average:

$$G = \frac{\sum w_i G_i}{\sum w_i} \quad (12)$$

where G_i is the specific regulatory measure (data set), and w_i is the weight for each i data set used to assess G based on the quality of information contained in the data sets with regard to estimates of regulation effectiveness (see Supplementary Table 3). For habitat resilience, fishing resilience, and CITES signatories (Convention on the International Trade of Endangered Species), any country without a score is given $G_i = 0$; otherwise, any country without data for G_i is excluded from equation (12) for that country.

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