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Public Preferences for Index Aggregation Imply Lower Ocean Sustainability*

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December 5, 2025

Abstract

Sustainability indices are essential to track development progress and guide policy. They often aggregate diverse dimensions into a composite index, requiring value-based choices about the importance of each dimension (weighting) and the extent to which weaknesses in some area can be offset by strengths in others (substitutability). Such choices strongly shape indices but lack empirical support. We introduce a preference-elicitation experiment to align aggregation choices with stakeholder views and apply it to the Ocean Health Index (OHI). Respondents from twelve coastal countries predominantly view OHI goals as complementary, challenging current assumptions of perfect substitutability. Incorporating these public preferences yields substantially lower OHI scores, suggesting that ocean sustainability may be overstated and that policy should focus more on improving the weakest-performing dimensions.

JEL Codes: H41, O13, Q01, Q25, C99

Keywords: Sustainability, indices, substitutability, oceans, experimental economics

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1 Introduction

The global oceans are indispensable, both for the ecosystems they sustain (Worm et al., 2006) and for their contributions to human societies—from supporting coastal livelihoods to regulating the climate and providing cultural values (de Groot et al., 2012; Cisneros-Montemayor et al., 2021; Bertram et al., 2021). Yet, the oceans are continuously under stress, requiring ambitious policy efforts to better manage human-ocean systems (Pauly et al., 2002; Costello et al., 2012; Duarte et al., 2020; Sala et al., 2021). It is only natural then that we are interested in measuring the extent to which countries manage human-ocean systems sustainably. To this end, composite metrics like the Ocean Health Index (OHI) (Halpern et al., 2012; Halpern, 2020) can help inform policymakers about the status of ocean management and to set policy priorities. The OHI measures a broad range of ocean-related policy goals and aggregates 10 major goals, each assessed on a scale from 0 to 100, into a single index value using a simple arithmetic mean. This index value serves as a benchmark for comparisons of ocean management across countries and can guide and track policy efforts within each country over time. By the year 2022, country scores ranged from 49 to 86, with a mean global OHI value of 74.

Composite indices, such as the OHI or the *Human Development Index* (HDI), are prevalent for measuring and managing progress towards diverse societal goals (Böhringer and Jochem, 2007). Yet, they entail key value-laden assumptions on how to weight different goals and how to deal with trade-offs among them. Specifically, aggregation through the simple arithmetic mean—as in the case of the OHI—makes two important assumptions: First, every indicator is equally important for overall index performance. Second, all indicators can perfectly substitute for one another. This aggregation implies that none of the indicators is essential for overall performance and that any loss in one goal can be compensated one-to-one by increases in any other goal. Such perfect substitutability is at odds with balancing various societal goals in the context of sustainable development (Neumayer, 2003; Heal, 2012; Baumgärtner et al., 2017; Cohen et al., 2019; Drupp et al., 2025). While seemingly innocuous, assumptions on substitutability or complementarity can be decisive for reflecting the role of scarce nature in policy measures (Drupp and Hänsel, 2021; Drupp et al., 2024; Rouhi Rad et al., 2021; Sterner and Persson, 2008) and for measuring overall societal progress (Böhringer and Jochem, 2007; Rickels et al., 2014).

Where we cannot rely on guidance based on objective scientific facts, for example by biophysical relationships, the decision about the appropriate aggregation, especially across diverse societal goals, is inherently value-laden and so far solely expresses the view of the index modelers. Many composite indices, such as the initial HDI, the *Sustainable Development Goals* (SDG) Index or the *Nature Relationship Index* (NRI) (Ellis et al., 2025) make the strong assumption that individual indicators are perfectly substitutable with one another by assuming the arithmetic mean. It remains unclear whether such ad-hoc or pragmatic choices on index aggregation reflect general population preferences. Although few studies have examined population views on how indicators should be weighted (McGillivray et al., 2023; Decancq and Watson, 2019), to date none has investigated preferences regarding their (limited) substitutability. This is striking given that the most prominent index revision has been to shift the HDI from an arithmetic mean to a geometric mean, precisely to address criticism that it is inappropriate to assume that some indicators are not essential and that there is perfect substitutability among indicators (UNDP, 2010, 2021).

In this paper, we provide the first elicitation of general population preferences for both the weighting and (limited) substitutability of indicators in a composite index, using the OHI as a case study and drawing on methods from experimental economics (Andreoni and Miller, 2002; Fisman et al., 2007, 2015). We find clear evidence that the ten OHI indicators are perceived as neither equally important nor perfectly substitutable. Indeed, a large majority of respondents perceives the diverse indicators as complementary to one another, more in line with the postulate of strong sustainability (Neumayer, 2003; Rickels et al., 2014). We then incorporate population preferences in a generalized mean aggregation framework that nests all common index types (including arithmetic and geometric mean). We find that this preference-based adjustment reduces average country-level scores by more than 20%, indicating that the state of the human-ocean system, as measured by the OHI, might have previously been substantially overstated. Furthermore, we also find that progress on ocean health has been slower when considering the preference-adjusted OHI. We show that the OHI adjustment is almost exclusively driven by the preferences on limited substitutability, whereas reweighting of indicator goals alone has only a small and statistically insignificant effect. Our findings imply that policymakers should more strongly prioritize improvements in the lowest-performing indicators, which most frequently concern goals in the dimensions of development (*Food Provision*), culture (*Sense of Place*), and the environment (*Clean Waters*). While our empirical demonstration focuses solely on the OHI, our main result—that a large majority of respondents perceive diverse policy goals as less than perfectly substitutable, which implies a devaluation of the index score and the need to more strongly prioritize lower-performing goals—will extend to a wide range of composite indices, including, but not limited, to the *Sustainable Development Goals Index* (SDG Index) (Xu et al., 2020; Schmidt-Traub et al., 2017; Sachs et al., 2025).

2 Background

2.1 The role of aggregation in composite indices

The aggregation of multidimensional indicators into a single index value serves to ease interpretation and analysis. Instead of tracking the levels and changes of many values, often pointing in different directions, one can focus on a single score instead. This facilitates comparisons of both cross-sections and time trends.

Meaningful methods of aggregation are governed by the measurability and comparability of the indicators (Ebert and Welsch, 2004; Böhringer and Jochem, 2007). The most general, meaningful aggregation method is available for a set of indicators measured on the same ratio-scale and constitutes the generalized mean (GM) function:

$$GM(\eta) = \left(\sum_{i=1}^{N} \alpha_i {x_i}^{\eta} \right)^{1/\eta} \tag{1}$$

In this function, $0 \leq \alpha_i \leq 1$ denotes the relative importance, or weighting, of each indicator i. In addition, $\eta \geq 0$ measures substitutability possibilities between the indicators, or the degree to which they can compensate for each other. A value of $\eta = 0$ indicates perfect substitutability and corresponds to the arithmetic mean case where the overall index value is the simple sum of (weighted) indicator scores. A value of $\eta = 1$ indicates the geometric mean case, in which the aggregation is multiplicative and each indicator is essential; a value of $\eta = 2$ indicates the harmonic mean, in which individual indicators are more strongly complementary. For $\eta \to \infty$ the aggregation converges towards the minimum function $min(x_i)$, where the overall index score is solely determined by the worst-performing indicator dimension.

2.2 Measuring the health of the coupled human-ocean system

The OHI is one example of a prominent index that relies on the aggregation of ratio-scaled fully comparable indicators via the special case of the arithmetic mean (Halpern et al., 2012). First published in 2012, the OHI aims to measure the health of the coupled human-ocean system, that is, the sustainable management of the oceans taking into account human dimensions. As such, it consists of ten diverse public policy goals: *Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP)* and *Tourism & Recreation (TR)*. We provide short descriptions of each goal in Appendix B.

Each goal is measured on a common ratio scale from 0 (least sustainable) to 100 (most sustainable). Country-level OHI scores are then calculated for 220 coastal countries or territories as the simple arithmetic mean of their ten indicator scores. By construction, this treats goals as equally important and perfectly substitutable: the overall score depends only on the total sum of indicators. For example, a 10-point decline in *Biodiversity (BD)* can be offset by a 10-point gain in *Tourism & Recreation (TR)*. While the authors provide a sensitivity analysis for weighting, they do not address the issue of limited substitutability (Halpern et al., 2012). Related simulation work has demonstrated that adjusting the possibilities for substitution can strongly influence OHI scores (Rickels et al., 2014).

2.3 Experimentally eliciting aggregation preferences

Using the OHI as a case study, we conduct an online experiment with more than 6,500 participants across 12 major coastal countries (see Appendix Fig. A1) to directly elicit public preferences on weighting and substitutability. To this end, we adapt the modified dictator game used in the experimental economics literature for studying consumer choices or fairness preferences in a constant elasticity of substitution (CES) or generalized mean framework (Andreoni and Miller, 2002; Fisman et al., 2007, 2015; Choi et al., 2007a,b). This literature asks participants to make repeated choices between giving or keeping money, such as to study preferences for equity-efficiency trade-offs of general population or elite samples (Fisman et al., 2015).

In our experiment, we instead consider trade-offs between different goals of a composite index, in our case the OHI. Specifically, we show participants possible score combinations for two goals of the OHI and ask them to choose the combination that best resembles a healthy coupled human-ocean system for them. In the interactive, graphical interface (see Appendix B), participants can increase the score of one goal by decreasing the score of the other goal at varying relative exchange prices, allowing us to statistically infer the relative importance (α_i) that they ascribe to each goal, as well as the degree to which they think the goal scores substitute (or compensate for) each other (η). Statistical inference is possible by repeating the trade-off decisions 20 times while varying the ease of exchanging goal scores

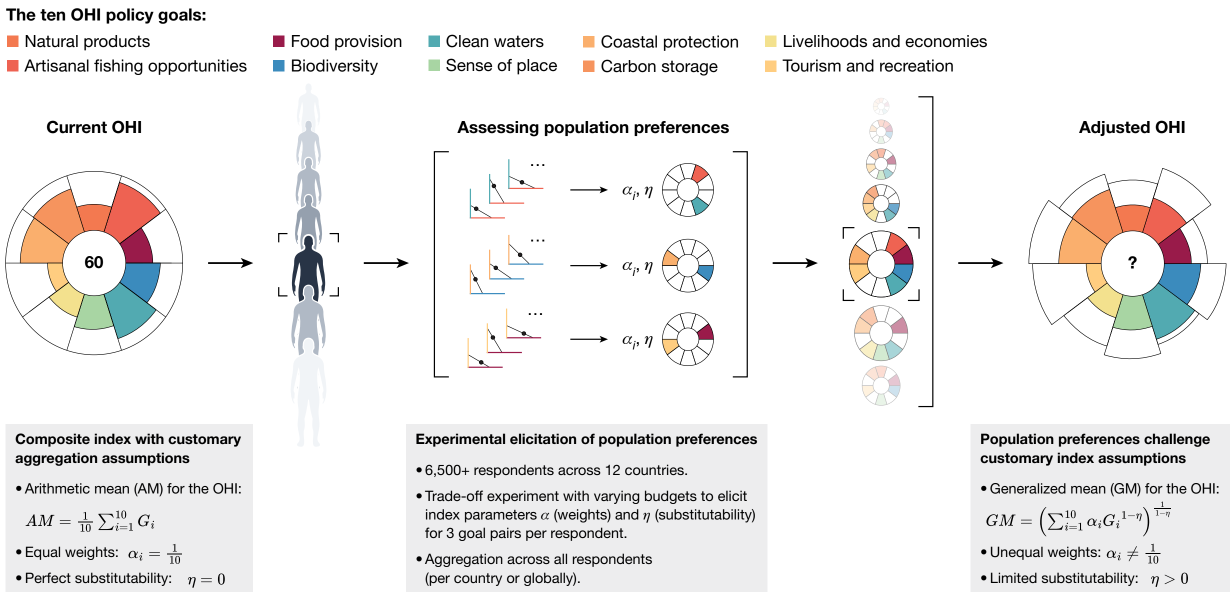

Figure 1: **Conceptual overview.** Outline showing the process of moving from baseline OHI scores to adjusted OHI scores based on experimentally elicited population preferences.

(relative price, p_x/p_y). Each participant, n, repeats this process for three random goal pairs, g, generating three estimates α_{ng} and η_{ng} each.

We aggregate individual goal-pair estimates into overall α_i and η values using the respective median estimates. This approach reflects the preferences of the general population because, according to the median voter theorem, these median values correspond to outcomes that a society could agree on under various voting rules, including simple majority voting (Black et al., 1958).

Equipped with overall values for α_i and η, we compute adjusted OHI values using the reported goal scores for each country and investigate implications of aligning the index aggregation with population preferences. We restrict our analysis to the 143 OHI countries with complete indicator scores, as missing data hinder interpretation, a point discussed further in Section 3. Figure 1 conceptually shows how we move from baseline OHI values to adjusted OHI values through our experimental approach.

3 Methodology

3.1 Experimental design

The generalized mean function is widely applied as a constant elasticity of substitution (CES) utility function to model consumer preferences over goods. The empirical estimation of the two-good case, $U(x_1, x_2) = (\alpha {x_1}^{1-\eta} + (1-\alpha){x_2}^{1-\eta})^{1/1-\eta}$, is particularly well studied and seminal papers by Andreoni and Miller (2002) and Fisman et al. (2007) use a graphic representation of a modified dictator game to retrieve the preference parameters $\rho = 1 - \eta$ and α from participants using this customary CES function (Andreoni and Miller, 2002; Fisman et al., 2007).

Adapting this experimental approach, we treat Ocean Health Index (OHI) goal scores as goods within our CES function to retrieve the substitutability parameters η_{ng} and weights α_{ng} from our participants n for pairs of OHI goals, g. We then aggregate these pairwise estimates to obtain an overall η and α_i values across all ten OHI goals i. Incorporating these parameters into the generalized mean function yields preference-adjusted OHI scores.

The core of our experimental design is as follows. For a randomly selected pair of OHI goals, participants are presented with a budget line representing all possible score allocations that fully exhaust a fixed budget. They are then asked to select the allocation that, in their view, best reflects sustainable ocean use. If participants' choices can be rationalized by a CES utility function—a point we revisit in the *Rationality* section—the selected allocation corresponds to a tangency point between the budget line and the underlying utility function. By collecting a sufficient number of such tangency points, we can infer the most likely shape of the utility function and estimate its parameters. Note that CES functions also provide meaningful environmental indices if indicators are ratio-scale fully comparable, as is the case for the OHI (Ebert and Welsch, 2004). Crucially, due to the homotheticity of the CES function, we have to vary the slope of the budget line, and therefore the relative prices of goal attainment, to learn more about the participants' utility function. Appendix B shows the full experimental instructions, including exemplary decision tasks.

Each participant is presented with 3 randomly selected OHI goal pairs from the 45 possible combinations. For each pair, they complete 20 independent allocation decisions at varying relative prices, where possible score allocations range from 0 to 100. A score of 100 represents the most sustainable fulfillment of the goal, while 0 represents the least. Each point allocated to goal i incurs a constant price p_i and choices are constrained by a normalized budget $m = 1$. Participants select a feasible score pair $\pi = (\pi_x, \pi_y)$ by choosing a point on the linear budget line defined by $p_x \pi_x + p_y \pi_y = m$.

Relative prices, p_x/p_y, vary randomly across decisions, alternating between a 'flat' set of prices and a 'steep' set, while excluding extreme values to ensure the budget lines remain visually interpretable. Specifically, in 'flat' rounds, prices are drawn from $p_x \in [1, 2]$ and $p_y \in [1, 10]$; in 'steep' rounds, from $p_x \in [1, 10]$ and $p_y \in [1, 2]$. The order of rounds – whether a decision block begins with a 'flat' or 'steep' set – is also randomized. The 20 price combinations are pre-drawn before the experiment and all participants are presented with the same 20 combinations across the three goal pairs, albeit in randomized order according to the aforementioned rules. We chose 20 allocations for 3 goal pairs to strike a balance between limited attention spans of online participants and the ability to still estimate preference parameters with a reasonable degree of precision.

At the start of the experiment, participants receive brief descriptions of each OHI goal. They are then introduced to the decision task design and must pass a comprehension test verifying their understanding of the varying relative prices. After completing three simple training tasks to familiarize themselves with the graphical interface, participants proceed to the main decision tasks, consisting of three decision blocks. Finally, demographic information is collected, and participants are invited to provide qualitative feedback.

Participants receive a fixed payment for completing the study. The decision tasks are not financially incentivized; instead, participants are informed that their choices will be used to inform policymakers and will be presented to the German Environmental Protection Agency (UBA). This framing is intended to promote careful and truthful reporting by emphasizing the potential policy relevance of their decisions (Vossler et al., 2012; Zawojska et al., 2019).

3.2 Data collection

The experiment was programmed using oTree (Chen et al., 2016) and pre-tested with 30 students in a laboratory setting at the University of Hamburg in July 2023. Participants for the main sample were recruited via the survey companies Bilendi and Dynata, with data collection conducted in two waves beginning in November 2023 and December 2024. The online experiment is conducted in the following 12 major coastal countries: Australia, Canada, China, France, Germany, India, Indonesia, Japan, Nigeria, Peru, Philippines and the United States of America (see Appendix Fig. A1). We targeted gender-representative samples of more than 500 participants per country and our final sample of 6,611 participants therefore provides, on average, more than 30 observations per goal pair per country.

We apply several exclusion criteria to the data. First, participants who completed the experiment in less than five minutes or more than two hours, or who failed the comprehension check more than ten times, are fully excluded. This removes 5.2% of the sample. Second, for the remaining participants, individual decision blocks are excluded if they violate the Generalized Axiom of Revealed Preference (GARP) or display uniform preferences. Both criteria are detailed in the Rationality subsection and result in the exclusion of an additional 12.2% of decision blocks.

To achieve our target sample of over 500 participants per country, after applying these exclusion criteria, we deliberately over-sample and draw participants at random from the remaining subject pool to achieve the highest possible sample size while maintaining gender-representativeness in each country.

3.3 Relative weights & substitutability

Interpretation of parameters

Following the experiment, we use the collected decision data to retrieve estimates of the substitutability and weighting parameters for each of the three goal pairs per participant. We are therefore interested in parameters η_{ng} and α_{ng} of the utility function:

$$U_{ng}(\pi_x, \pi_y) = \left(\alpha_{ng}{\pi_x}^{1-\eta_{ng}} + (1-\alpha_{ng}){\pi_y}^{1-\eta_{ng}}\right)^{1/1-\eta_{ng}}, \tag{2}$$

where π_x and π_y denote the scores allocated to goals x and y of goal pair g and individual n.

The relative importance of goal x is captured by $\alpha_{ng} \in [0, 1]$. Values above 0.5 indicate a preference for goal x over goal y, with $\alpha_{ng} = 1$ implying that goal y is irrelevant to the participant's decision. The parameter $\eta_{ng} \in [0, \infty]$ reflects the curvature of the utility function and represents the degree of complementarity between the two goals. An extreme value of $\eta_{ng} = 0$ implies perfect substitutability, reducing utility to the sum of both goal scores. In this case, a participant would always allocate their entire budget to the relatively cheaper goal. In the case of $p_x/p_y = 1$, and adjusted for relative weighting α_{ng}, this also implies that any point on the budget line would be an optimal allocation. Thus, we would expect that participants whose preferences align with current OHI practices to always allocate all their budget to the corner solution of one goal, except for the special case of $p_x/p_y = 1$.

The higher the value of η_{ng}, the more limited are the substitution possibilities. A value of $\eta_{ng} = 1$ defines the *'knife-edge'* case of Cobb-Douglas substitutability. For $\eta_{ng} \to \infty$ we approach the Leontief case $U_{ng} = min\{\pi_x, \pi_y\}$ where goals in the OHI are treated as perfect complements. Participants with such preferences would only choose score allocations that are exactly equal after adjusting for relative weights, resulting in interior solutions along the diagonal through the origin.

Therefore, the parameter η_{ng} can be interpreted as increasingly *punishing* unequal distributions as its value rises. This interpretation becomes central when recalculating OHI scores based on the mean aggregation function. A baseline value of $\eta_{ng} = 0$ is the only case that does not penalize inequality across the ten OHI goals. Any higher value necessarily leads to adjusted OHI scores falling below the baseline, except in the special case of complete equality across all ten goals, where scores remain unchanged regardless of η (Rickels et al., 2014).

Maximum likelihood estimation

We now return to Equation 2. Since utility is not directly observable, we rely on observed demand shares for each goal. Following the approach of Fisman et al. (2007), we solve the corresponding optimization problem to derive the following expression:

$$p_x \pi_x^* = \left(\left(\frac{p_y}{p_x} \right)^{\frac{\eta_{ng}-1}{\eta_{ng}}} \left(\frac{1-\alpha_{ng}}{\alpha_{ng}} \right)^{\frac{1}{\eta_{ng}}} + 1 \right)^{-1} \tag{3}$$

where $p_x \pi_x^*$ is the income share for demand of π_x, considering that we normalize the budget to $m = 1$. This gives rise to the following econometric specification:

$$p_x \pi_x^t = \left(\left(\frac{p_y^t}{p_x^t} \right)^{\frac{\eta_{ng}-1}{\eta_{ng}}} \left(\frac{1-\alpha_{ng}}{\alpha_{ng}} \right)^{\frac{1}{\eta_{ng}}} + 1 \right)^{-1} + \epsilon_{ng}^t, \tag{4}$$

where $t = 1, ..., 20$ denotes individual decision tasks and the error term ϵ_{ng}^t is assumed to be distributed normally with mean zero and variance σ_{ng}^2. Notice that the observed demand shares are censored from below by 0 and censored from above by 1. We therefore use a (two-limit) tobit maximum likelihood model, implemented in Matlab, to retrieve the parameters η_{ng} and α_{ng} that most likely generated the observed choices (Maddala, 1983; Andreoni and Miller, 2002).

The tobit model estimates coincide strongly with the solutions of an alternative non-linear least squares model. Qualitatively similar results are also obtained for a simple maximum likelihood estimation of the logit equation form:

$$ln\left(\frac{p_x\pi_x^t}{1-p_x\pi_x^t}\right) = \frac{1-\eta_{ng}}{\eta_{ng}} ln\left(\frac{p_y^t}{p_x^t}\right) + \frac{1}{\eta_{ng}} ln\left(\frac{\alpha_{ng}}{1-\alpha_{ng}}\right) + \epsilon_{ng}^t, \tag{5}$$

after adjusting for the clusters at zero and one. Although the numerical optimization is more stable without parameters in the exponents, the necessary transformation of the boundaries possibly introduces a bias. Therefore, we report the main results using the outlined tobit model.

Rationality

Afriat's Theorem guarantees that participants' choices in our experiment can be rationalized by customary utility functions (Afriat, 1967). Specifically, there exists a well-behaved (continuous, increasing, and concave) utility function that explains the observed data *if and only if* the choices satisfy the Generalized Axiom of Revealed Preference (GARP). Importantly, this result only applies to linear budget sets, which we use by design. By further assuming separability and homotheticity — following Andreoni and Miller (2002) and Fisman et al. (2007) — the rationalizing utility function must take the CES form.

Adherence to GARP is therefore a necessary condition for meaningfully describing participants' behavior with our chosen utility function. GARP demands that if some allocation A is indirectly revealed preferred to allocation B, then B is not strictly directly revealed preferred to A. To assess compliance with GARP we use the Critical Cost Efficiency Index (CCEI), which ranges from 0 to 1 and measures the degree to which each budget constraint has to be adjusted to remove all GARP violations. While the literature offers no universal threshold, commonly used cutoffs include 0.95 (Varian, 1991) and 0.8 (Fisman et al., 2007). For our main analysis, we adopt the latter. By restricting the estimation to individuals with a CCEI score of at least 0.8, we ensure that preference parameters η_{ng} and α_{ng} can be credibly identified. Additionally, we exclude goal pair observations where participants allocate more than 98% of their distributed scores ($\pi_i/(\pi_i + \pi_j) \geq 0.98$) to a single goal on average. This is necessary as such choice patterns are consistent with any degree of substitutability and therefore do not allow for meaningful estimation of η_{ng} (Fisman et al., 2015).

3.4 Recalculation of index scores

To recalculate index scores, we aggregate goal-pair estimates by taking the median values of the parameters η_{ng} and α_{ng}, either across the full sample or at the country level, depending on the analysis. This approach is motivated by both practical and interpretative considerations. Since η diverges to infinity, using the mean would distort aggregation. Moreover, median preferences align naturally with the median voter theorem, facilitating clearer interpretation (Black et al., 1958).

Retrieving the median sample preferences for the weighting parameters α_i requires one additional step. The goal-pair level estimates α_{ng} only refer to a specific pairwise comparisons. Simply taking the median goal-pair level estimate and dividing by five, to ensure that the weights of all goals sums up to 1, would not accurately reflect the relative relationships between the ten goals and create an artificial ceiling at $\alpha_i = 0.2$.

To derive the latent weights α_i^{Median} from the observed weights $\tilde{\alpha}_{i,ij}^{Median}$ of the pairwise comparisons of goal-pairs ij, we define a 10×10 matrix $C = (c_{ij})$, where $c_{ij} = \alpha_i^{Median}/\alpha_j^{Median} = \tilde{\alpha}_{i,ij}^{Median}/\tilde{\alpha}_{j,ij}^{Median}$. The best logarithmic least-squares approximation is then given by (Hovanov et al., 2008):

$$\hat{\alpha}_i^{Median}(C) = \left(\prod_{j=1}^{n} \frac{c_{ij}}{c_{ji}} \right)^{\frac{1}{2n}} \tag{6}$$

Dividing by the sum of all estimated weights normalizes each weight such that the sum of all weights equals one.

Preference-adjusted index scores are calculated by applying the aggregated parameters to the generalized mean function, $GM(\eta) = \left(\sum_{i=1}^{N} \alpha_i {x_i}^{\eta} \right)^{1/\eta}$, alongside the corresponding indicator scores. Unless otherwise specified, median parameter values from the total sample are used, and indicator scores correspond to the reported scores for the year 2022 (Ocean Health Index, 2025). While the OHI reports index values for 220 countries and territories, we limit our analysis to the 143 countries for which complete indicator scores are available. The interpretation and application of our weighting estimates becomes convoluted when recalculating index scores using only a subset of the ten goals, as these weights reflect the relative relationships among all ten goals. Moreover, participants' decisions in the experiment are based on their knowledge of and consideration for the full set of goals. In Appendix Fig. A4a we present a sensitivity analysis with all 220 regions of the OHI, in which we only adjust the substitutability of indicators according to median population preferences.

Due to the COVID-19 pandemic, most countries saw a sharp decline in indicators, most notably for *Tourism & Recreation*. The OHI updates scores continuously as required data for indicators becomes available. At the time of writing this paper, the scores for the year of 2022 are the latest scores that do not include the effects of the COVID-19 pandemic yet. We therefore use this year as our baseline, and as the last year for the analysis of time trends, as the score adjustments due to the COVID-19 pandemic lead to substantially more extreme results that do not seem to be representative for pre- and post-pandemic years. For completeness, we report a sensitivity analysis that includes the effects of the COVID-19 pandemic in Appendix Fig. A4b.

4 Results

4.1 Reassessing ocean health based on population preferences

Descriptive statistics of our experimental sample are presented in the Appendix Table A1. Estimates of the weighting parameters (Fig. 2a) indicate that population preferences do not support the null hypothesis of equally weighted goals in the OHI: $H_0 : \alpha_i = 0.1 \; \forall i$ (two-sided bootstrap t-test, for each goal $p \leq 0.001$, $|t| > 19$, $df = 99$). Some goals, like *Clean Waters* and *Food Provision*, are more important to the participants in our study than goals like *Sense of Place* and *Tourism & Recreation*. Notably, indicators rated as more important include both nature-dimension goals, such as *Clean Waters*, and human-dimension goals, such as *Food Provisioning*. This suggests that participants broadly agree with index modelers that human dimensions should factor into assessments of ocean sustainability. They don't agree, however, that all of these goals should be equally weighted. Our results complement the four alternative weighting scenarios, discussed as a sensitivity analysis by the creators of the OHI (Halpern et al., 2012). While their "value sets" mainly focus on the dichotomy of nature-related- and human-dimensions, we can offer a more nuanced re-balancing scenario in line with population preferences. Recalculating OHI scores with population-preference adjusted values for α_i while keeping η unchanged, shows that solely adjusting the index for these alterations does not make a sizable difference (Fig. 2b). Specifically, the weighting-adjusted country scores decline by only 2% on average and are indistinguishable from the baseline scores (p=0.101).

Estimates for the substitutability parameter η show a pronounced heterogeneity (Fig. 2c) but are predominantly in the complements domain, with a median estimate of 3.03. We clearly reject the null hypothesis of perfect indicator substitutability: $H_0 : \eta = 0$ (two-sided Sign-Test, $p \leq 0.001$, $S = 19,821$, 95%-CI $= 2.92 - 3.15$, $n = 19,821$). The cumulative density function of our estimates signifies that perfect substitutability is an extreme case that is to a large extent unsupported by the general population: Only 1.12 percent of preference

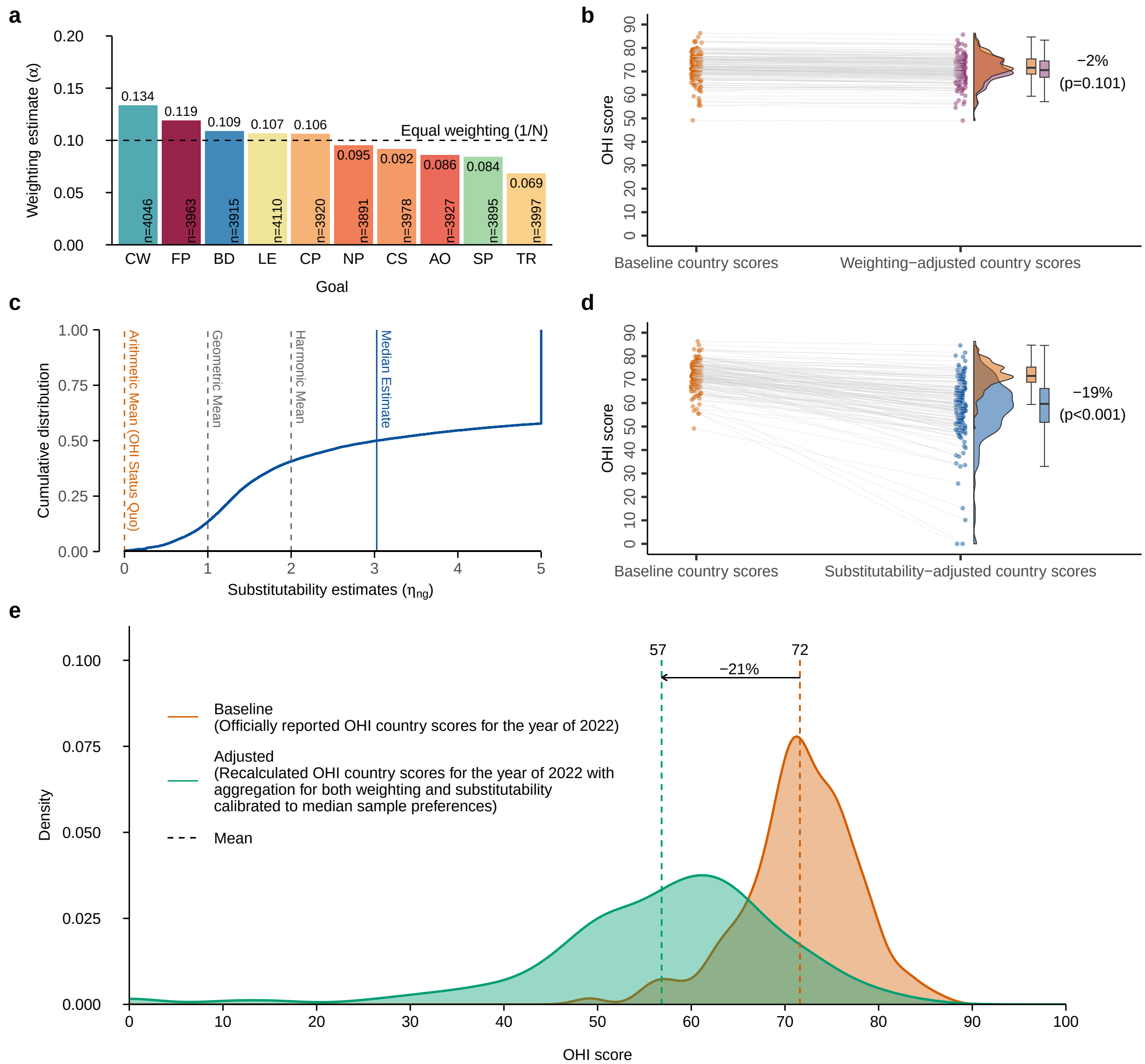

Figure 2: **Summary of estimates and adjusted OHI scores. a-b** display results for weighting preferences, **c-d** display results for substitutability preferences and **e** consolidates both dimensions. **a**, Derived estimates in the main experimental sample for the relative importance of each OHI goal according to median sample preferences. **b**, Change in OHI scores (for the year 2022 and n=143 countries) when solely adjusting the relative weighting according to the sample estimates of panel a. A two-sided t-test reveals no statistically significant difference at the 95% level between baseline scores and weighting-adjusted scores (CI: -0.23; 2.56). **c**, Empirical distribution function of the main sample substitutability estimates, visually cut-off at a value of five. **d**, Change in OHI scores (for the year 2022 and n=143 countries) when solely adjusting indicator substitutability according to the sample estimates of panel c. A two-sided t-test reveals a statistically significant difference at the 95% level between baseline scores and substitutability-adjusted scores (CI: 11.22; 16.18). **e**, Comparison of the distributions of baseline OHI scores and adjusted OHI scores (for the year 2022 and n=143 countries) that incorporate both the weighting effect displayed in panel a-b and the substitutability effect displayed in panel c-d. Abbreviations: Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP) and Tourism & Recreation (TR).

estimates fall into the near-perfect (or strong) substitutability range of $0 \leq \eta \leq 0.2$. The effect of adjusting OHI scores by limited substitutability (η), while keeping the OHI weighting scheme (α_i), is very pronounced and leads to an average decrease in country scores of 19% when considering the median sample estimate of 3.03 (Fig. 2d). In Appendix Fig. A4a we present a sensitivity analysis of this result for all OHI countries, including regions with missing indicator values, and find a comparable decrease in country scores of 20% for the median substitutability estimate. For our main sample, this compares to reductions in the OHI for the other canonical means of 6% (geometric mean, $\eta = 1$) and 13% (harmonic mean, $\eta = 2$). The response of country scores to adjustments of the substitutability is markedly heterogeneous, a point we will revisit in the next section.

Combining both effects, and therefore fully calibrating the generalized mean aggregation to population preferences, leads to a significant change in the distribution of OHI scores (Fig. 2e): Overall, the distribution becomes wider, with the standard deviation shifting from 6.05 to 13.64 (Brown-Forsythe Test, $p \leq 0.001$, $F = 140.25$, $df = 195.21$) and with more mass particularly in the lower tail, and the mean country score shifts by a value of 15, from 72 to 57 (-20.64%) (two-sided Welch Two Sample t-test, $p \leq 0.001$, 95%-CI $= 12.32 - 17.24$, $t = 11.84$, $df = 195.85$). Therefore, the current state of the coupled human-ocean system is considerably worse than currently portrayed by the OHI, when following population preferences for index aggregation. In addition, the increased dispersion of scores suggests that differences in the management of the human-ocean system across coastal countries are more aggravated than previously portrayed.

Appendix Figure A2 displays disaggregated goal-pair-level estimates, which uncovers additional heterogeneity in weighting and substitutability. These results show that, even on a goal-pair-level, there is no estimate that aligns with the current OHI assumption of perfect substitutability.

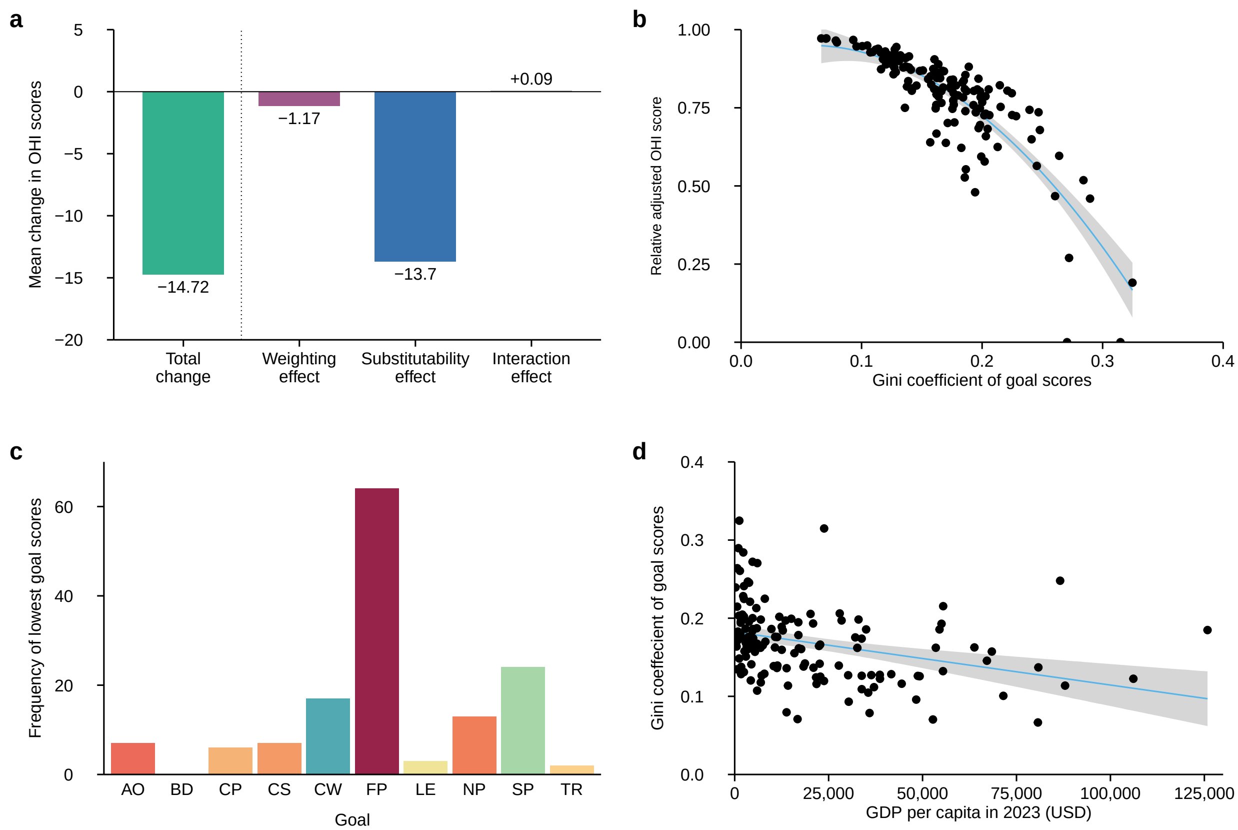

Figure 3: **Decomposition of OHI score adjustments, substitutability effect and goal attainment inequality. a**, Decomposition of the average total adjustment of OHI scores into the weighting effect, substitutability effect and the interaction effect between them. **b**, Relationship between the degree of OHI score adjustments and inequality of country-level goal scores for the year 2022 and n=143 countries, including a second-order polynomial regression line with 95% confidence bands in grey. **c**, Bar chart showing how often each policy goal is the lowest performing goal for a country (for the year 2022 and n=143 countries). **d**, Relationship between the Gini coefficient of country-level goal scores and the respective GDP per capita (in 2023) for the year 2022 and n=143 countries, including a linear regression line with 95% confidence bands in grey. Abbreviations: Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP) and Tourism & Recreation (TR).

4.2 Drivers of OHI index adjustments

What drives the reduction and dispersion of preference-adjusted OHI scores vis-à-vis reported OHI scores? In principle, a country's score can improve by changes in the goal weights, i.e. if public preferences suggest that one should put more weight on better performing indicators and less weight on worse performing indicators. For adjustments in the substitution possibilities, the direction of change is unambiguous: Any increase in η, and therefore any movement away from the arithmetic mean case, decreases the aggregated index score, unless a country would have perfectly balanced scores in all indicators, which applies to none of the 143 countries.

Disaggregating the adjustment in OHI scores into weighting and substitutability effects reveals that limited substitutability primarily drives the mean change in scores (Fig. 3a). The weighting effect is negative, but comparatively small. An additional, small interaction effect emerges when both parameters are adjusted simultaneously rather than individually. While its magnitude is negligible, it indicates that reweighting tends to balance scores: on average, participants assign higher weight to low-performing goals than to high-performing ones (OLS regression: $\alpha_{ng} = \beta_0 + \beta_1 \times Score_{ng}^{Goal1}$, $\beta_1 = -0.002$, 95%-CI$= -0.002; -0.001$, $p \leq 0.001$, $F = 179.6$, $R^2 = 0.009$, $df = 19,819$).

We next examine how heterogeneous country effects arise by plotting the change in OHI scores against the Gini coefficient of each country's indicator scores (Fig. 3b). This reveals a clear pattern: countries with more uneven distributions across the ten OHI goals experience larger declines. This occurs because a higher η penalizes uneven score distributions by limiting the extent to which strong performance in one goal can offset weak performance in another. Consequently, countries with particularly unbalanced goal scores are most affected by the preference-adjusted aggregation. This also means that, under limited substitutability, country scores can be particularly increased by targeting the worst-performing index dimensions. For the OHI, the policy goals that most frequently show the weakest performance are *Food Provision*, *Sense of Place* and *Clean Waters* (Fig. 3c).

Which countries tend to exhibit more uneven indicator score distributions? First, countries with higher baseline OHI scores generally show less inequality across indicators, as uniformly strong performance in all dimensions is required to achieve a high overall score under the arithmetic mean. Second, plotting the Gini coefficient of indicator scores against per capita GDP (Fig. 3d) reveals a negative relationship between score balance and country development ($\beta = -0.007$, $p \leq 0.001$ for GDP per capita in 10,000 USD). This shows that more developed countries tend to have more balanced indicator scores, although the relationship is not pivotal ($R^2 = 0.11$).

4.3 Exploring the heterogeneity in scores & preferences

Due to the substantial spread in the Gini coefficients of goal scores and the heterogeneous responses to preference-adjusted aggregation when considering limited substitutability, we also find that relative country rankings change. Therefore, some coastal countries manage the oceans relatively more sustainable, in comparison to other countries, than previously perceived. In Appendix Fig. A3, we plot the reported OHI score for each country against its adjusted score to visualize these relative differences. For our 12 sample countries (Fig. 4a), we can additionally compare adjustments under the aggregated 'global preferences' with adjustments using the preferences confined to each country's subject pool ('country preferences'). In Appendix Table A2 we display the corresponding median substitutability and weighting parameters on a sample-country level. Furthermore, using GDP per capita as a proxy for economic development (United Nations, 2025), we find that higher development is associated with higher η values, i.e. higher degrees of complementarity among OHI goals as perceived by respondents (Fig. 4c). Indeed, OECD countries show a markedly different median substitutability value of $\eta = 3.79$ when compared to the median value of $\eta = 2.49$ for non-OECD countries (two-sided Wilcoxon rank sum test, $p \leq 0.001$, $W = 44,050,160$).

Beyond spatial differences, preference-adjusted aggregation also alters temporal trends in OHI scores besides a clear downward level-shift in index values (Fig. 4b). For example,

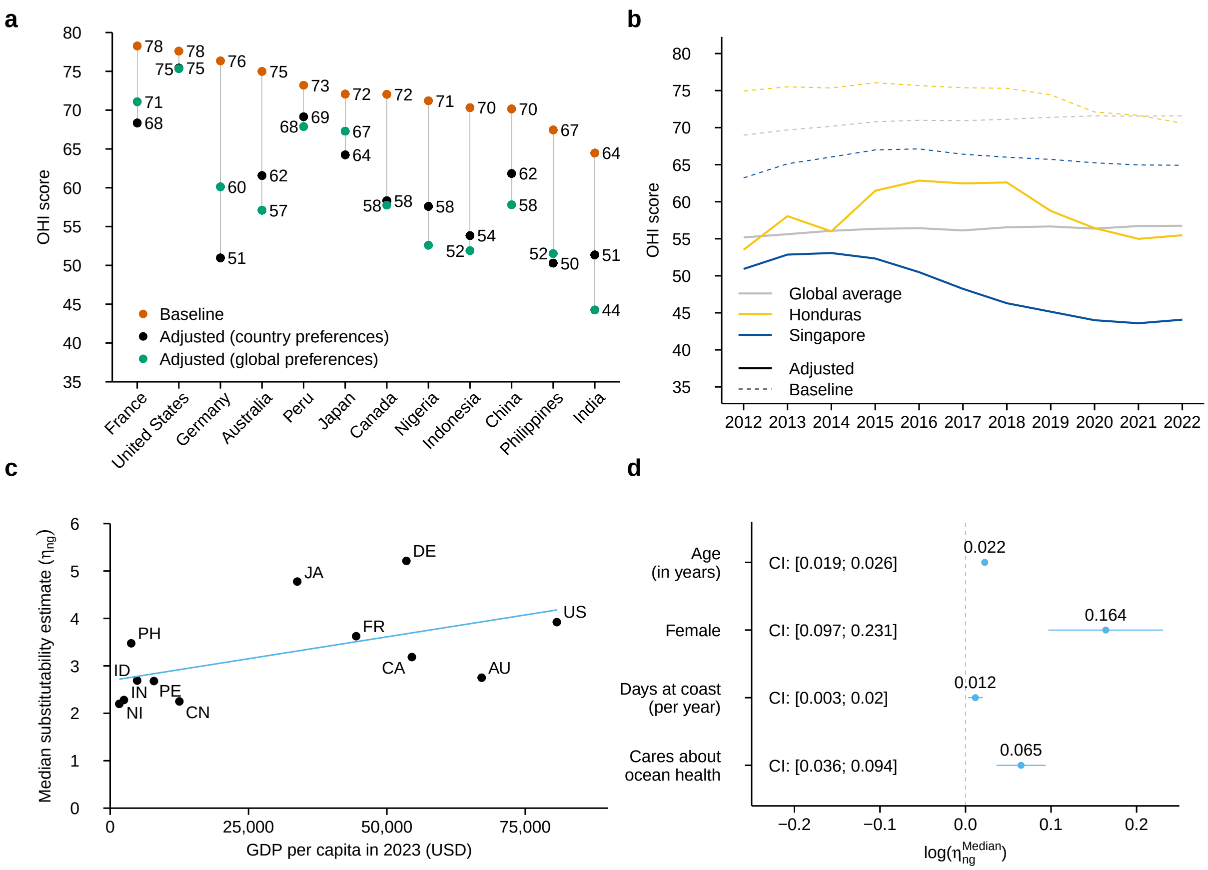

Figure 4: **Heterogeneity in scores & preferences.** **a**, Adjustments of OHI scores for the countries in our experimental sample based either on estimates of the total sample or confined to the participants of the respective country. **b**, Timetrends of OHI scores for two selected countries and the average country score. **c**, Relationship between median sample estimates of the substitutability parameter and GDP per capita (in 2023) for the countries in our experimental sample, including a linear trend line for illustrative purposes. **d**, Median quantile regression of main sample substitutability estimates on selected survey measures (in every case, n=19,623) and including country fixed effects. The outcome variable is the natural logarithm of the median substitutability parameter estimate. *Cares about ocean health* is measured on a 7-point Likert scale and treated as continuous variable. *Female* is a dummy variable which returns 1 for participants that self-reported as female and 0 for participants that self-reported as male. *Days at coast (per year)* is a self-reported measure of the number of days that participants visit the coast where the answer "more than 10 days" is coded as numerical value 11. *Age (in years)* is a self-reported measure of the age of participants, with possible integer values ranging from 18 to 99. Light blue dots indicate point estimates and light blue bars indicate 95% confidence intervals.

the change in the global average country score from 2012 to 2022 is smaller for the adjusted OHI (with an increase of 2.9% percent over the time horizon) than for the baseline OHI (3.8%). We also find that some country trends reverse: Singapore, which previously showed an increase in OHI from 2012 to 2022, now exhibits an overall decline according to the population preference adjusted OHI, whereas Honduras, which had a downward baseline trend, sees a slight positive growth over the same period. Note that we generally do not extend our analyses beyond 2022, as this is the last year for which the reported scores do not include distorting effects from the COVID-19 pandemic. A more detailed discussion is featured in Section 3 and a corresponding sensitivity analysis of our main results is carried out in Appendix Fig. A4b.

Finally, examining the relationship between median substitutability estimates and participant characteristics reveals key sources of individual-level heterogeneity (Fig. 4d). We find that older participants show higher median η estimates ($\beta = 0.022$, $p \leq 0.001$). We further find that female participants exhibit a $100 \times (e^{0.164} - 1) = 17.82\%$ higher median substitutability preference than male participants ($p \leq 0.001$), indicating that men are more willing to allow different policy goals to compensate for one another. Individuals who report caring more about ocean health are less willing to allow compensation between indicators, reflected in significantly higher η values ($\beta = 0.065$, $p \leq 0.001$). We also asked participants how many days per year they spend at the coast, using this as a proxy for coastal proximity or affinity with coastal environments. Participants spending 10 days or more per year at the coast were classified as coastal-affine ($n = 1,821$), and contrasted with non-coastal-affine participants who spend fewer than 10 days per year at the coast ($n = 4,786$). This reveals that coastal-affine participants exhibit a significantly different median substitutability value of $\eta = 3.34$, compared with $\eta = 2.92$ for non-coastal-affine participants (two-sided Wilcoxon rank sum test, $p = 0.0078$, $W = 38,261,176$). Recalculating OHI scores using the preferences of coastal-affine participants (Appendix Fig. A4c) reduces the average country score by an additional 2 percentage points relative to the main sample, suggesting that those more closely connected to oceans might assess the state of the human-ocean system as even less sustainable.

The heterogeneity analysis above focused on substitutability, the most decisive mechanism in preference-adjusted aggregation. Appendix Figure A5 presents analogous results for the weighting parameters, offering a more nuanced view of how different population subgroups value the relative importance of policy goals. For example, participants who report caring more about ocean health primarily favor policy goals related to nature dimensions, such as *Biodiversity*, *Clean Waters* or *Carbon Storage* and put less weight on human dimensions such as *Food Provision*, *Livelihoods & Economies* and *Tourism & Recreation*.

5 Discussion & Conclusion

The OHI has developed into a key index for measuring and managing ocean health. It is crucial to emphasize that the OHI does not aim to measure the health of oceans objectively, governed solely by biophysical processes (Halpern et al., 2012). Instead, it evaluates—from a societal perspective—the extent to which we achieve society's goal of sustainably managing the coupled human–ocean system. Accordingly, humans determine which goals to include, their relative importance, and the degree to which they can compensate for one another. We have shown that population samples across twelve countries view the OHI goals as complementary to one another, in contrast to the current assumption in the OHI of perfect substitutability across goals. Adjusting the OHI to reflect public preferences reveals that the human–ocean system is considerably less sustainable than previously assumed, with an aggregate index score that is over 20 percent lower.

Our analysis has focused on the issues of index aggregation, while treating the measurement of scores of individual OHI goals at the country-level as given and largely determined by objective measurement. However, at least two elements of these individual country-level goal scores also carry subjective elements. First, we have not investigated the aggregation of subindicators within goals and, thus, implicitly carried through the OHI's assumption of perfect substitutability on this sub-layer, such as between *'Iconic species'* and *'Lasting special places'* within the goal *'Sense of place'*. Studying and introducing limited substitutability also at this sub-goal layer would further reduce adjusted OHI performance. Second, the normalization of values into indicators scores between 0 and 100 relies on setting reference points for acceptable minimum and maximum values, which can also contain subjective choices. Public as well as expert views may also be of value here to illuminate these normalization choices.

Our experimental approach has sought to elicit weighting and substitutability preferences in the simplest possible format to make it possible to conduct this survey with general population samples. In particular, we have asked participants to trade off two goals at a time, to reduce choice complexity. While trading off more than two dimensions is conceptually feasible, doing so would complicate graphical representation and reduce the likelihood of obtaining sensible responses. Moreover, the informational gain would be minimal: the generalized mean function employs a single substitutability parameter that applies to all ten indicators. Therefore, learning about this parameter through trading-off two dimensions at a time loses no information while being more accessible to a general population sample. Furthermore, we have followed the literature (Fisman et al., 2007, 2015) to solely consider linear budget lines. However, some goal pairs may exhibit synergies: for example, improvements in *Clean Water* could also enhance *Biodiversity*, so that progress in one goal benefits the other. Such interactions could potentially be captured using non-linear budget sets (Castillo and Freer, 2023). While there is evidence that coastal ecological functions and values scale non-linearly (Barbier et al., 2008) and that the oceans goal (SDG14) shares many co-benefit associations with other SDGs (Singh et al., 2018) as well as trade-offs, such as with the No Poverty goal (Barbier and Burgess, 2019), more research is needed on how OHI goals relate non-linearly to one another to inform more complex experimental designs. Furthermore, we have implicitly assumed that preferences for index aggregation are constant over time, as we are only able to provide a single snapshot in time. Future work should investigate how aggregation preferences may change over time and also how this relates to changes in individual goal scores. It might be conceivable, for instance, that goals that exhibit a declining trend might become more important over time. Interestingly, we find that the two goals that receive the highest weights (Fig. 2a), namely *Food Provision* and *Clean Waters*, also appear among the top three most cases of lowest goal scores (Fig. 3c).

We have studied OHI aggregation preferences in 12 major countries. Our results suggest some important nuances on how preferences for index aggregation may differ across countries, which naturally also raise the questions of whether and for which purposes one should craft a one-preference-fits-all index. Indeed, we show that when using country-specific preferences, OHI adjustments can differ markedly from performance measures using our global preference measure (Fig. 4a). Both may serve distinct purposes: While using common global preference measures facilitates comparable cross-country rankings to hold countries internationally accountable for ocean management, country-specific index designs that better reflect local population preferences may be more helpful in determining country-specific policy priorities that can garner public support.

We have provided a conceptual and empirical roadmap for how composite indices can be put on a more democratic footing. Our analysis of how population samples from different countries view the OHI goals as complements has highlighted that governments will have to invest substantially more in the health our human-ocean systems to crease a sustainable ocean economy (Duarte et al., 2020; Lubchenco et al., 2020). In particular, our findings highlight that efforts should be focused on improving low-performing goals. These insights are likely also relevant for other composite indices, including the HDI or the SDG Index, and thus for managing sustainable development more broadly.

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Online Appendix

A Additional Tables & Figures

Figure A1: **Sample countries.** Map with countries where experimental data was collected highlighted in red.

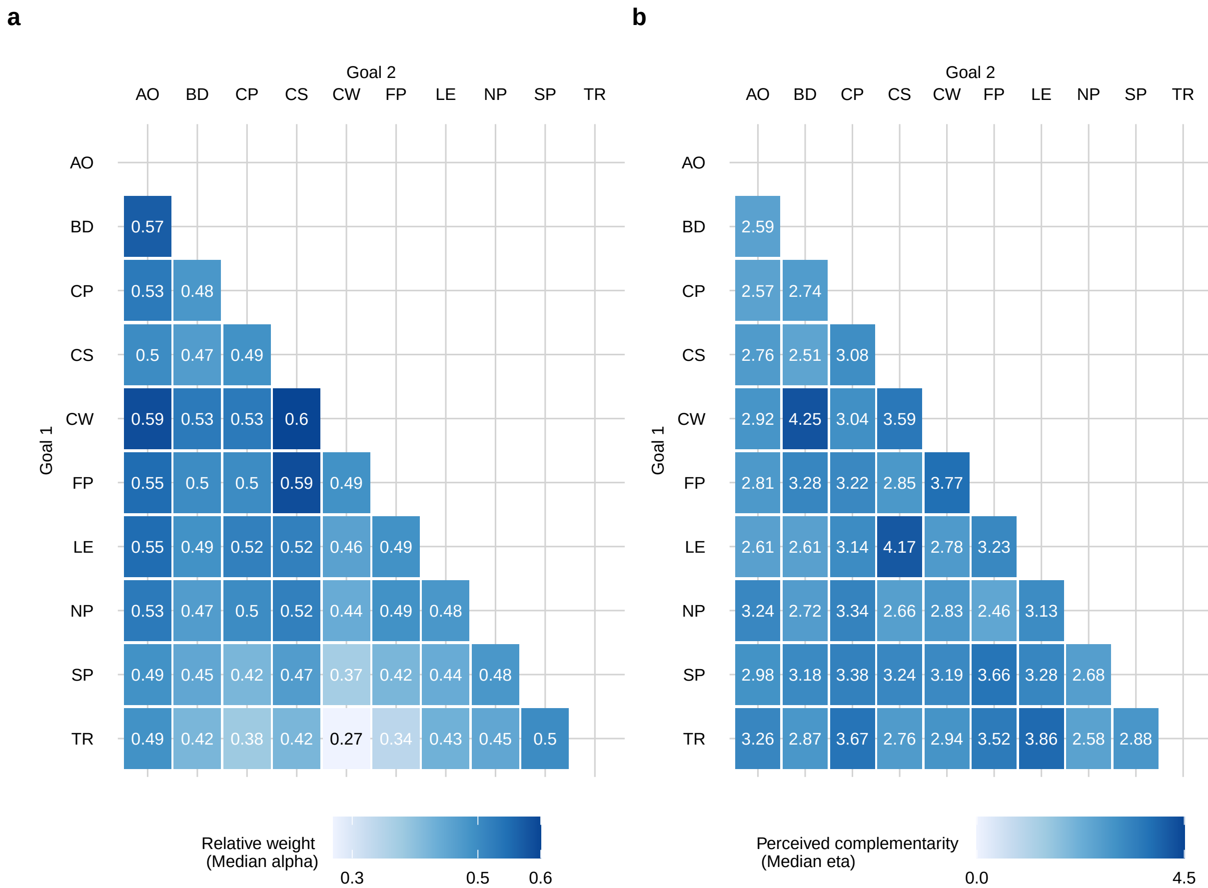


Figure A2: **Goal-pair-level estimates.** **a**, Heatmap of the estimated median relative weighting for all goal pair combinations. Values always refer to the relative importance of Goal 1 vis-à-vis Goal 2. **b**, Heatmap of the estimated median substitutability parameter for all goal pair combinations. Abbreviations: Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP) and Tourism & Recreation (TR).

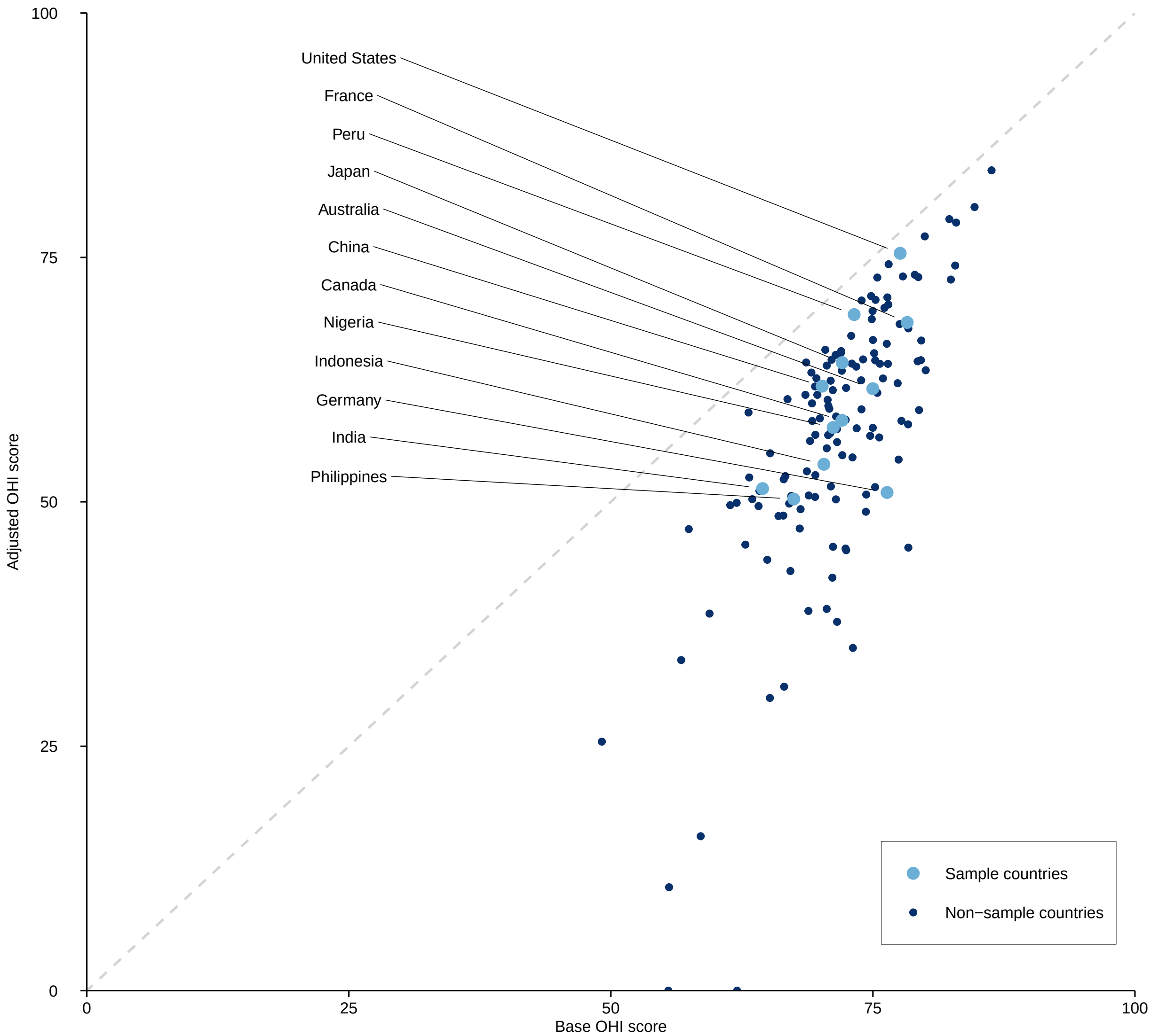


Figure A3: **OHI scores before and after adjustment.** Comparison of baseline OHI scores and adjusted OHI scores (for the year 2022 and n=143 countries

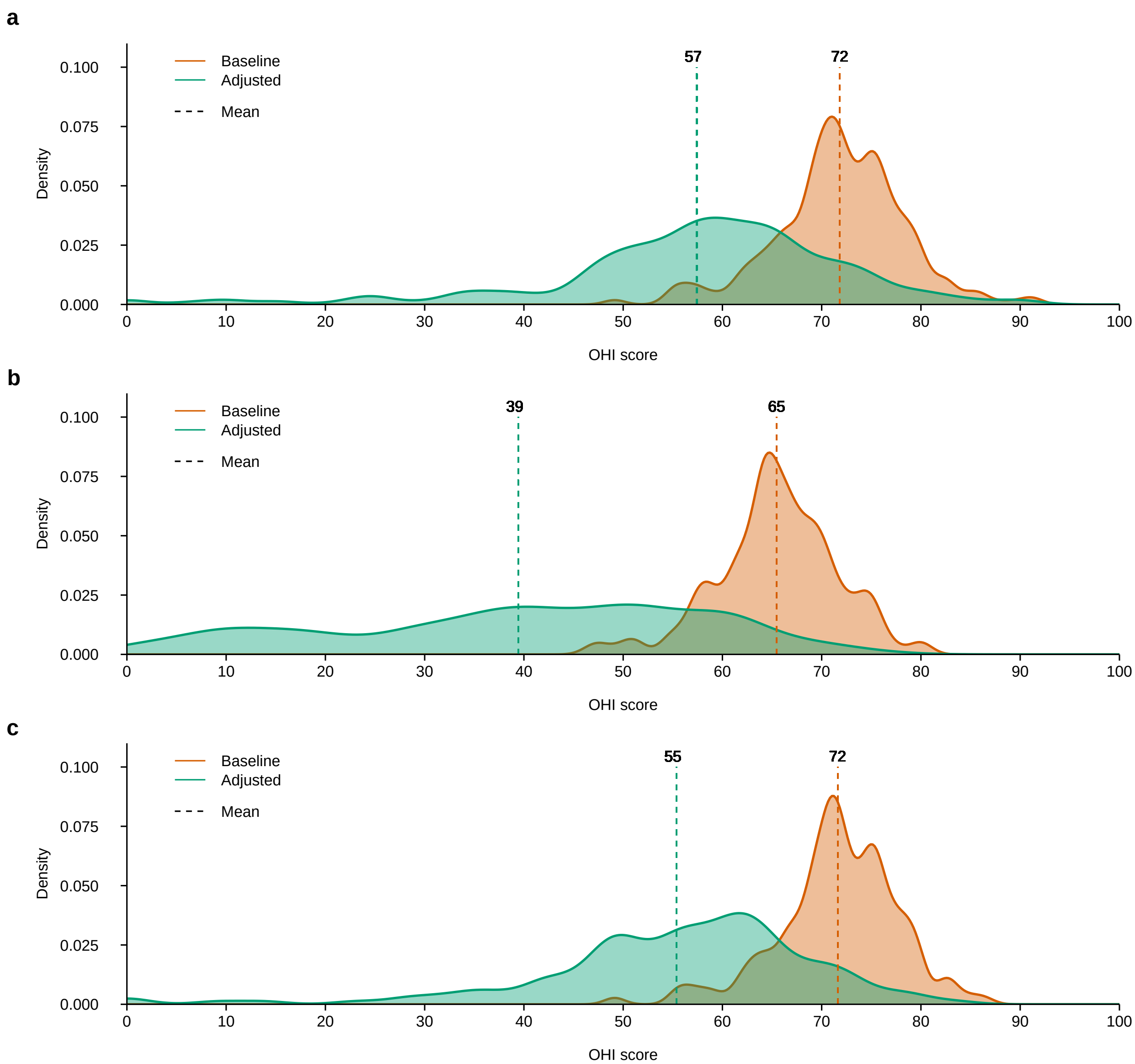


Figure A4: **Sensitivity analyses.** **a**, Comparison of baseline and adjusted OHI score distributions (for the year 2022 and n=220 countries) using the full sample of countries in the OHI and only adjusting for median substitutability preferences. **b**, Comparison of baseline and adjusted OHI score distributions (for the year 2024 and n=141 countries) based on the most recent OHI data incorporating COVID-19 pandemic effects. **c**, Comparison of the distributions of baseline OHI scores and adjusted OHI scores (for the year 2022 and n=143 countries) when the sample is confined to coastal-affine participants i.e. participants that self-reported that they spend more than 10 days per year at the coast.

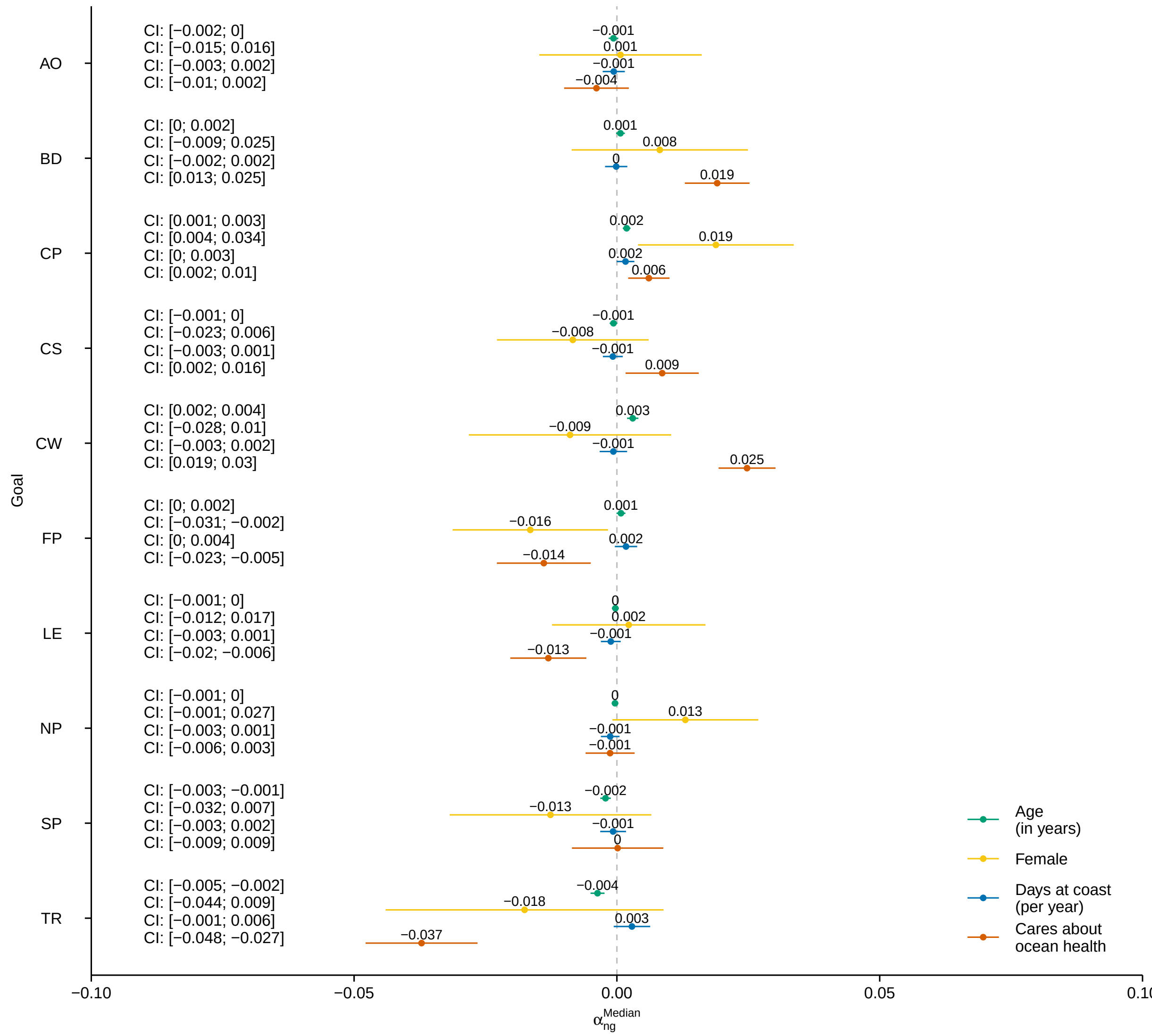


Figure A5: **Heterogeneity analysis of perceived OHI goal importance.** Median quantile regressions of main sample weighting estimates on selected survey measures (in every case, n=19,623) and including country fixed effects, for each of the ten OHI goals. The outcome variable is always the median relative weighting estimate for the respective goal. *Cares about Ocean Health* is measured on a 7-point Likert scale and treated as continuous variable. *Female* is a dummy variable which returns 1 for participants that self-reported as female and 0 for participants that self-reported as male. *Days at Coast (per year)* is a self-reported measure of the number of days that participants visit the coast where the answer "more than 10 days" is coded as numerical value 11. *Age (in years)* is a self-reported measure of the age of participants, with possible integer values ranging from 18 to 99. Coloured dots indicate point estimates and coloured bars indicate 95% confidence intervals. Abbreviations: Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP) and Tourism & Recreation (TR).

		Gender		Age			
Country / Variable	N	Male	Female	Mean	SD	Min	Max
Australia	524	260	264	41.83	13.35	18	79
Canada	525	261	264	46.77	14.90	18	85
China	502	256	246	35.55	7.87	18	68
France	572	277	295	47.62	15.18	18	92
Germany	581	287	294	48.85	14.63	18	82
India	598	309	289	34.62	11.10	18	72
Indonesia	516	260	256	34.27	8.85	18	60
Japan	539	262	277	52.11	12.11	23	81
Nigeria	579	293	286	31.88	8.99	18	68
Peru	577	286	291	34.55	11.25	18	76
Philippines	552	280	272	35.18	12.06	18	69
Usa	542	269	273	53.05	13.03	18	82

Table A1: **Descriptive statistics.** Demographic summary information of the main experimental sample.

	All	AU	CA	CN	DE	FR	ID	IN	JA	NI	PE	PH	US
Eta	3.03	2.75	3.18	2.25	5.21	3.62	2.69	2.28	4.78	2.2	2.68	3.48	3.92
AO	76.42	73.86	40.96	47.73	75.11	77.94	93.05	78.53	87.74	97.52	84.79	85.65	77.88
	(0.086)	(0.098)	(0.106)	(0.11)	(0.073)	(0.101)	(0.093)	(0.093)	(0.101)	(0.074)	(0.093)	(0.077)	(0.088)
BD	76.31	72.03	73.65	75.48	73.29	76.17	75.4	73.79	73.17	80.51	75.06	81.7	69.2
	(0.109)	(0.102)	(0.098)	(0.106)	(0.148)	(0.117)	(0.101)	(0.113)	(0.092)	(0.091)	(0.103)	(0.114)	(0.087)
CP	82.35	68.9	92.08	80.75	62.02	98.57	80.9	75.21	71.78	91.23	58.22	93.22	76.67
	(0.106)	(0.1)	(0.107)	(0.094)	(0.133)	(0.08)	(0.094)	(0.075)	(0.091)	(0.095)	(0.103)	(0.123)	(0.072)
CS	81.1	71.27	86.7	82.58	91	81.89	74.01	76.75	62.76	96.71	76.28	75.25	75.48
	(0.092)	(0.09)	(0.082)	(0.101)	(0.119)	(0.096)	(0.082)	(0.107)	(0.124)	(0.087)	(0.091)	(0.07)	(0.101)
CW	71.09	84.92	85.45	39.69	53.53	50.62	60.22	30.33	62.1	29.27	58.05	54.14	73.17
	(0.134)	(0.113)	(0.151)	(0.106)	(0.199)	(0.168)	(0.102)	(0.111)	(0.13)	(0.112)	(0.109)	(0.148)	(0.129)
FP	50.1	26.58	32.59	76.39	32.34	58.15	24.69	28.97	44.36	48.99	69.46	27.32	67
	(0.119)	(0.103)	(0.091)	(0.099)	(0.104)	(0.117)	(0.123)	(0.088)	(0.108)	(0.12)	(0.09)	(0.104)	(0.123)
LE	80.79	95.62	87.11	96.34	89.31	79.41	70.42	69.16	76.07	76.04	60.68	43.94	75.7
	(0.107)	(0.094)	(0.127)	(0.1)	(0.06)	(0.096)	(0.113)	(0.099)	(0.103)	(0.118)	(0.126)	(0.113)	(0.164)
NP	73.38	91.74	70.4	67.18	94.19	72.78	65.46	84.32	90.15	75.63	99.97	61.64	88.31
	(0.095)	(0.101)	(0.069)	(0.093)	(0.068)	(0.089)	(0.099)	(0.139)	(0.105)	(0.109)	(0.091)	(0.104)	(0.095)
SP	62.57	90.03	51.47	35.48	92.68	87.21	59.08	27.67	80.49	37.64	54.79	57.76	72.83
	(0.084)	(0.098)	(0.096)	(0.083)	(0.062)	(0.07)	(0.112)	(0.083)	(0.09)	(0.106)	(0.083)	(0.094)	(0.06)
TR	92.27	100	100	100	100	100	100	100	100	78.51	94.82	93.89	99.77
	(0.069)	(0.1)	(0.073)	(0.109)	(0.034)	(0.067)	(0.081)	(0.093)	(0.055)	(0.088)	(0.111)	(0.052)	(0.08)

Table A2: **Summary of estimates & reported goal scores.** Eta denotes the median Eta-estimate of the respective country. Goal cell values indicate reported scores with estimated weights in parenthesis. The reported values for 'All' countries represent all sample countries for the median Alpha- and Eta-estimates and the global average goal scores as reported by the OHI. Abbrevations: Artisanal Fishing Opportunities (AO), Biodiversity (BD), Coastal Protection (CP), Carbon Storage (CS), Clean Waters (CW), Food Provision (FP), Livelihoods & Economies (LE), Natural Products (NP), Sense of Place (SP) and Tourism & Recreation (TR).

B Experiment Instructions

General Information

Reading progress (0%)

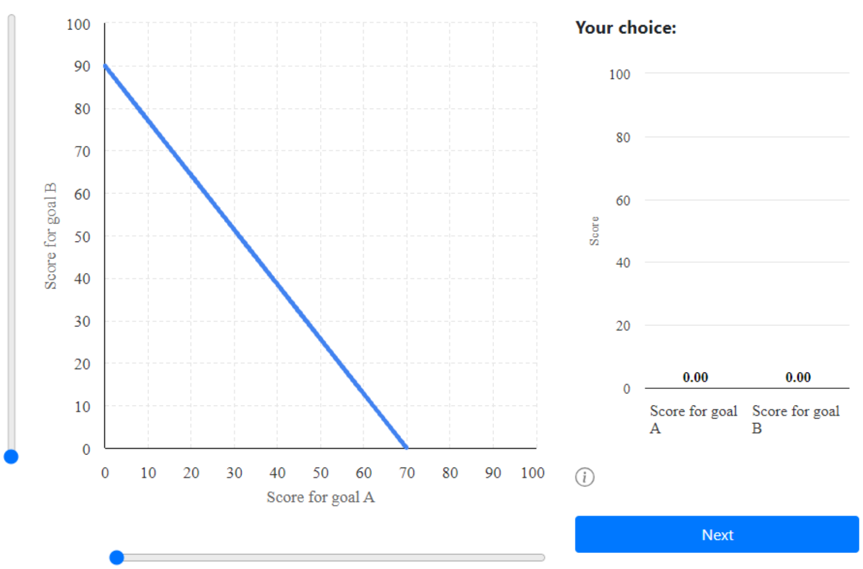
Welcome to this scientific study on decision-making in the field of economic and environmental policy, conducted by researchers at the University of Hamburg.

The results of this study are used for research projects funded by the German Federal Ministry of Education and Research. The results will be used to inform environmental and economic policy decision-making by government agencies. To this end, we will make the study results available to our project partners, the Federal Environment Agency and the Federal Agency for Nature Conservation. It is therefore important that you carefully read, follow and seriously execute all instructions. Note that you will remain anonymous throughout the experiment.

You will likely need about 30 minutes to complete this experiment. The experiment involves a standardized environment in which you are presented with a series of individual decision problems. The experiment ends with a short questionnaire.

Please note that you can <u>not</u> participate in this experiment with a smartphone!

To complete the experiment, you have to concentrate and carefully read and understand our instructions. In addition, you will have to make allocation decisions between different societal goals in graphs such as the following:



Have you read the above and consent?

◯ Yes

◯ No

Would you like to participate in this experiment?

- ◯ Yes
- ◯ No

Next

General Information

Reading progress (

What gender do you identify with?

How old are you?

Next

General Information

Reading progress (28%)

In studies like ours, it sometimes happens that some participants do not carefully read the questions they are asked and simply "click through the survey quickly". Such random responses are problematic because they can bias the research results. It is therefore very important that you pay close attention and read and answer each question carefully.

To show that you read our questions carefully, please answer "Newspapers" (regardless of your own opinion).

- ○ Television
- ○ Newspapers
- ○ Youtube
- ○ Radio
- ○ Reddit
- ○ TikTok
- ○ Other
- ○ Facebook

Next

General Information

Reading progress (43%)

This experiment will focus on various policy goals for the sustainable use of the oceans, taking into account human needs. In this context, an international team of researchers, led by scientists from the *University of California, Santa Barbara*, published a paper in the leading journal *Nature* identifying a total of 10 goals that cover a wide range of societal considerations.

The goals are measured on a scale from 0 to 100, with 0 always representing the lowest (or least sustainable) rating. Correspondingly, 100 represents the highest (or most sustainable) rating.

On the following page you will find a breakdown of the goals, including a brief description for each one.

Please read the goals and their descriptions carefully.

Next

Policy Goals

Reading progress (56%)

Coastal protection

Marine and coastal habitats can provide protection for areas on the coast that are of importance to people. This goal measures that degree of protection. Included are inhabited areas (homes and other structures) and also uninhabited areas (parks, special places, etc.). A score of 100 represents the greatest protection achievable at one point in the past (1975-2010).

Livelihoods and economies

The jobs created by maritime industries and the revenue they generate are of great value to many people, including those not directly involved in these industries. Accordingly, this goal measures both the provision of jobs (and thus livelihoods) by maritime-related industries, as well as the revenue they generate. Here, 100 represents a retention of jobs and economic output. A lower score therefore represents a loss.

Natural products

The seas are not only a source of food, but also of non-food products. Here, a score of 100 here represents the maximum sustainable yield of living marine resources such as corals, shells, seagrass or fish for the aquarium trade. Both overproduction and underproduction result in a lower score, as does the use of unsustainable fishing methods.

Sense of place

People can see aspects of the coastal and marine system as part of their cultural identity. This goal attempts to capture this idea. It applies to both people who live near the sea and those who live far from it but still derive a sense of identity from knowledge of the existence of certain places or species. In this case, sense of place is measured on the basis of the iconic animal and plant species of a region and the persistence of iconic places. A score of 100 corresponds to a state in which no iconic animal and plant species are threatened with extinction and in which all iconic places are under special protection.

Carbon storage

Coastal habitats such as mangroves, sea grasses and salt marshes store large amounts of carbon. They thus contribute to tackling climate change. A score of 100 represents the largest possible area of carbon-storing habitats that a region could achieve in a past reference period (1975-2010).

Food provision

The seas are an important pillar of our food supply. This goal describes the amount of fish and seafood sustainably harvested in a region. Here, 100 represents the maximum sustainable yield. Both overproduction and underproduction result in a lower score, as does the use of unsustainable fishing methods.

Tourism and recreation

Tourism and recreation in coastal areas are an important component of thriving coastal communities and a measure of how much people value the ocean system. By traveling to coastal and marine areas, people express their preference for visiting these places. That's what this goal tries to measure. This goal is not about the revenue or livelihood generated by tourism and recreation, but about the value people assign to experiencing and enjoying coastal areas. Here, 100 represents the highest or most sustainable tourism and recreation value that a comparable region could achieve.

Biodiversity

People value biodiversity and are concerned about the extinction of species and habitats. Both are captured by this goal. A score of 100 therefore corresponds to a state in which no species in a region is threatened with extinction, and the area of habitats (e.g. mangroves, coral reefs, ...) is at a peak compared to a past reference period (1975-2010). Accordingly, endangerment of species and a loss of habitats leads to a lower score.

Clean waters

People value marine waters that are free of pollution and trash, both for aesthetic and health reasons. Residents and people who visit these marine waters in their leisure time are directly affected. Indirectly, it also affects people who care about clean waters, even if they are not in direct contact with them. This goal covers both. A score of 100 represents a pollution level of zero. The greater the pollution, however, the lower the score.

Artisanal fishing opportunities

It may be desirable to preserve different forms of fishing. Here, industrial fishing often contrasts with traditional fishing. The latter often involves only private households or small businesses that operate on a small scale and use the fish mainly for local consumption or local trade. It is also often valued differently by local communities. This goal therefore measures how much the opportunities for traditional fishing are preserved. A score of 100 means that all demand for traditional fishing is permitted or met and is conducted in a sustainable manner.

Next

General Information

Reading progress (71%)

In this experiment, we are interested in how you personally trade off between different policy goals.

The experiment consists of 3 sections with 20 decision tasks (or rounds) each. In each section we show you two random policy goals and give you the task to allocate points between these two policy goals.

In each round, we show you a graph that represents all possible point distributions between the two policy goals. Your task is to select a distribution of points on this graph that, for you personally, most closely represents sustainable use of the oceans while taking human needs into account. A score of 100 always represents the best or most sustainable attainment of a policy goal, and a score of 0 represents the worst or least sustainable attainment of a policy goal.

While some policy goals are naturally interdependent, they are treated as independently relevant when assessing the overall health of the human-ocean system. Thus, even if such interdependencies come to mind we ask you to treat individual policy goals as <u>independent</u> in the following decision tasks. For example, the score you assign to “Biodiversity” should only be based on the importance you attached to that policy goal and not its potential contribution to reaching other goals, such as “Natural Products".

An example of such a graph looks like the following:

In each decision problem, the computer randomly selects a graph.

To choose a distribution, click directly in the graph or use the sliders to select your desired distribution. When you have made your decision, click the "Next" button.

After that, you will be asked to make a distribution in another independent decision. This process is repeated until all 20 rounds are completed.

Before each of the 3 sections, you will receive a brief explanation of the two policy goals between which you are asked to trade off. This explanation will also be displayed to you during the decision task.

Next

Exchange rate between policy goals

Reading progress (86%)

For each decision task, imagine that you only have a certain budget to use to achieve the two policy goals. Pursuing a policy goal and thus achieving a higher score in that area involves effort or cost. The higher the cost, the lower the maximum number of points you can attain in a policy goal, even if you use your entire budget just for that goal.

The cost per point may vary depending on the policy goal. In reality, these costs depend on the specific situation of a country (e.g. geographical location, available technology,...). In this experiment, these costs are randomly chosen in each round to simulate different situations. Your task is to make 20 decisions for the same pair of policy goals, with different costs to attain each goal.

In each round you must use your full budget and cannot use it for other purposes. The (budget-) line thus represents all possible point distributions you can potentially choose based on your budget. You therefore have to make a trade-off, because the more points you want to attain in one policy goal, the less you can attain in the other goal.

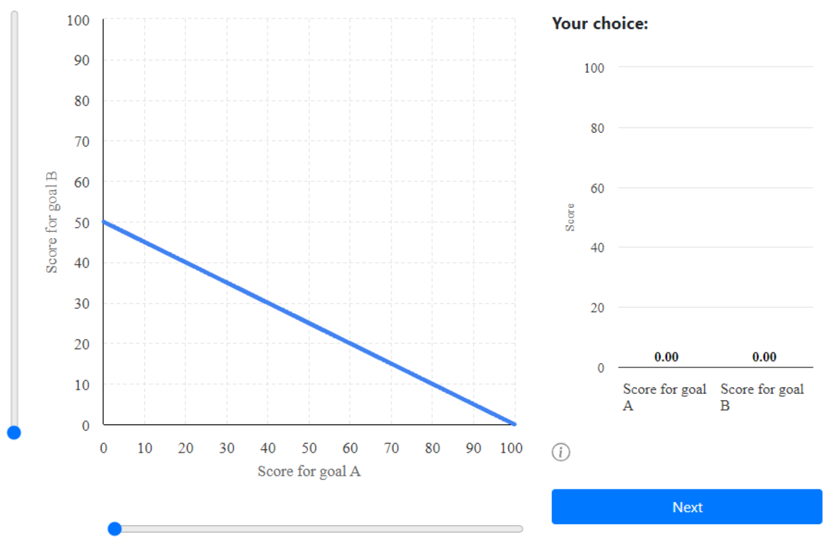
It is important to pay attention to the slope of the budget line, because it displays the ratio in which you can exchange the points of one policy goal for the points in the other policy goal.

Take a look at the two examples below to get a better understanding of these concepts. We will then ask you a comprehension question.

Example 1:

In this situation, if you want to spend your entire budget on only a single policy goal, you can have a total of 100 points for policy goal A or 50 points for policy goal B. So each point for policy goal B is twice as expensive for you as one point for policy goal A.

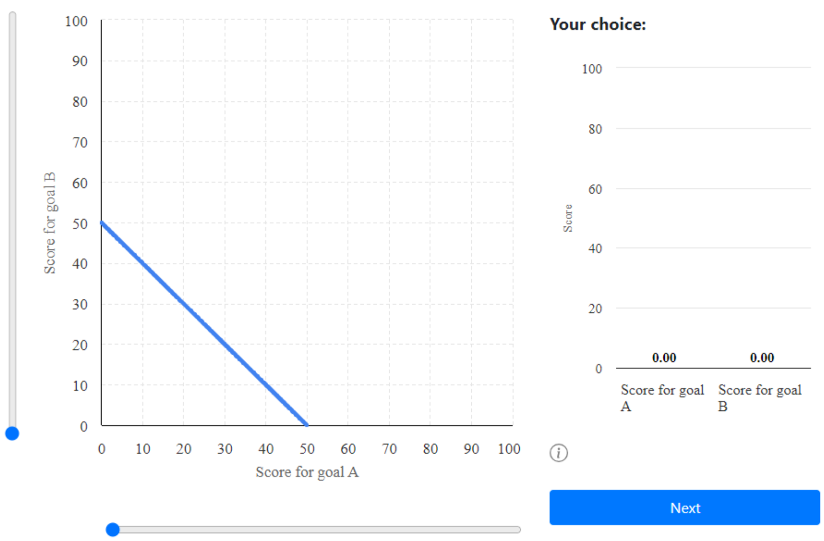
This means that you can increase the score of policy goal A by 2 points for every point you do not spend on goal B.



Example 2:

In this situation, if you want to spend your entire budget on only one policy goal, you can have a total of 50 points for policy goal A or 50 points for policy goal B. In this situation you can only have a maximum of 50 points for both policy goals, but policy goal B is now no more expensive than policy goal A in relative terms.

This means that you can increase the score of policy goal A by exactly 1 point for each point you do not spend on goal B.



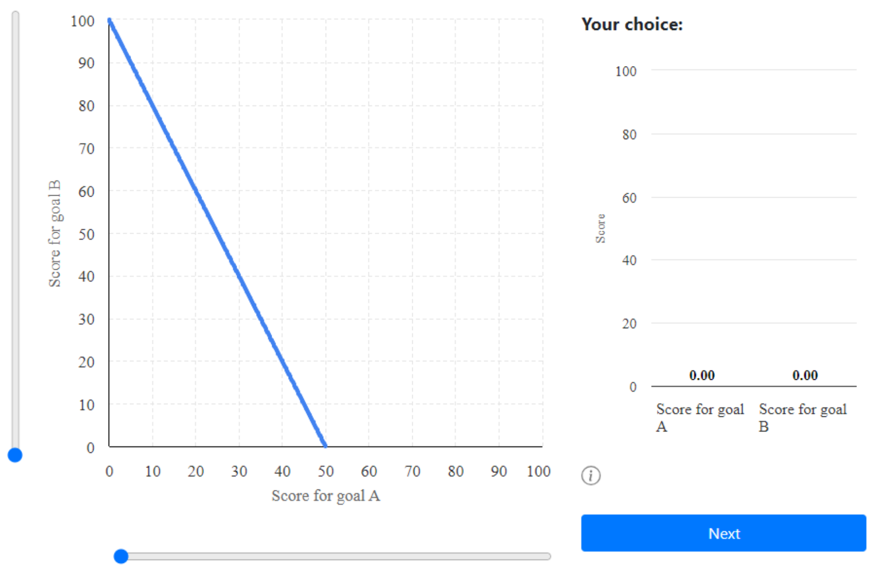
Next

Exchange rate between policy goals

Reading progress (86%)

On the last page you read information about the "exchange rate between policy goals". Please now select the option that best summarizes the costs of allocating points in the following context:

- ◯ The score for goal A could be increased by about 0.5 for every point not spent on goal B.
- ◯ The score for goal A could be increased by about 2 for every point not spent on goal B.
- ◯ The score for goal A could be increased by about 1 for every point not spent on goal B.



Next

Practice rounds

Reading progress (100%)

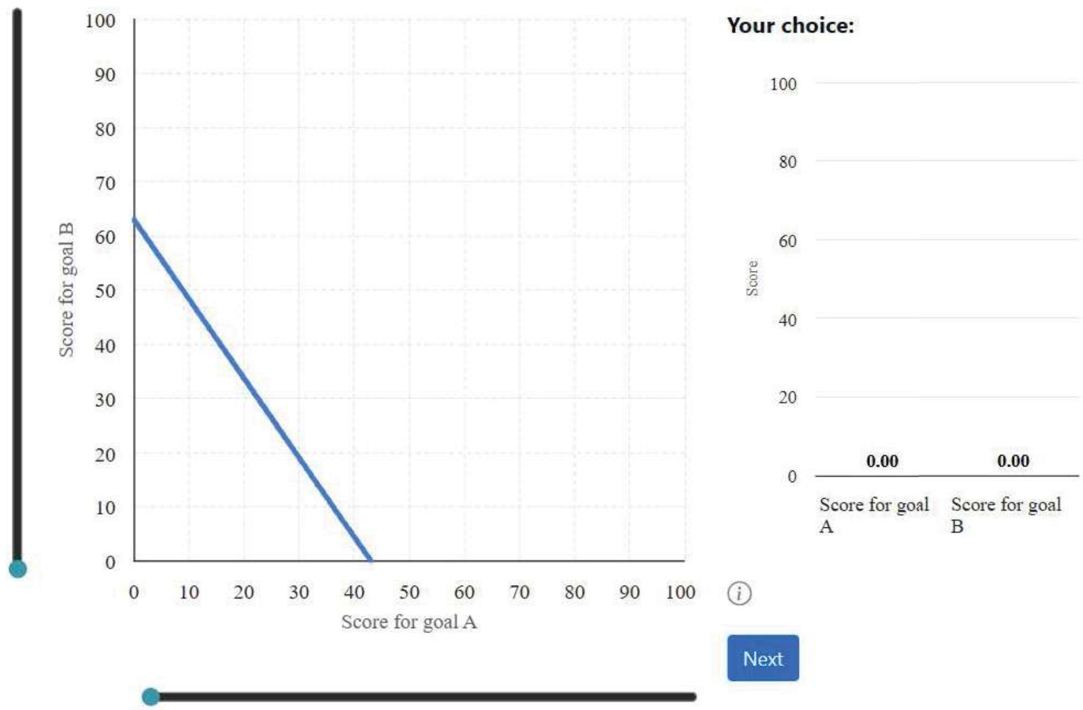
On the next page, we ask you to familiarize yourself with the decision problem. Please click "Next" to start with 3 practice rounds.

Next

Practice rounds

(1/3)

Task:
Please assign a similar number of points to both goals.



During the actual decision tasks, you are shown a reminder of the two policy goals including a description here:

Goal A

Here you can see a short description of goal A in the following decision tasks.

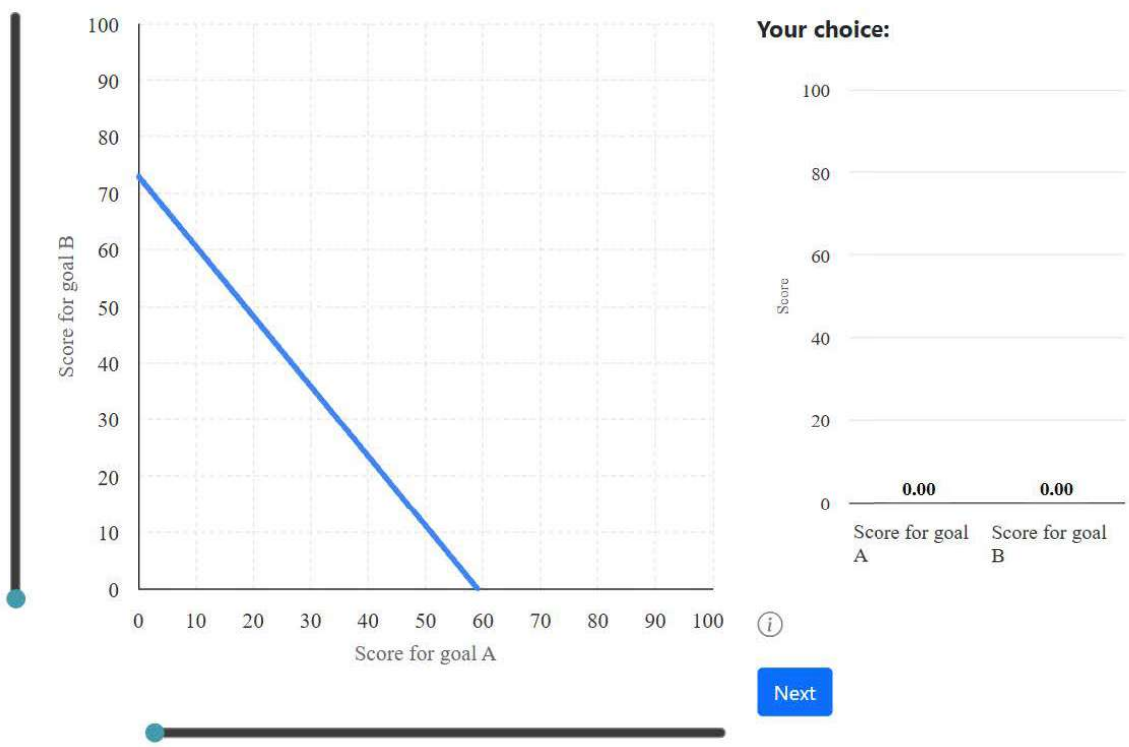
Goal B

Here you can see a short description of goal B in the following decision tasks.

Practice rounds

(2/3)

Task:
Please assign more points to goal A than goal B using the slider.



During the actual decision tasks, you are shown a reminder of the two policy goals including a description here:

Goal A

Here you can see a short description of goal A in the following decision tasks.

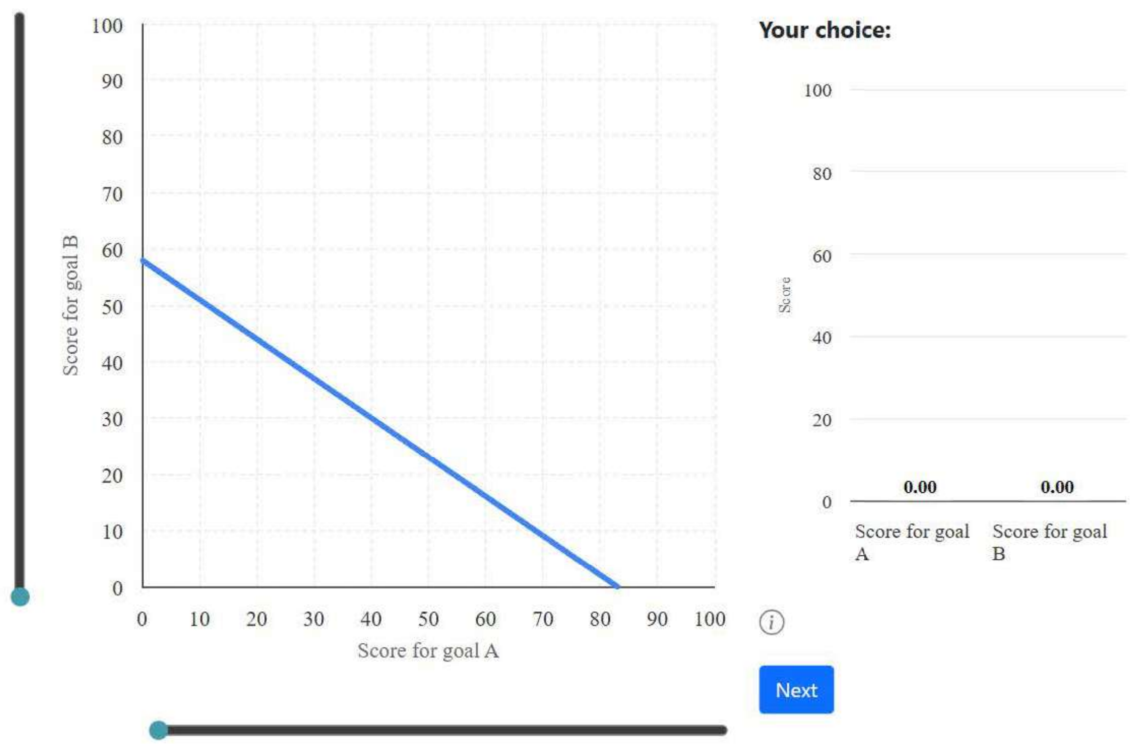
Goal B

Here you can see a short description of goal B in the following decision tasks.

Practice rounds

(3/3)

Task:
Please assign more points to goal B than to goal A by clicking directly into the graph.



During the actual decision tasks, you are shown a reminder of the two policy goals including a description here:

Goal A

Here you can see a short description of goal A in the following decision tasks.

Goal B

Here you can see a short description of goal B in the following decision tasks.

Practice rounds finished

Thank you very much! You have successfully completed all practice rounds.

To start the actual task, please click "Next".

Next

Decision Tasks - Section 1 of 3

In this section, we show possible score allocations between these two policy goals:

Livelihoods and economies

The jobs created by maritime industries and the revenue they generate are of great value to many people, including those not directly involved in these industries. Accordingly, this goal measures both the provision of jobs (and thus livelihoods) by maritime-related industries, as well as the revenue they generate. Here, 100 represents a retention of jobs and economic output. A lower score therefore represents a loss.

Clean waters

People value marine waters that are free of pollution and trash, both for aesthetic and health reasons. Residents and people who visit these marine waters in their leisure time are directly affected. Indirectly, it also affects people who care about clean waters, even if they are not in direct contact with them. This goal covers both. A score of 100 represents a pollution level of zero. The greater the pollution, however, the lower the score.

In each of the following 20 rounds, please select an allocation between the two goals that for you personally closest represents sustainable use of the oceans taking human needs into account. A score of 100 always represents the best or most sustainable attainment of a policy goal. Correspondingly, a score of 0 represents the worst or least sustainable attainment of a policy goal.

Please base your decision on the part of the ocean (or the seas) immediately off the coast of your country (i.e. up to 370 km or 230 miles from the shoreline). Smaller or larger bodies of inland water (e.g. lakes) are not considered.

When making your decision, please disregard the current status quo of your region.

Remember that your decisions represent important information for environmental and economic policy advice.

Please click on "Next" to continue.

Next

Decision Tasks - Section 1 of 3

On the previous page, we informed you about the two policy goals that will be covered in the next rounds. Please select these two policy goals from the list below.

- [ ] Food provision
- [ ] Artisanal fishing opportunities
- [ ] Natural products
- [ ] Carbon storage
- [ ] Coastal protection
- [ ] Livelihoods and economies
- [ ] Tourism and recreation
- [ ] Sense of place
- [ ] Clean waters
- [ ] Biodiversity

To start the actual task, please click "Next".

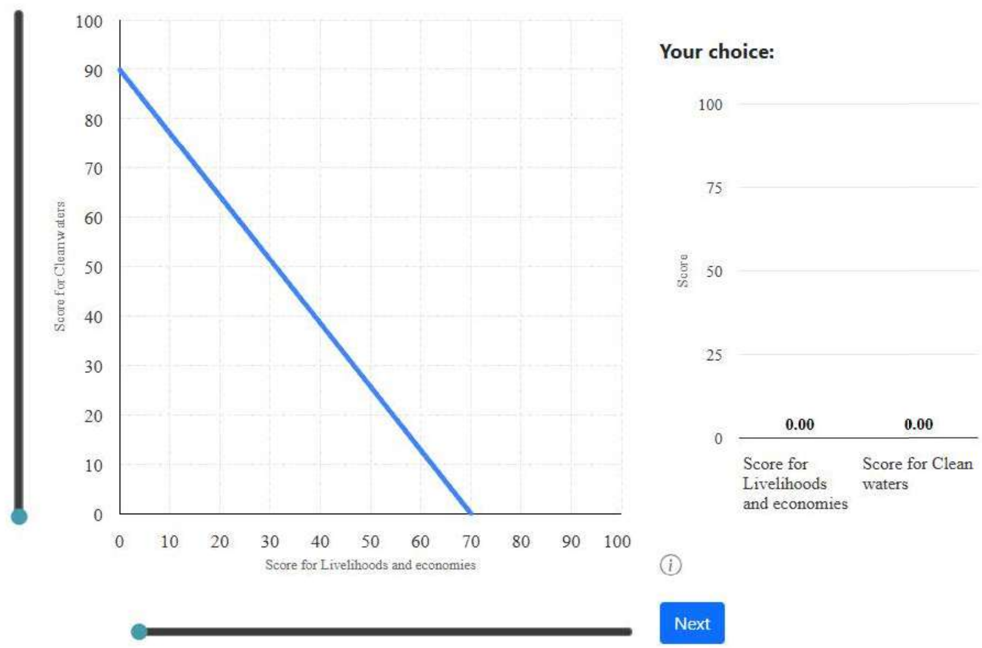
Next

Decision Tasks - Section 1 of 3

(1/20)

Please select an allocation of points between the following two policy goals:
Livelihoods and economies
Clean waters

A score of 100 always represents the best or most sustainable attainment of a policy goal, and a score of 0 represents the worst or least sustainable attainment of a policy goal.



As a reminder, the descriptions of the two policy goals are shown below:

Livelihoods and economies

The jobs created by maritime industries and the revenue they generate are of great value to many people, including those not directly involved in these industries. Accordingly, this goal measures both the provision of jobs (and thus livelihoods) by maritime-related industries, as well as the revenue they generate. Here, 100 represents a retention of jobs and economic output. A lower score therefore represents a loss.

Clean waters

People value marine waters that are free of pollution and trash, both for aesthetic and health reasons. Residents and people who visit these marine waters in their leisure time are directly affected. Indirectly, it also affects people who care about clean waters, even if they are not in direct contact with them. This goal covers both. A score of 100 represents a pollution level of zero. The greater the pollution, however, the lower the score.

Click here to show all policy Goals

Decision Tasks - Section 1 of 3

Thank you very much for your answers. Please click on "Next" to proceed to the next task.

Next

Decision Tasks - Section 2 of 3

In this section, we show possible score allocations between these two policy goals:

Clean waters

People value marine waters that are free of pollution and trash, both for aesthetic and health reasons. Residents and people who visit these marine waters in their leisure time are directly affected. Indirectly, it also affects people who care about clean waters, even if they are not in direct contact with them. This goal covers both. A score of 100 represents a pollution level of zero. The greater the pollution, however, the lower the score.

Natural products

The seas are not only a source of food, but also of non-food products. Here, a score of 100 here represents the maximum sustainable yield of living marine resources such as corals, shells, seagrass or fish for the aquarium trade. Both overproduction and underproduction result in a lower score, as does the use of unsustainable fishing methods.

In each of the following 20 rounds, please select an allocation between the two goals that for you personally closest represents sustainable use of the oceans taking human needs into account. A score of 100 always represents the best or most sustainable attainment of a policy goal. Correspondingly, a score of 0 represents the worst or least sustainable attainment of a policy goal.

Please base your decision on the part of the ocean (or the seas) immediately off the coast of your country (i.e. up to 370 km or 230 miles from the shoreline). Smaller or larger bodies of inland water (e.g. lakes) are not considered.

When making your decision, please disregard the current status quo of your region.

Remember that your decisions represent important information for environmental and economic policy advice.

Please click on "Next" to continue.

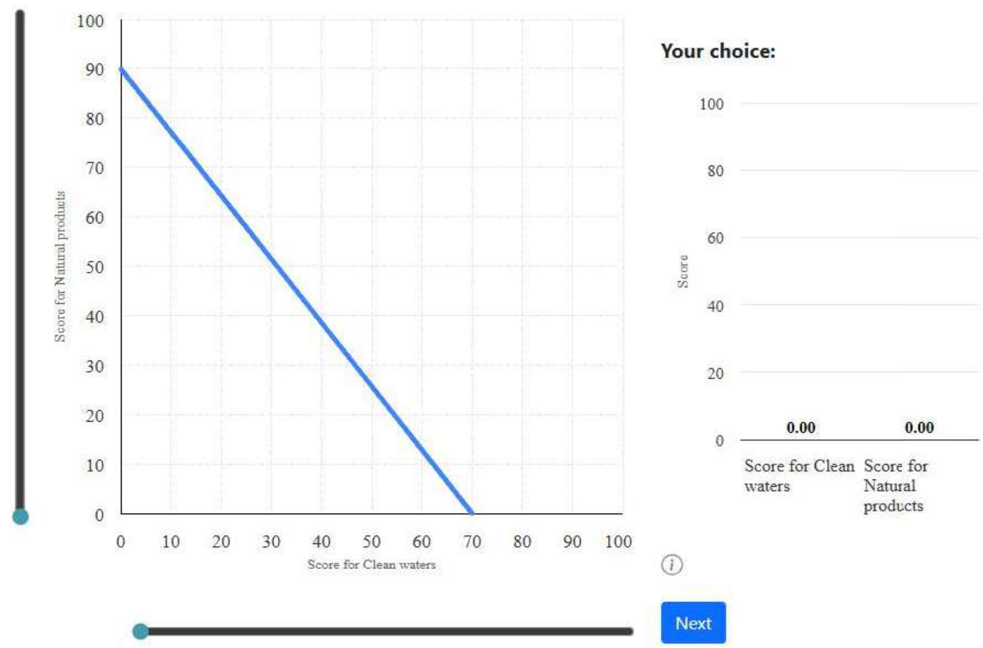
Next

Decision Tasks - Section 2 of 3

(1/20)

Please select an allocation of points between the following two policy goals:
Clean waters
Natural products

A score of 100 always represents the best or most sustainable attainment of a policy goal, and a score of 0 represents the worst or least sustainable attainment of a policy goal.



As a reminder, the descriptions of the two policy goals are shown below:

Clean waters

People value marine waters that are free of pollution and trash, both for aesthetic and health reasons. Residents and people who visit these marine waters in their leisure time are directly affected. Indirectly, it also affects people who care about clean waters, even if they are not in direct contact with them. This goal covers both. A score of 100 represents a pollution level of zero. The greater the pollution, however, the lower the score.

Natural products

The seas are not only a source of food, but also of non-food products. Here, a score of 100 here represents the maximum sustainable yield of living marine resources such as corals, shells, seagrass or fish for the aquarium trade. Both overproduction and underproduction result in a lower score, as does the use of unsustainable fishing methods.

Click here to show all policy Goals

Decision Tasks - Section 2 of 3

Thank you very much for your answers. Please click on "Next" to proceed to the next task.

Next

Decision Tasks - Section 3 of 3

In this section, we show possible score allocations between these two policy goals:

Sense of place

People can see aspects of the coastal and marine system as part of their cultural identity. This goal attempts to capture this idea. It applies to both people who live near the sea and those who live far from it but still derive a sense of identity from knowledge of the existence of certain places or species. In this case, sense of place is measured on the basis of the iconic animal and plant species of a region and the persistence of iconic places. A score of 100 corresponds to a state in which no iconic animal and plant species are threatened with extinction and in which all iconic places are under special protection.

Livelihoods and economies

The jobs created by maritime industries and the revenue they generate are of great value to many people, including those not directly involved in these industries. Accordingly, this goal measures both the provision of jobs (and thus livelihoods) by maritime-related industries, as well as the revenue they generate. Here, 100 represents a retention of jobs and economic output. A lower score therefore represents a loss.

In each of the following 20 rounds, please select an allocation between the two goals that for you personally closest represents sustainable use of the oceans taking human needs into account. A score of 100 always represents the best or most sustainable attainment of a policy goal. Correspondingly, a score of 0 represents the worst or least sustainable attainment of a policy goal.

Please base your decision on the part of the ocean (or the seas) immediately off the coast of your country (i.e. up to 370 km or 230 miles from the shoreline). Smaller or larger bodies of inland water (e.g. lakes) are not considered.

When making your decision, please disregard the current status quo of your region.

Remember that your decisions represent important information for environmental and economic policy advice.

Please click on "Next" to continue.

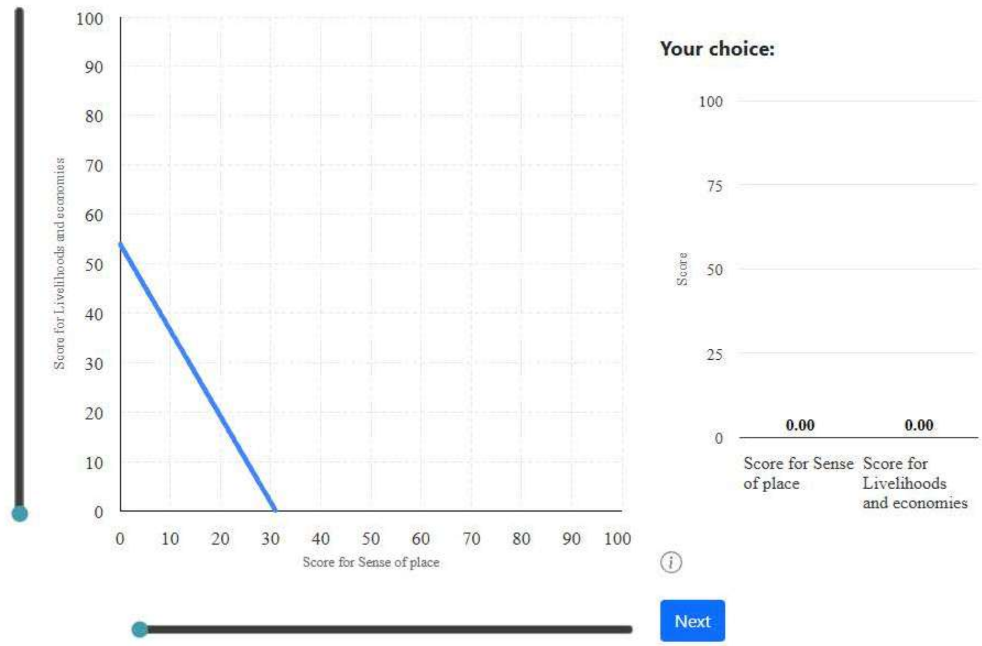
Next

Decision Tasks - Section 3 of 3

(1/20)

Please select an allocation of points between the following two policy goals:
Sense of place
Livelihoods and economies

A score of 100 always represents the best or most sustainable attainment of a policy goal, and a score of 0 represents the worst or least sustainable attainment of a policy goal.



As a reminder, the descriptions of the two policy goals are shown below:

Sense of place

People can see aspects of the coastal and marine system as part of their cultural identity. This goal attempts to capture this idea. It applies to both people who live near the sea and those who live far from it but still derive a sense of identity from knowledge of the existence of certain places or species. In this case, sense of place is measured on the basis of the iconic animal and plant species of a region and the persistence of iconic places. A score of 100 corresponds to a state in which no iconic animal and plant species are threatened with extinction and in which all iconic places are under special protection.

Livelihoods and economies

The jobs created by maritime industries and the revenue they generate are of great value to many people, including those not directly involved in these industries. Accordingly, this goal measures both the provision of jobs (and thus livelihoods) by maritime-related industries, as well as the revenue they generate. Here, 100 represents a retention of jobs and economic output. A lower score therefore represents a loss.

Click here to show all policy Goals

Decision tasks completed

Thank you very much for your answers. Following this last task, we would like you to answer a few more questions.

Next

Questionnaire

How many siblings do you have?

How often have you moved in your life?

How many days a year do you spend on the coast?

How important is the sustainable use of the oceans to you?

Next

Questionnaire

Thank you for your responses. If you have any comments or suggestions about this experiment, please feel free to let us know using the text boxes below. We appreciate your feedback.

Did any part of this survey seem confusing to you, and if so, which one?

Is there anything else that we should know?

Next

End

Thank you for your participation!

Complete survey