# Enabling conservation theories of change

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# Enabling conservation Theories of Change

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**Abstract**

Global Theories of Change (ToCs) can provide broad, overarching guidance for conservation and sustainable use of Earth's ecosystems. However, broad guidance alone cannot inform how conservation actions will lead to desired socio-ecological outcomes. Here, we develop a framework for translating a global-scale ToC into focussed, ecosystem-specific ToCs that consider feasibility of actions, as determined by national socioeconomic and political context (i.e., enabling conditions). We used coastal wetlands as a case study for developing the framework and identified six distinct multinational profiles of enabling conditions ('enabling profiles') for their conservation. For countries belonging to profiles with high internal capacity to enable conservation, we described plausible ToCs that involved strengthening policy and regulation. Alternatively, for profiles with low internal

enabling capacity, plausible ToCs typically required formalising community-led conservation. Our 'enabling profile' framework can be applied to other ecosystems to help operationalise the Kunming-Montreal Global Biodiversity Framework and meet Sustainable Development Goals.

## Introduction

Theories of Change (ToCs) have been used to describe how conservation interventions can achieve desired outcomes[1]. The Convention on Biological Diversity's Kunming-Montreal Global Biodiversity Framework (KM-GBF) has an overarching ToC for achieving a 2050 vision of 'humans living in harmony with nature'[2]. However, the KM-GBF ToC is not described in detail despite recognition that a comprehensive ToC is necessary to achieve its goals and targets[3]. Operationalising the KM-GBF ToC is further challenged by the scale and complexity of the conservation planning task; conservation actions will need to be implemented by a diverse set of actors working internationally, regionally, and locally, including NGOs, governments, and communities[1,4]. Ultimately, many of these actors may benefit from well-defined ToCs that state how action can address drivers of ecosystem loss and degradation, dependent on socioeconomic and political factors that influence conservation feasibility (hereafter referred to as 'enabling conditions'). Enabling conditions are fundamental to the development of a meaningful ToC, as ToCs will not be valid unless social, economic, and political mechanisms are in place to enable conservation action[5].

We propose a framework for translating a global ToC into nested, ecosystem-specific ToCs informed by enabling conditions and drivers of ecosystem loss. Nesting regional or location-specific ToCs within an over-arching ToC, such as the KM-GBF, can help to coordinate multi-actor action towards global conservation goals[1]. Our approach involves three steps (Fig. 1A). 1) Identify and understand 'enabling profiles', which represent unique socioeconomic and political enabling condition contexts for the conservation of a focal ecosystem, e.g., national-scale differences in governance effectiveness, regulatory quality, or NGO support (Fig. 1B). 2) Identify drivers of ecosystem loss and degradation within each enabling profile, such as land-use conversion, pollution, or extractive industries (Fig. 1B). 3) Describe plausible ToCs for each enabling profile, i.e., conservation implementation pathways, ensuring that actions to address drivers of ecosystem loss, such as restoration, policy development, or strengthening regulations (Fig. 1B) are feasible as determined by enabling conditions. Nesting of regional or location-specific ToCs within enabling profiles does not imply that ToCs should be developed from the 'top-down'. Instead, enabling conditions can be used to determine the most effective combination of top-down (e.g., national policy) and bottom-up (e.g., community-led governance) approaches. Importantly, stakeholders representative of all spatial scales within a nested ToC pathway (e.g., national to local) should be involved in its development to ensure just and equitable decision-making. This follows Ostrom's recommendations for managing commonly owned resources via nested cross-scale cooperation and governance, from local to global[6].

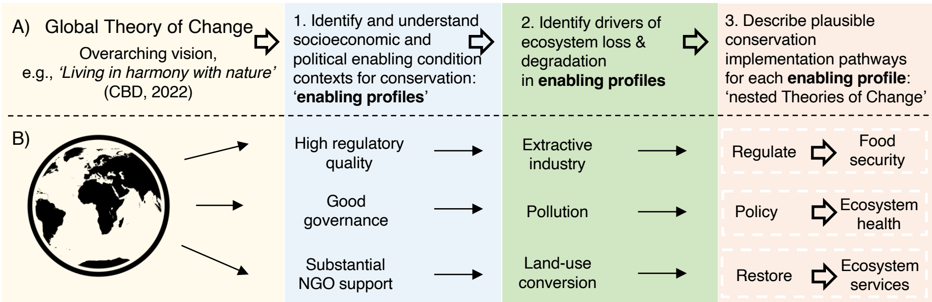



**Fig. 1. Operationalising a global Theory of Change (ToC).** A) Steps to translate a global ToC into nested, ecosystem-specific ToCs informed by enabling conditions, B) Simplified example of three distinct enabling condition contexts (i.e., enabling profiles), their primary drivers of ecosystem loss, and nested ToCs. Note that in this example only one enabling condition and driver of ecosystem loss or degradation are provided for illustrative purposes. In reality there may be multiple, interacting enabling conditions and drivers of ecosystem loss and degradation that will need to be considered when developing a Theory of Change.

Here, we use vegetated coastal wetlands – mangroves, seagrass, saltmarsh – as a case-study to demonstrate the proposed framework and summarise lessons learned as guiding principles for future application to other ecosystems (see Discussion section 'Recommendations for operationalising Theories of Change'). Vegetated coastal wetlands provide important services that support global environmental goals, such as action to regulate climate[7,8] and preserve biodiversity[9]. However, pressure on coastal ecosystems is increasing in all regions of the world[10], degrading these services and creating an urgent need for their conservation. Furthermore, coastal wetlands were under-represented in global ecosystem assessments that informed the Convention on Biological Diversity's previous global ToC, the 'Strategic Plan for Biodiversity'[11], suggesting there is a need for more focused attention on their conservation. The current mechanism for implementing the KM-GBF are National Biodiversity Strategy and Action Plans[12] and so in our case-study we consider how national enabling conditions relevant to coastal wetland conservation can inform the development of multinational enabling profiles and associated ToCs. Nested, sub-national enabling profiles for coastal wetlands could also be established using information on regional (e.g., state-based) and location-specific enabling conditions, thereby informing the development of locally-relevant ToCs. In our case-study we only describe ToCs for seagrass and mangroves because global data on drivers of saltmarsh loss were lacking.

## Results

### Identifying and understanding enabling profiles

From a database of 19 national socioeconomic and political enabling condition indicators (Supplementary Table S1), we used cluster analysis to identify 6 multinational enabling profiles for coastal wetland ecosystems (Fig. 2A). We then used classification trees to determine the relative importance of national indicators in differentiating enabling profiles (Fig. 2B), and how individual indicators define each profile (Fig. 2C). To aid interpretation, we categorised the 19 national indicators into the following groups: 1) Policy – policy commitments and governance frameworks to facilitate conservation work (including international treaties), 2) Regulation – active management of pressures and impacts to the environment, 3) Engagement – active engagement with conservation, either through financial investment (domestic or foreign) or social interest (Fig. 2B&C).

Key indicators differentiating enabling profiles were the regulation of wastewater pollutants, regulation via environmental tax, the number of biodiversity-related projects funded by international aid, domestic conservation spending, Ramsar management, and commitment to international climate policy (Nationally Determined Contributions - NDCs) (Fig. 2B). Post-hoc hierarchical cluster analysis revealed that enabling conditions in Profiles 1 & 2 were less similar relative to Profiles 3, 4, 5 & 6 (Fig. 2A). The majority, i.e., 91%, of countries in Profiles 1 & 2 were high-income countries, 77% of countries in Profiles 3 & 4 were middle-income countries, and 52% of countries in Profiles 5 & 6 were low or lower middle-income countries (see Supplementary Fig. S1 for country income-status and enabling profile designation).

Profiles 1 & 2 had high capacity to enable conservation through policy, regulation, and domestic conservation investment relative to other enabling profiles, however mangroves, seagrass and saltmarsh were not included in their NDC climate mitigation and adaptation policy strategies (Fig. 2C). Profile 2 also had relatively low protection of vegetated coastal wetlands via the Ramsar convention, although implementation of management plans in Ramsar protected areas was high (Fig. 2C). Profiles 3, 4, 5, & 6 generally had higher capacity for enabling conservation through engagement mechanisms linked to foreign aid and social interest, although Profile 1 had relatively high NGO-support for environmental projects and social interest in biodiversity. Conversely, policy and regulatory capacity in Profiles 3, 4, 5 & 6 was typically lower, with the exception of NDC climate mitigation and adaptation strategies and Ramsar protection.

There were clear differences in the policy and regulatory capacity of Profiles 3, 4, 5, & 6 (Fig. 2C). Specifically, Profile 3 had moderate to high capacity for most policy and regulation indicators, whereas Profile 4 had moderate to low capacity on most of these indicators (Fig. 2C). Profile 5 had relatively low policy capacity and moderate regulatory capacity (Fig. 2C). Profile 6 included countries affected by internal conflict (e.g., Somalia) and international sanctions (e.g., North Korea) (Fig. 2A), and had moderate to low capacity for most policy and regulation indicators, with the exception of including vegetated coastal wetlands in NDC climate change mitigation and adaptation strategies (Fig. 2C).

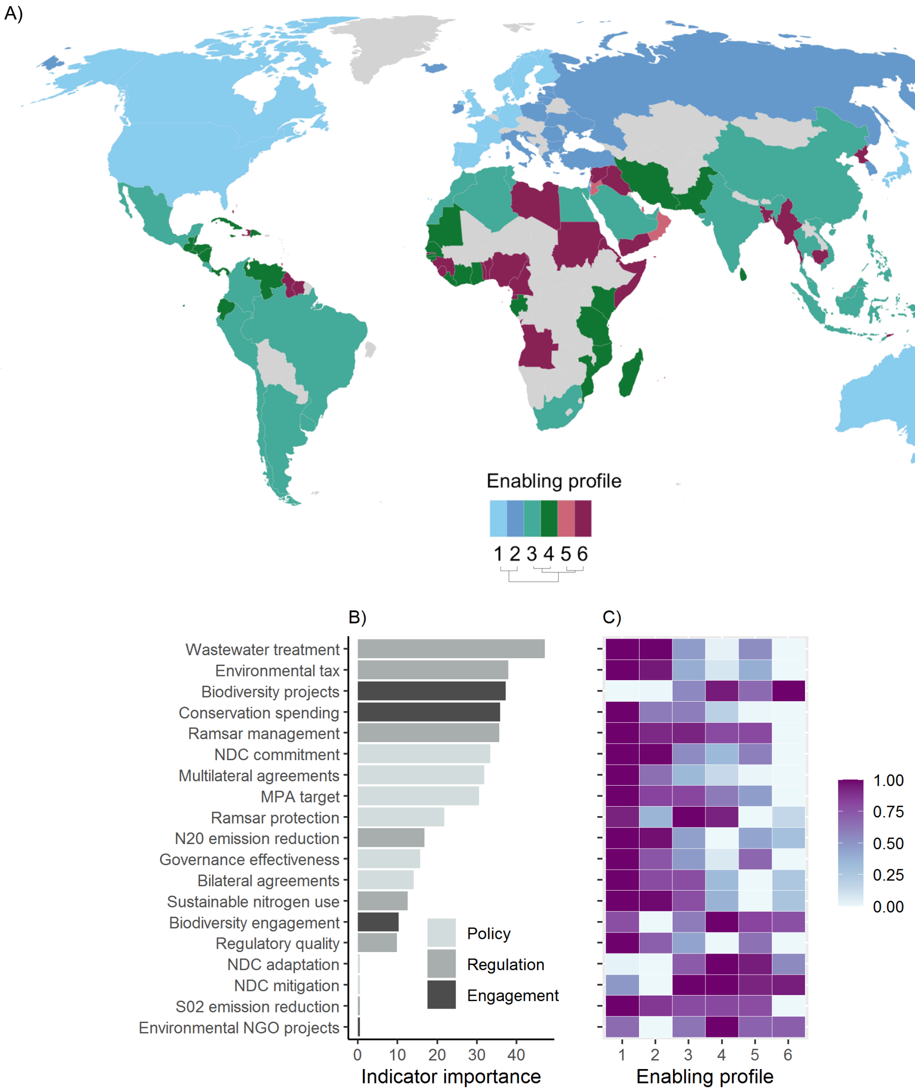



**Fig. 2. Enabling profiles for conserving coastal wetland ecosystems.** A) Enabling profiles for vegetated coastal wetland ecosystems (seagrass, mangroves, and saltmarsh) ordered by their overall similarity (see dendrogram below the profile legend), B) relative importance of national indicators for defining enabling profiles and C) relative ranking of national indicator thresholds across enabling profiles (low = 0 and high = 1). For ease of interpretation, national indicators are grouped as most relevant to policy, regulation or engagement.

**Identifying drivers of ecosystem loss**

We identified drivers of ecosystem loss within enabling profiles for mangroves and seagrass only, as global data on drivers of saltmarsh loss were not available. For mangroves, the main drivers of loss within enabling profiles were non-productive conversion or erosion, although for Profile 3, agri/aquaculture accounted for a substantial proportion of loss (Fig. 3B). Profile 2 countries did not intersect with the global distribution of mangroves and so are absent from Fig. 3.

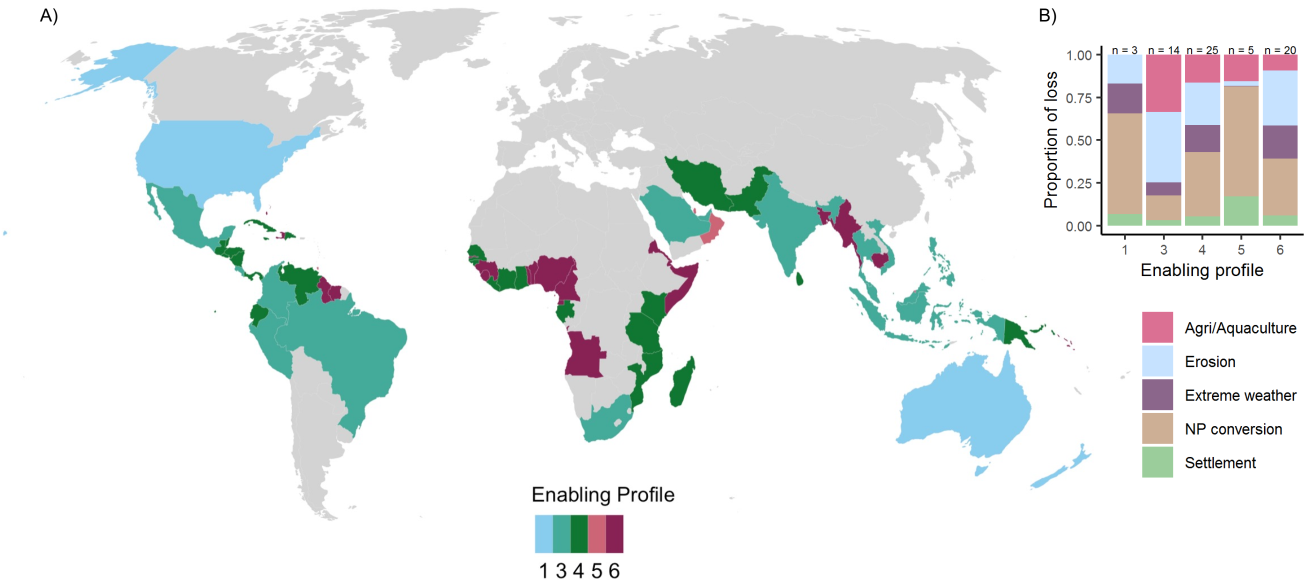



**Fig. 3. Drivers of mangrove loss in enabling profiles.** A) Intersection of enabling profiles with countries where drivers of recent mangrove loss (i.e., agri/aquaculture, erosion, extreme weather events, clearing, and human settlement) have been mapped[40], and B) the proportion of mangrove loss attributed to each driver within each enabling profile (n = number of countries; NP = non-productive).

For seagrass, catchment processes (e.g., coastal development, erosion, flooding) were a driver of loss common to all enabling profiles, while boating-related losses were unique to Profile 1 (Fig. 4). Climate/storms were also a driver of loss for Profiles 1 & 3, aquaculture and fishing drove seagrass loss in Profiles 1, 2, 3, & 4, and disease drove seagrass loss only in Profiles 1 & 4 (Fig. 4). Profile 5 countries did not intersect with the global seagrass change data and so are absent from Fig. 4.

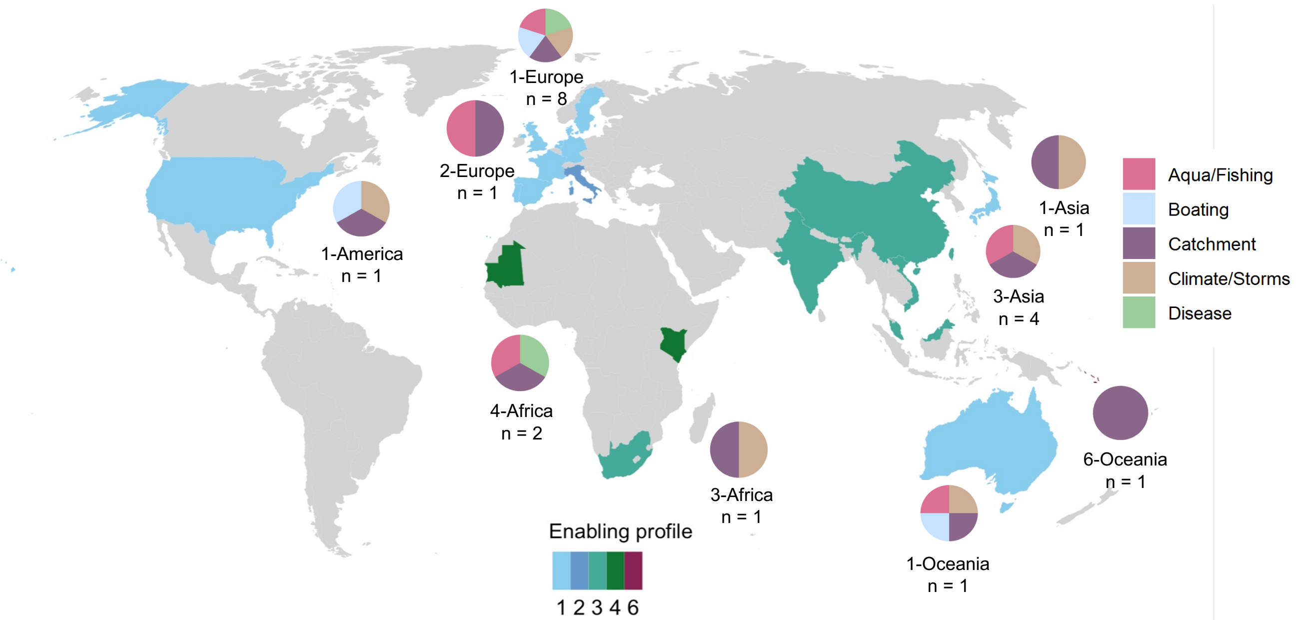
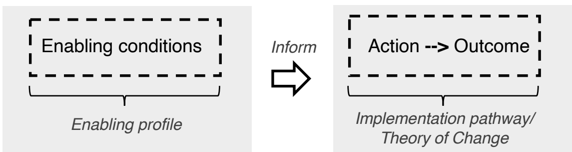


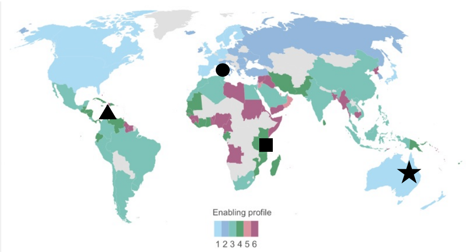

**Fig. 4. Drivers of seagrass loss in enabling profiles**. Countries where seagrass drivers of loss (i.e., aquaculture and fishing, boating, catchment processes, climate and storms, and disease) have been identified, coloured by enabling profile. Pie charts represent the drivers of seagrass trends identified in each continent and enabling profile (n = number of countries). Seagrass driver data represents sites where seagrass drivers have been identified via a synthesis of peer-reviewed literature[41] rather than the entire global distribution of seagrasses.

## Describing plausible, nested ToCs

We described a plausible ToC for conserving mangroves or seagrass in each enabling profile. Our ToC descriptions were formalised as causal statements of how action can address drivers of loss and lead to desired conservation outcomes (*sensu* Qiu et al., 2018[5]; Fig. 5 and see Supplementary Table S2 for a detailed description of all ToCs and case-studies providing qualitative validation). In enabling profiles 1 & 5, non-productive conversion (e.g., vegetation dieback from nearby human development such as mines and roads, harvesting of mangrove trees for timber) was a main driver of mangrove loss, but ToCs differed (Fig. 5; Supplementary Table S2). In Profile 1, improved monitoring of indirect negative effects on mangroves could inform improved policy and regulations to reduce mangrove dieback[13,14] (Fig. 5; Supplementary Table S2). Alternatively, in Profile 5, mangrove clearing for fuel or timber could be reduced if NGOs are engaged to support the development of community-based sustainable management of mangroves and ensure this is recognised in government policy[15] (Fig. 5). For seagrass, ToCs to address the loss driven by aquaculture or fishing differed between Profiles 2 & 4 (Fig. 5). In Profile 2, policy could be established to ensure aquaculture is not placed near seagrass[16]. In Profile 4, external support and funding to establish payments for seagrass ecosystem services could provide an alternative source of income that incentivises the reduction of destructive fishing practices that negatively impact seagrass[17] (Fig. 5).

A) Defining a Theory of Change




B) Examples where mangrove loss is driven by non-productive conversion

| Enabling profile | Enabling conditions | Implementation pathway/ nested Theory of Change | Case study validation |
|---|---|---|---|
| 1 | Capacity to enable conservation via policy and regulation, and domestic funding is high | Monitor indirect effects of development on mangroves --> Tailor policy/regulations to mitigate indirect effects --> Decreased mangrove dieback | Australia: mangrove dieback from herbicide run-off ★ |
| 5 | Capacity to enable conservation via policy, regulation & domestic funding is generally low, but moderately high governance effectiveness | External NGO supports development of community-based sustainable management of mangroves with well-defined resource-use rights --> Government establishes policy that recognises communities as management authority --> Reduced mangrove clearing for fuel and timber | St. Lucia: community-based sustainable management of mangroves ▲ |

C) Examples where seagrass loss is driven by aquaculture or fishing

| Enabling profile | Enabling conditions | Implementation pathway/ nested Theory of Change | Case study validation |
|---|---|---|---|
| 2 | Capacity to enable conservation via policy, regulation and domestic funding is high | Establish policy that prevents fish farms from being established near seagrass --> Reduced loss of seagrass to anoxia associated with fish farm pollution | Cyprus: seagrass recovers following strategic fish-farm placement ● |
| 4 | Capacity to enable conservation via policy, regulation & domestic funding is generally low | External support and funding secured to incentivise community-based management of fishing threats through payments for ecosystem services --> Decreased loss and degradation of seagrass from fishing | Kenya: seagrass payments for ecosystem services ■ |

**Fig. 5. Enabling conditions inform nested Theories of Change (ToC).** A) How to define a ToC, B) selected mangrove case-study ToCs, and C) selected seagrass case-study ToCs. A comprehensive set of ToCs for each enabling profile and coastal wetland ecosystem is provided in Supplementary Table S2, along with a detailed description of supporting case-study examples. An interactive visualisation of the enabling profiles and all case-studies is available at: https://github.com/cabuelow/enabling-profiles-app.

## Discussion

Our framework for operationalising a global Theory of Change (ToC) ensures that enabling conditions underpin action-based pathways towards goals related to conservation and sustainable-use of the planet, thereby increasing the likelihood of achieving desired outcomes[5]. Multinational enabling profiles, such as those developed in our coastal wetland case-study, offer a platform for knowledge transfer between nations that have similar enabling conditions and drivers of ecosystem loss and degradation. In an era of rapid and complex global change, sharing knowledge about how to effectively implement sustainable management practices is important. Our framework could also encourage testing of conservation actions under similar or different enabling condition contexts, thereby encouraging experimental adaptation of ToCs[18].

## Theories of Change for coastal wetland ecosystems

We identified six distinct multinational enabling profiles to inform nested ToCs for globally coordinated conservation of coastal wetland ecosystems. Profiles 1 & 2 generally had high capacity to enable conservation via policy, regulation, and domestic funding relative to other profiles. Many countries in Profiles 1 & 2 belong to the European Union (EU) where multilateral environmental agreements (e.g., the Water and Marine Strategy Framework Directives) have improved water quality and led to recovery of lost seagrass[19]. Alternatively, in Profiles 3, 4, 5 & 6, capacity to leverage support for conservation via engagement with external actors was relatively high (see Supplementary Table S2 for a detailed description of enabling conditions in each profile). In the past, external actors such as NGOs have played an important role in prompting governments of countries in these profiles, e.g., Mexico and South Korea, to effectively implement Ramsar protection of wetlands[20]. We used enabling condition contexts unique to each profile to describe plausible ToCs for addressing dominant drivers of mangrove and seagrass loss (Fig. 5), and used examples of recent conservation interventions to validate proposed implementation pathways (Supplementary Table S2). Our coastal wetland ToCs are most relevant to actors developing and coordinating conservation actions internationally, but sub-national data on enabling conditions could be used to develop ToCs relevant to regional and local scales.

Our case-study had several limitations that impose constraints on the robustness of the enabling profiles and ToCs developed here. Of primary importance is the lack of comprehensive data on indicators for some of the enabling conditions, e.g., 'Conservation spending', 'Ramsar management', 'Biodiversity projects', and 'Environmental NGO projects', which may bias construction of the enabling profiles. Furthermore, ToCs may not address all the important drivers of seagrass loss and degradation in each enabling profile, as these are also not based on globally comprehensive data (see Supplementary Table S3 for a detailed description of all caveats). Our case-study also lacked a systematic process for developing ToCs that engages stakeholders. In the next subsection we make recommendations to guide future application of our framework to other spatial scales and/or ecosystems that is systematic and reproducible.

## Recommendations for operationalising global Theories of Change

Constructing enabling profiles that are representative of all conditions relevant to implementing conservation for a specific ecosystem will require compiling a comprehensive database of appropriate indicators. Where possible, indicators should be chosen systematically by first reviewing the literature for enabling conditions and management actions relevant to the conservation of a focal ecosystem, and then by asking stakeholders and/or external experts to a) confirm the relevance of each indicator identified in the review to enabling conservation action and b) rank the relative importance of relevant indicators to enabling actions against different drivers of ecosystem loss and degradation. In cases where there are several suitable indicators to represent an enabling condition, sensitivity analysis could be used to determine whether results are robust regardless of which indicator is chosen, or whether greater consideration is needed to choose between competing indicators. Rankings of the relative importance of each enabling condition could be used to tailor enabling profiles to the most important drivers of ecosystem loss and degradation. For example, in our case-study, enabling condition indicator scores could be weighted according to their importance for enabling action against dominant drivers of coastal wetland loss in each country. Finally, robust enabling profile construction may be hindered by lack of comprehensive data for indicators of enabling conditions, in which case the limitations this imposes on interpretation of enabling profiles should be communicated to end-users, and effort should be made to fill indicator data gaps in the future to improve enabling profile robustness.

Ideally, effective actions to conserve focal ecosystems will be identified via systematic review of the literature and consultation with stakeholders and/or experts (see recommendations in previous paragraph). Plausible ToCs will describe how specific actions can feasibly address drivers of ecosystem loss given enabling conditions. Guidelines for developing conservation ToCs have been developed comprehensively elsewhere[1,5], and so we do not provide specific recommendations for this process here. However, we do suggest that, where possible, pathways for implementation be tested quantitatively by relating enabling conditions to successful conservation interventions, thereby ensuring ToCs are robust (sensu Williamson et al., 2018[21]). Alternatively, in data-sparse contexts, real-world examples of conservation interventions can provide a qualitative alternative for justifying proposed ToCs, e.g., our case-study validations. We also suggest that where a range of competing plausible implementation pathways are developed, they could become testable hypotheses and form a basis for experimental adaptation of ToCs[18]. If experimentation cannot be used to choose from competing implementation pathways, the heuristic ‘Mitigation and Conservation Hierarchy’ could help differentiate priority actions (i.e., refrain, reduce, restore, renew)[4].

There is no 'one-scale-fits-all' ToC. For example, the nested ToCs that we have described in our case-study may not have sufficient detail or local context for actors working to implement conservation on the ground. To overcome this, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has recognised the need for multi-scale conservation planning[22]. Future applications of our framework could be extended to support multi-scale conservation planning by establishing multi-level, hierarchical enabling profiles that represent enabling condition contexts operating at different spatial scales (e.g., sub-national enabling profiles nested hierarchically within multinational enabling profiles). To be relevant to local-scale conservation practitioners, ToCs could be developed using a participatory framework (*sensu* Reed et al., 2022[23]) that engages actors working across sectors and scales, from local practitioners to international policymakers, and ensures ToCs are just and equitable. It is also important to recognise that human behaviour can play an important role in whether ToCs will achieve desired outcomes. Tacit working models of how human behaviour and conservation relate to one another could be used to integrate this understanding into ToC development[24]. Finally, ToCs will be dynamic, requiring adaptation as enabling conditions and drivers of loss change through time. In our coastal wetland case-study, for example, rapidly developing middle- and low-income countries may acquire greater internal capacity for facilitating conservation and rely less on international aid[25], causing them to shift from Enabling Profiles 3,4,5, or 6 to Profiles 1 or 2. Their ToCs could be adapted based on what has or has not worked for other countries belonging to Profiles 1 or 2.

Nested ToC's could inform the development of globally coordinated National Biodiversity Strategies and Action Plans (NBSAPs), which are the current mechanism for implementing the Kunming-Montreal Global Biodiversity Framework[12]. The effectiveness of NBSAPs is challenged in part by a lack of specific guidelines and accountability for their development[12]. If adopted, our approach provides a quantitative framework that allows NBSAP developers to a) incorporate enabling conditions and drivers of ecosystem degradation into conservation action pathway development (i.e., ToCs), and b) co-create nested ToC pathways with actors working sub-nationally, allowing opportunities for collaboration towards collective national and global conservation goals to be more easily identified. In this way, our framework for nested ToC development acts as a mechanism for cross-scale conservation action. This is especially important for resources such as coastal wetlands that are typically communally owned and threatened by global, regional, and local scale processes, making effective cross-scale coordinating mechanisms, such as nested ToCs, essential[6,26].

A public platform for sharing knowledge could facilitate communication and cooperation between actors working at different levels of a nested ToC pathway or, alternatively, between actors in different enabling profiles that are working to address the same drivers of ecosystem loss. A web-based tool would not only make sharing information and coordinating actions easier, but could also serve as a monitoring, adaptation, and accountability platform to ensure progress towards conservation goals is made[27]. The platform would report on the enabling conditions and conservation plans, actions and outcomes of all contributing parties to the global ToC through time. Ideally the platform would also allow direct integration with NBSAP development and reporting, such as through the NBSAP online forum (https://www.learningfornature.org/en/nbsap-forum/). Making enabling profiles and ToCs underpinning NBSAPs publicly available in an online platform where progress can be tracked could help improve transparency and accountability in NBSAP development.

Operationalising a global ToC with our proposed framework could be challenged by lack of information on enabling conditions and effective conservation actions, and the technical expertise required to gather and analyse data to construct enabling profiles and develop ToCs. International NGOs, intergovernmental organizations, and philanthropists can play a role in providing resources to overcome these challenges. Furthermore, effectively coordinating actions by actors working at different scales and institutions may also require the development of new cooperative mechanisms that increase information exchange and build capacity for achieving common conservation and sustainable development goals.

Global conservation planning and mapping has been criticised for lacking a clear ToC[28]. Whilst global ToCs are at risk of failing to achieve goals if they are not translated effectively into tangible and discrete pathways for implementing action, our framework for operationalising a global ToC ensures conservation efforts are at the forefront in developing robust implementation pathways. Adoption of our framework as a coordinating mechanism for global action towards sustainable use of the Earth's ecosystems will help reduce rates of loss and degradation.

## Methods

### Database of national enabling condition indicators

We compiled a database of national values for 19 policy, regulation, and engagement indicators representative of enabling conditions for vegetated coastal wetland conservation in 138 countries, i.e., 70% of all countries with oceanic coastline. To identify countries with these wetlands, we intersected the EEZ boundaries of countries that have oceanic coastline[29] with the global distributions of mangroves[30], seagrass[31], and saltmarsh[32]. Our enabling condition indicator database was developed via web-based searches for suitable, publicly-available global datasets providing information on policy, regulation and engagement, and whose relevance to coastal wetland conservation was informed by previous research [33,34] (see Supplementary Table S1 for literature supporting our choice of indicators). A caveat of our analysis is that we consider enabling condition indicators and drivers of loss to be static through time (Supplementary Table S3) using indicators with variable temporal ranges (Supplementary Table S1). Ideally, enabling condition indicators will be based on contemporary data and ToCs will be updated accordingly as new information becomes available.

We used national indicators to classify countries into global enabling profiles that represent similar policy, regulation, and engagement settings for conservation. We first used a Bayesian latent variable model (LVM) to gap-fill missing indicator values prior to classification[35]. The LVM estimates correlations among all indicators across countries and leverages these correlations to interpolate missing values. The model assumes that values are 'missing at random', conditional on the other indicators. The model was formulated:

$$\log(\mu_{ij}) = \theta_{0j} + z_i^T \boldsymbol{\theta}_j$$

eqn 1

where $\mu_{ij}$ is the mean response at country $i$ for indicator $j$, $\theta_{0j}$ is the indicator-specific intercept, $z_i$ are vectors of latent variables, and $\boldsymbol{\theta}_j$ are their corresponding indicator-specific coefficients[35]. We set the number of latent variables in our model to 9 (approximately half the number of indicators), which provided accurate estimates of indicator responses (see Appendix 1 in the supplementary materials for a detailed description of model settings). Prior to fitting the LVM, continuous indicator response variables were log-transformed and z-score standardised (mean = 0, standard deviation = 1). We then used equation 1 to predict indicator values to all countries, including interpolating to those countries with missing values. Where indicators were found to have values missing not at random, we fit an additional LVM without these indicators to check our predictions were robust.

Eleven indicators had missing values that were interpolated (see Supplementary Table S1 for the percentage of missing values for each indicator, ranging from 0 – 46%; and see Supplementary Fig. S2 for assessment of model fit). Data for the 'Conservation spending' indicator were only available for countries that were signatories to the Convention on Biological Diversity or the Sustainable Development Goals[36]. However, only one country (the United States) was missing a value for this reason, and all other missing values were due to insufficient data[36]. The 'Ramsar Management' indicator also had non-random missing values because countries without coastal wetland Ramsar sites were designated as 'NA' (Supplementary Table S1). Although there were non-random missing values in these indicators, this did not necessarily violate assumptions of the latent variable model because it assumes missing at random, conditional on other indicators. Furthermore, predictions from LVMs fit with and without each indicator were positively correlated (Supplementary Fig. S3 & S4), demonstrating that parameter estimates were robust. We also performed a simulation study to measure interpolative capacity of LVMs under scenarios where response variables have large proportions of values missing not at random (i.e., 30, 40, and 50%). Under each scenario, we simulated 100 datasets with 20 response variables (n = 100) by randomly drawing values from a multivariate normal distribution (correlation strength varying between -0.5 and 0.5). We then manipulated each simulated dataset so that one variable had large proportions of values missing not at random (i.e., values above the 50$^{th}$, 60$^{th}$ and 70th percentiles were missing). We used LVMs to interpolate missing values for response variables with missing values and found sufficient correlation between simulated data and the LVM predictions under all scenarios (median $R^2$ = 0.65-0.72) to justify the inclusion of variables with high proportions of values missing not at random in our case-study (Supplementary Fig. S5). Supplemental methods for fitting models are also provided in Supplementary Appendix 1.

**Classification of countries into global enabling profiles**

We performed a cluster analysis on the gap-filled, standard-normal indicator values obtained from the LVM to group countries into enabling profiles. Specifically, we used k-medoid clustering with the 'partitioning-around-medoids' algorithm on a Euclidean distance matrix of indicator values. Standard-normal indicator values were rescaled to the minimum and maximum values of the indicator with the narrowest range before clustering to reduce leverage of indicators with exceptionally large ranges (i.e., binomial response variables: NDC commitment, NDC adaptation, NDC mitigation, and Ramsar protection). We investigated a range of clustering configurations (n = 5 to 10) to identify the number of clusters that best represented country-level variability in indicator values, while also identifying general patterns useful for informing coastal wetland conservation. We used average silhouette width[37] to measure the quality of each clustering configuration (i.e., cluster cohesion and separation). All configurations were of similar quality, so we chose 6 clusters as the final configuration because it best balanced national indicator variability with generalisable patterns across countries. We assessed the robustness of clusters by re-evaluating the cluster analysis across the full distribution of indicator values predicted by the LVM (see Supplementary Fig. S6 and S7 for an assessment of the robustness of the final clustering configuration). We also tested the robustness of cluster configurations to the removal of variables with high proportions of missing values (i.e., Conservation spending and Ramsar Management) by calculating the proportion of cases where pairwise clustering differed for each country with removal of these indicators (Supplementary Fig. S8). Overall, the pairwise clustering of the majority of countries was robust to removal of the Conservation spending indicator (pairwise clustering of >50% countries differed in less than 20% of cases) and Ramsar Management (pairwise clustering of >50% of countries differed in less than 10% of cases) (Supplementary Fig. S8). Finally, we used post-hoc hierarchical cluster analysis of cluster medoids to group and order enabling profiles by their similarity, and we used principal components analysis to visualise country-level variability within enabling profiles.

**Indicators defining global enabling profiles**

We used classification trees to determine 1) the relative importance of national indicators in the classification of enabling profiles, and 2) how individual indicators define each profile. Classification trees are non-parametric, supervised machine-learning models that use recursive partitioning to generate decision rules that relate predictor variables (i.e., indicator values) to response variables (i.e., enabling profiles) [38]. Observations are repeatedly split into sub-groups by predictor variables, aiming to minimize heterogeneity of observations in each sub-group of the final tree[38].

To measure the relative importance of indicators, we fit a classification tree using indicator values as predictors of enabling profiles. Indicator importance was measured as the sum of the Gini goodness of split measure where the indicator was a primary splitting variable in the classification tree. Gini goodness of split is measured as the inverse of Gini impurity, an estimate of the probability of misclassification[39]. We also used decision rules generated by individual classification trees, where each indicator was the sole predictor of enabling profiles, to identify indicator thresholds that define each profile. To minimize the influence of outliers on threshold definition, we fit individual classification trees using only indicator values within the interquartile range of each enabling profile. Threshold values were re-scaled from 0 to 1 to provide a relative measure of indicator scores defining each profile, where 0 = low and 1 = high.

**Drivers of ecosystem loss in each enabling profile**

We identified drivers of coastal wetland loss and degradation in each enabling profile using 1) data on drivers of mangrove areal loss derived from satellite data[40], and 2) data on the drivers of seagrass areal loss from a meta-analysis of in-situ and remote sensing data[41]. Global data on drivers of saltmarsh loss was not available[11]. We use the term 'drivers' to refer to environmental stressors (both human and natural) that can cause ecosystem loss and degradation. This is unlike the well-known DPSIR (Driver-pressures-state-impact-response) framework, first elaborated in the European Environment Agency (EEA) programme and later on adopted for other environmental issues in Europe[42], which refers to human environmental stressors as 'pressures'. However, our terminology is consistent with the literature for mangroves[40] and seagrass[41].

Global drivers of mangrove loss from 2010 to 2016 were: erosion, extreme weather events, commodities (i.e., agriculture or aquaculture), non-productive conversion (including clearing and dieback from indirect effects of human development), and human settlement[40]. We calculated the proportion of mangrove loss attributed to each driver in each country, and then averaged these proportions across enabling profiles. This statistic standardizes for differences in overall mangrove area across different countries. Seagrass study locations from Dunic et al., 2021[41] were intersected with country EEZ and enabling profile boundaries, and drivers of trends were identified for each enabling profile and continent to determine opportunities for conservation.

Seagrass data were not globally comprehensive and so the identification of ecosystem loss drivers was limited to countries where peer-reviewed studies identified drivers of trends in seagrass meadow area. Primary drivers were identified from original sources in one of two ways: 1) attribution by visual (aerial imagery or graphical) or inferential (statistical) methods or 2) the driver that was described and discussed most frequently[41]. We opted to exclude the 'invasive species' driver from our analysis because invasive fauna, such as tunicates, crabs, and lugworm disturbance, were not reported in the peer-reviewed literature, which may mis-represent the distribution and influence of this driver. Note that absence of these invasive fauna in the peer-reviewed literature may be due to lack of classification/nomenclature. For example, lugworm disturbance has been identified as a driver of seagrass loss, but the lugworm was not classified as an invasive species[41]. A complete description of mangrove and seagrass drivers is provided in Supplementary Table S4.

**Nested ToCs for each enabling profile**

We described nested ToCs for each enabling profile as causal statements that define how actions can lead to desired conservation outcomes for mangroves and seagrass. Descriptions of plausible implementation pathways were informed by grey and peer-reviewed literature documenting effective action against drivers of ecosystem loss. We used case-study examples to qualitatively validate nested ToCs.

**Data availability**

All input data used in analyses were obtained from published sources cited in the Methods and Supplementary Material, are stored on Github (https://github.com/cabuelow/enabling-theories-of-change), and archived on Zenodo (https://doi.org/10.5281/zenodo.8125788).

**Code availability**

Code to run analyses and reproduce figures is available on Github (https://github.com/cabuelow/enabling-theories-of-change) including an interactive application for exploring the profiles (https://github.com/cabuelow/enabling-profiles-app). Code is archived on Zenodo (https://doi.org/10.5281/zenodo.8125788).

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**Author contributions**

CAB, CJB, RMC, LG, and VT conceived of the project idea; CAB, CJB, RMC, LG, VT, BH, JCD, SYL, BGM, PSM, RMP, AR, MS, AIS, MPT, and JVR contributed to the methodology; LG, CAB, and BH collected the data; CAB and CJB analysed the data; CAB wrote the first draft, and CJB,

RMC, LG, VT, BH, JCD, SYL, BGM, PSM, RMP, AR, MS, AIS, MPT, and JVR contributed to revising the manuscript; CJB, BGM, and RMC resourced the project.

**Competing interests statement**

The authors declare no competing interests.

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# Enabling conservation Theories of Change

## SUPPLEMENTARY MATERIAL

**Table S1. Description of national indicators of policy, regulation and engagement, their relevance to coastal wetland conservation, the temporal range of the underlying data, source information, and the percentage of missing indicator values.**

| Category | Indicator | Description | Relevance | Temporal range (years) | Source | % missing values |
|---|---|---|---|---|---|---|
| Policy | Nationally Determined Contribution (NDC) commitment | The commitment of a country to reducing green-house gas emissions, pledged as Nationally Determined Contributions (NDC). Source data scored countries as: Sufficient = 3, Partially Sufficient = 2, Partially Insufficient = 1, and Insufficient = 0 (Watson et al. 2019). The original NDC commitment score was converted to a binary score where 1 = 'Sufficient' and 'Partially sufficient', and 0 = 'Partially Insufficient' and 'Insufficient'. Countries without a commitment score do not have an NDC strategy, and so were grouped with 'Insufficient' countries. | Indicates whether policy commitment will sufficiently contribute to halving global emissions by 2030 (Watson et al. 2019). | 2015 – 2019 | Watson, R., McCarthy, J.J., Canziani P., Nakicenovic, N., Hisas, L. 2019. The truth behind the climate pledges. The Universal Ecological Fund (FEU-US). Retrieved from https://feu-us.org/ | 0 |
| Policy | Nationally Determined Contribution (NDC) mitigation | Whether coastal wetlands are included in a country's Nationally Determined Contribution (NDC) mitigation strategy (1 = yes, 0 = no). | Represents policy commitment to consider coastal wetland conservation for the purpose of mitigating climate change (Herr and Landis 2016). | 2015 | Herr, D., & Landis, E. 2016. Coastal blue carbon ecosystems Opportunities for Nationally Determined Contributions. Policy brief. *Gland, Switzerland: IUCN and Washington, DC, USA: TNC*. Retrieved from www.bluecsolutions.org | 0 |
| Policy | Nationally Determined Contribution (NDC) adaptation | Whether coastal wetlands are included in a country's Nationally Determined Contribution (NDC) adaptation strategy (1 = yes, 0 = no). | Represents policy commitment to consider coastal wetlands for climate change adaptation (Herr and Landis 2016). | 2015 | Herr, D., & Landis, E. 2016. Coastal blue carbon ecosystems Opportunities for Nationally | 0 |

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|---|---|---|---|---|---|---|
| | | | | | Determined Contributions. Policy brief. *Gland, Switzerland: IUCN and Washington, DC, USA: TNC*. Retrieved from www.bluecsolutions.org | |
| Policy | Multilateral environmental agreements (MEAs) | Cumulative count of a country's multilateral environmental agreements (MEAs) since the year of its first MEA membership until 2019. | Represents commitment to cooperate internationally to prevent or manage human impacts (Mitchell et al., 2020). | 1850 – 2019 | Ronald B. Mitchell. 2020. IEA Membership Count Dataset from the International Environmental Agreements Database Project (Version 20200214). Eugene: IEADB Project. Retrieved from https://iea.uoregon.edu/. Dataset generated on: 14 February 2020 | 1 |
| Policy | Bilateral environmental agreements (BEAs) | Cumulative count of a country's bilateral environmental agreements (BEAs) since the year of its first BEA membership until 2019. | Represents commitment to cooperate internationally to prevent or manage human impacts (Mitchell et al., 2020). | 1850 – 2019 | Ronald B. Mitchell. 2020. IEA Membership Count Dataset from the International Environmental Agreements Database Project (Version 20200214). Eugene: IEADB Project. Retrieved from https://iea.uoregon.edu/. Dataset generated on: 14 February 2020 | 1 |

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|---|---|---|---|---|---|---|
| Policy | Governance effectiveness | Several indicators of perceptions of the quality of a country's public services, civil service, degree of its independence from political pressures, quality of policy formulation and implementation, and credibility of its government's commitment to such policies were aggregated into a single standard-normal score ranging from -2.5 to 2.5 using an unobserved components model. | Represents likelihood that policy commitments will effectively enable conservation (e.g., Amano et al., 2018). | 2019 | Worldwide Governance Indicators, The World Bank. 2019. www.govindicators.org, accessed on [24/11/2020] | 0 |
| Policy | Marine protected areas (MPA) target | The percent of a country's Economic Exclusion Zone (EEZ) set aside as a marine protected area, re-scaled as a performance indicator so that 10% = best, 0% = worst. | Represents degree to which marine and coastal areas are protected (Wendling et al., 2020). | 1990 – 2020 | Wendling, Z., Emerson, J., de Sherbinin, A., and Esty, D. 2020. Environmental Performance Index 2020. New Haven, CT: Yale Center for Environmental Law & Policy. Retrieved from epi.yale.edu | 2 |
| Policy | Ramsar protection | The area of coastal wetlands under Ramsar jurisdiction in a country standardised by coastline length. Ramsar sites with coastal wetlands were selected according to the Ramsar definition of intertidal marshes, intertidal forested wetlands, and marine subtidal aquatic beds. | Represents degree to which internationally-important coastal wetlands are protected (Finlayson et al. 2011). | 1974 – 2021 | The Ramsar Convention Secretariat. 2014. https://rsis.ramsar.org/, accessed on [04/04/2021] | 0 |
| Regulation | Ramsar management | Whether a country has Ramsar-listed coastal wetland sites (i.e., intertidal marshes, intertidal forested wetlands, and marine subtidal aquatic beds) with management plans implemented (0 = no, 1 = yes). If a country did not have any Ramsar-listed coastal wetlands the value was NA. | Represents whether action has been taken towards regulating impacts on protected coastal wetlands (Mauerhofer et al., 2015). | 1974 – 2021 | The Ramsar Convention Secretariat. 2014. https://rsis.ramsar.org/, accessed on [04/04/2021] | 27 |
| Regulation | Regulatory quality | Several indicators of regulatory quality that represent the ability of a country's government to formulate and implement sound policies and regulations that permit and promote private sector development were aggregated into a single standard-normal score ranging from -2.5 to 2.5 using an unobserved components model. | Represents capacity to regulate and manage impacts to the environment (Kaufmann et al. 2010). | 2019 | Worldwide Governance Indicators, The World Bank. 2019. www.govindicators.org, accessed on [24/11/2020] | 0 |

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|---|---|---|---|---|---|---|
| Regulation | Wastewater treatment | The percentage of wastewater that undergoes at least primary treatment in each country, normalised by the proportion of the population connected to a municipal wastewater collection system. | Represents capacity to manage wastewater pollutants that may degrade water quality (Wendling et al., 2020) and negatively impact coastal wetlands. | 2018 | Wendling, Z., Emerson, J., de Sherbinin, A., & Esty, D. 2020. Environmental Performance Index 2020. New Haven, CT: Yale Center for Environmental Law & Policy. Retrieved from epi.yale.edu | 1 |
| Regulation | Sustainable nitrogen use | How far a country is from achieving sustainable nitrogen use for crop fertilisation. The Euclidean distance from an ideal point with optimal nitrogen use efficiency (NUE) and crop yield is measured and rescaled as a performance indicator so that 0 = best performance, $99^{th}$ percentile = worst performance. | Represents capacity to manage negative impacts of nutrient pollution to coastal wetlands (Schaffelke et al., 2005). | 1961 –s 2015 | Wendling, Z., Emerson, J., de Sherbinin, A., & Esty, D. 2020. Environmental Performance Index 2020. New Haven, CT: Yale Center for Environmental Law & Policy. Retrieved from epi.yale.edu | 1 |
| Regulation | Sulphur dioxide ($SO_2$) emission reduction | The average annual rate of increase or decrease in $SO_2$ adjusted for economic trends to isolate change due to policy rather than economic fluctuation and rescaled as a performance indicator so that the most negative trend = best performance, and the trends in the top $95^{th}$ percentile = worst. | Represents capacity to manage negative impacts of air pollution (e.g., acidification and poor water quality (Wendling et al., 2018)) that may degrade coastal wetlands. | 2005 – 2014 | Wendling, Z., Emerson, J., de Sherbinin, A., & Esty, D. 2020. Environmental Performance Index 2020. New Haven, CT: Yale Center for Environmental Law & Policy. Retrieved from epi.yale.edu | 3 |
| Regulation | Nitrous oxide ($N_2O$) emission reduction | The average annual rate of increase or decrease in $N_2O$ adjusted for economic trends to isolate change due to policy rather than economic fluctuation and rescaled as a performance indicator so that the most negative trend = best performance, and the trends in the top $95^{th}$ percentile = worst. | Represents capacity to manage negative impacts of air pollution (e.g., acidification and poor water quality degradation (Wendling et al., 2018)) that may degrade coastal wetlands. | 2005 – 2014 | Wendling, Z., Emerson, J., de Sherbinin, A., & Esty, D. 2020. Environmental Performance Index 2020. New Haven, CT: Yale Center for | 3 |

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|---|---|---|---|---|---|---|
| | | | | | Environmental Law & Policy. Retrieved from epi.yale.edu | |
| Regulation | Environmental taxes | A measure of the number of taxes, charges, or fees for the following categories: 1) environmental management, 2) air pollution, 3) energy, 4) noise pollution, 5) fossil fuels, 6) transport management, 7) waste management, and 8) water management. A final 'environmental fee' score for each country was calculated as the sum of the number of taxes, fees, or charges (rescaled between 0 and 1) across all eight categories. | Represents the implementation of pricing instruments that can improve environmental quality (Bashir et al. 2020). | 1980 – 2020 | OECD, Policy Instruments for the Environment (PINE) Database, http://oe.cd/pine , accessed on [24/11/2020] | 40 |
| Engagement | Conservation spending | Average annual conservation investment (I$m) for countries that are signatories to the Convention on Biological Diversity (CBD) and Sustainable Development Goals (SDGs). Sources of investment include government, donors, trust funds and self-funding via user payments. For countries that were not signatories to the SDGs or CBDs, or data was insufficient to estimate average annual conservation investment, values were gap-filled (see methods). | Represents engagement in conservation through domestic financial investment (Waldron et al., 2017). | 1992 - 2003 | Waldron, A., Mooers, A. O., Miller, D. C., Nibbelink, N., Redding, D., Kuhn, T. S., Timmons Roberts, J., & Gittleman, J. L. 2013. Targeting global conservation funding to limit immediate biodiversity declines. https://doi.org/10.5061/dryad.p69t1<br><br>Waldron, A., Miller, D. C., Redding, D., Mooers, A., Kuhn, T. S., Nibbelink, N., Roberts, J. T., Tobias, J. A., & Gittleman, J. L. 2017. Reductions in global biodiversity loss predicted from | 46 |

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|---|---|---|---|---|---|---|
| | | | | | conservation spending. Nature, 551, 364–367. https://doi.org/10.1038/nature24295 | |
| Engagement | Biodiversity projects | The number of biodiversity-related conservation projects in a developing country that are receiving funding from OECD (Organisation for Economic Cooperation and Development) countries, standardised by country area ($km^2$). High income countries generally do not receive development assistance, although there are some exceptions (8 countries). | Represents foreign investment in biodiversity conservation (e.g., Miller, 2014). | 2002 – 2017 | http://www.oecd.org/dac/stats/biodiversity.htm, accessed on [24/11/2020] | 0 |
| Engagement | Environmental NGO projects | The number of environmental NGO aid projects in a country standardised by country area ($km^2$). Note that data is provided on a voluntary basis and so is not fully comprehensive. Due to the voluntary nature of reporting, this variable should be interpreted as an indication of engagement and policy advocacy rather than absolute number of projects. | Represents NGO engagement and policy advocacy to bolster conservation initiatives (e.g., Pacheco-Vega & Murdie, 2021). | 1970 – 2020 | https://ngoaidmap.org/, accessed on [24/11/2020] | 0 |
| Engagement | Biodiversity engagement | A score based on the number of times biodiversity key words have been sourced from twitter, online newspapers and google in a country (per month). The percentage of tweets or online newsletters that contain a species or keyword in each country was calculated and then rescaled between 0 and 100. Google trends data (already rescaled between 0 and 100) for each keyword are averaged for a country. A final score was calculated by averaging across scores for tweets, online newsletters and google trends. | Represents public awareness of biodiversity topics (Cooper et al. 2019) and is a proxy for social willingness to engage in conservation action. | 2017-2019 | http://biodiversityengagementindicator.com/, accessed on [24/11/2020] | 9 |

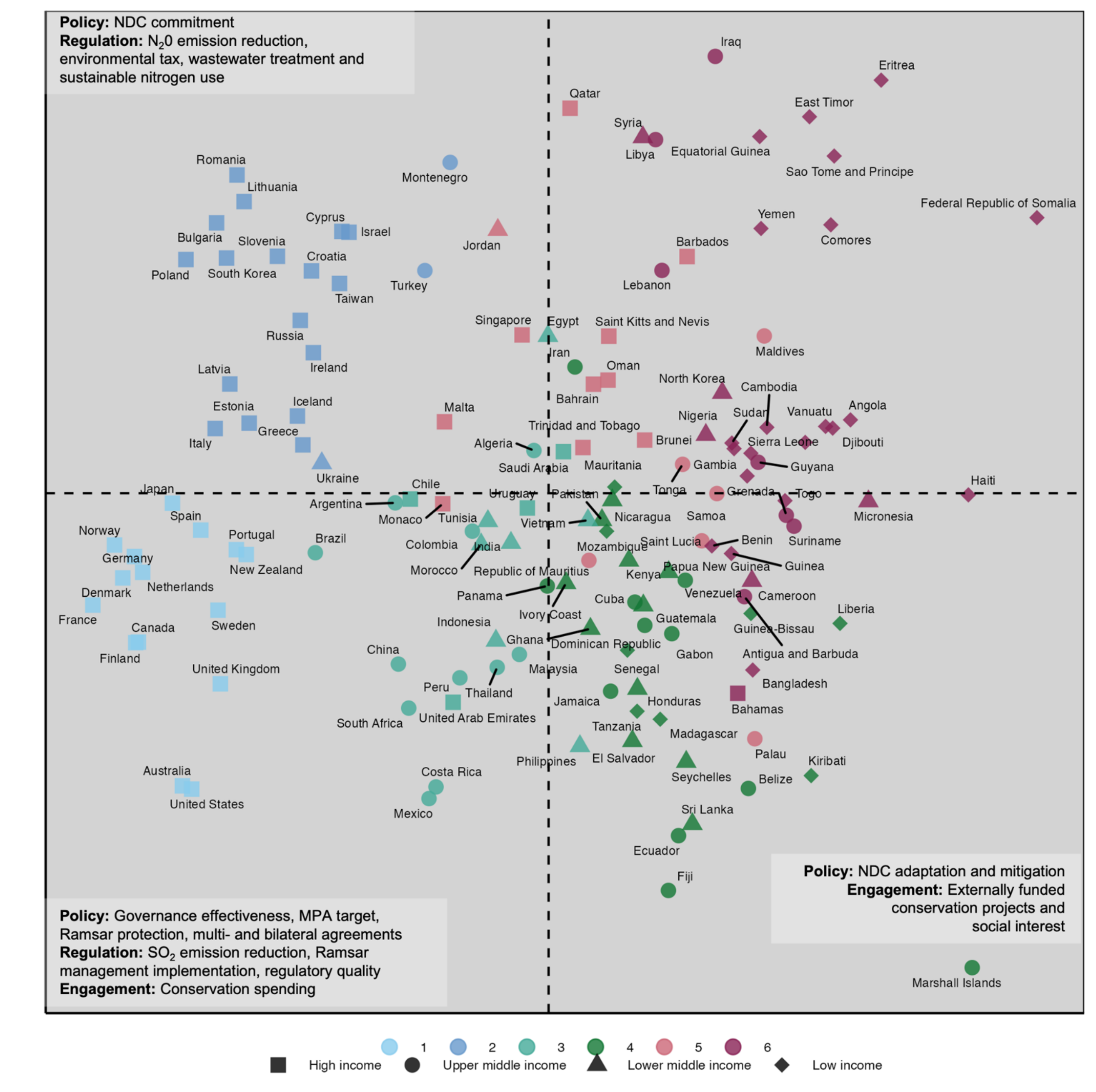


**Fig. S1. Ordination of countries according to their national indicator values using principal components analysis.** Indicators positively correlated with each quadrant of the ordination are listed. Colours represent global enabling profiles (see Table S2 below for details) and shapes represent country income status.

**Table S2. Theories of Change for mangrove and seagrass conservation in each enabling profile.** Enabling conditions are described as the current status of policy, regulatory and engagement mechanisms (classified as 'low', 'moderate', or 'high' based on the relative ranking of indicator thresholds across enabling profiles in Figure 1C). Drivers of loss were identified differently for mangroves and seagrass. For mangroves we chose the most prevalent driver of loss, while for seagrass we chose the driver of loss that was shared across all continents belonging to a profile. Potential pathways for addressing drivers of mangrove and seagrass loss given enabling conditions are described for each profile, supported by a case-study example.

| Enabling profile | Enabling conditions (status of policy, regulatory and engagement indicators) | Driver of loss | Implementation pathway/nested ToC | Case-study example (qualitative validation of implementation pathway) |
|---|---|---|---|---|
| 1 | **Policy**: high, except for prioritisation of vegetated coastal wetlands in NDC mitigation and adaptation strategies.<br><br>**Regulation**: high.<br><br>**Engagement**: moderate to high, except foreign investment in biodiversity projects. | **Mangroves:** clearing/non-productive conversion<br><br>**Seagrass:** catchment processes (e.g., coastal development & poor water quality) and climate/storm events | **Mangroves:** Monitor indirect effects of development on mangroves -><br>Tailor policy/regulations to mitigate indirect effects -> decreased loss of mangroves to non-productive conversion<br><br>**Seagrass:** Establish seagrass as an indicator of ecosystem health in catchment policy -> improved monitoring and management of catchment threats to seagrass -> reduced loss of seagrass to catchment processes | **Mangroves:** Herbicide run-off from crops caused mangrove dieback in Australia (Duke et al. 2005). Focussed regulation of herbicides could help to avoid future losses of mangroves due to the indirect effects of nearby agricultural production (King et al. 2013).<br><br>**Seagrass:** Seagrass was established as a biological quality element (BQE) to be used as an indicator of ecosystem health (when compared to reference conditions and integrated with other BQEs) in the EU Water Framework Directive, leading to improved management and seagrass recovery (de los Santos et al., 2019). |
| 2 | **Policy**: high, except for prioritisation of vegetated coastal wetlands in NDC mitigation and adaptation strategies, and protection via the Ramsar convention.<br><br>**Regulation**: high.<br><br>**Engagement**: moderate to low. | **Mangroves:** not present in this profile<br><br>**Seagrass:** Aquaculture/fishing | **Mangroves:** not present in this profile<br><br>**Seagrass:** Establish policy that prevents fish farms from being established near seagrass -> reduced loss of seagrass to anoxia associated with fish-farm pollution | **Mangroves:** not present in this profile<br><br>**Seagrass:** Following substantial seagrass loss, managers in Cyprus only allowed fish farms to operate in deep waters and seagrass expansion and recovery was documented (Kletou et al. 2018). |
| 3 | **Policy**: moderate to high.<br><br>**Regulation**: moderate to high.<br><br>**Engagement**: moderate. | **Mangroves:** commodities and erosion<br><br>**Seagrass:** catchment processes (e.g., | **Mangroves:** Establish national policy to protect mangroves from conversion to commodities and restore areas that have been converted -> incentivise community-lead restoration and sustainable management -> reduced loss of mangroves and livelihoods maintained | **Mangroves:** The Indonesian government established policy to naturally rehabilitate mangroves via permeable dams, a 'Building with Nature' hybrid engineering approach to preventing erosion, while also |

| | | | | |
|---|---|---|---|---|
| | | coastal development & poor water quality) and climate/storm events | **Seagrass:** NGOs raise awareness and lobby for management of catchment-based threats to seagrasses -> government establishes policy to manage catchment-based threats -> reduced seagrass loss | fostering community involvement and ownership with assistance from an NGO (Winterwerp et al. 2020).<br><br>**Seagrass:** An NGO has partnered with the Malaysian government to establish seagrass conservation projects in Malaysia, given the critical role of seagrass as habitat for dugongs (https://www.dugongconservation.org/where-we-work/malaysia/). |
| 4 | **Policy**: moderate to low, except that capacity for Ramsar protection and prioritisation of vegetated coastal wetlands in NDC mitigation and adaptation strategies was high.<br><br>**Regulation**: moderate to low, except that capacity for implementation of management plans in Ramsar-listed wetlands and reduction of sulphur dioxide emissions was high.<br><br>**Engagement**: high, except for domestic conservation spending. | **Mangroves:** clearing/non-productive conversion<br><br>**Seagrass:** aquaculture/fishing | **Mangroves:** NGO and governmental support for establishing community-lead sustainable management of mangroves -> reduced mangrove loss of mangroves for timber harvesting and livelihoods maintained<br><br>**Seagrass:** External support and funding secured to incentivise community-based management of fishing threats through payments for ecosystem services -> decreased loss and degradation of seagrass from fishing | **Mangroves:** In Madagascar a small-scale crab fishery lead to increased harvesting of mangroves for timber, but community-lead management supported by NGOs and government actors resulted in reduced mangrove loss (Long et al. 2021).<br><br>**Seagrass:** Support from an NGO and external funding established a payments for ecosystem services (PES) project in Kenya that enables carbon credits to be secured from seagrass, thereby providing an alternative source of income for local communities that depend on seagrass for fishing (via destructive practices; i.e., beach seining and trawling) (Shilland et al. 2021). |
| 5 | **Policy:** moderate to low, except for commitment to NDCs, prioritisation of vegetated coastal wetlands in NDC mitigation and adaptation strategies, and governance effectiveness.<br><br>**Regulation:** moderate to low, except that capacity for Ramsar management and sustainable nitrogen use high. | **Mangroves:** clearing/non-productive conversion<br><br>**Seagrass:** not present in this profile | **Mangroves:** External NGO support for developing community-based sustainable management of mangrove forests with well-defined resource-use rights -> Government establishes policy that recognises communities as management authority -> reduced mangrove clearing for fuel and timber<br><br>**Seagrass:** not present in this profile | **Mangroves:** Mangroves in St. Lucia were historically cleared for charcoal production. Establishment of a common property institution that recognised resource rights of the local community and incentivised sustainable management resulted in reduced mangrove degradation (Smith and Berkes 1993). Subsequently, the St. Lucian government supported community-based management of mangroves by establishing policy that protected the mangroves but also formalised charcoal producers as the management authority.<br><br>**Seagrass:** not present in this profile |

| | | | | |
|---|---|---|---|---|
| | **Engagement:** moderate to high, except for domestic conservation investment. | | | |
| 6 | **Policy**: low, except for prioritisation of vegetated coastal wetlands in NDC mitigation and adaptation strategies.<br><br>**Regulation**: low.<br><br>**Engagement**: moderate to high, except for domestic conservation investment. | **Mangroves:** erosion<br><br>**Seagrass:** catchment processes (e.g., coastal development & poor water quality) | **Mangroves:** External NGO and industry actors provide support for installing permeable dams that trap sediment and provide space for mangrove regeneration and planting -> develop ecotourism as a livelihood that incentivises community involvement in mangrove conservation -> self-sustaining management of mangroves that reduces loss to erosion<br><br>**Seagrass:** External and state actors establish policy to raise awareness of the importance of seagrass -> build seagrass research and monitoring capacity -> inform catchment-based management plans -> reduced loss of seagrass from catchment-based threats | **Mangroves:** Erosion is a driver of loss in Suriname, and **s**everal external actors (industry and NGOs) installed permeable dams and initiated mangrove planting in Suriname to raise awareness and involve local communities in mangrove conservation (Winterwerp et al. 2019).<br><br>**Seagrass:** In the Solomon Islands, terrestrial logging is a major threat to seagrass due to increased sedimentation and turbidity in the coastal zone (Brodie et al. 2020). To inform watershed management planning, the Solomon Islands government secured external support and funding to establish policy that aimed to raise awareness of the need for seagrass conservation and improve research and monitoring to enable better protection of seagrass as critical habitat for dugongs (WorldFish 2018) |

**Table S3. Caveats of the data and analysis.**

| Caveat | Description |
|---|---|
| Temporality of indicators | Data underlying indicators have different temporal ranges (Table S1) and all indicators are dynamic, therefore enabling conditions within countries are subject to constant change, such as with policy revisions or nations signing onto international agreements. |
| Interpolation of missing indicator values | Missing values for the 'Conservation spending' and 'Ramsar management' indicators had non-random missing values. However, assessment of the sensitivity of the latent variable model parameter estimates demonstrates that predictions were robust (Figure S3 & S4). A simulation study also demonstrated that latent variable models can adequately interpolate large proportions of missing not at random indicator values (Figure S5). Finally, pairwise clustering of the majority of countries was robust to removal of indicators with large proportions of missing values (Figure S8). |
| Data gaps in drivers of seagrass and saltmarsh loss | Globally comprehensive data on drivers of seagrass and saltmarsh loss was not available, constraining the opportunities for vegetated coastal wetland conservation that were able to be identified. |
| Indicators not specific to coastal wetlands | Not all indicators were specific to vegetated coastal wetlands (e.g., MPA target), but were included for their relevance to conservation more broadly. |
| Current and future drivers of coastal wetland loss were not considered | Only historical drivers of mangrove and seagrass loss were used to identify opportunities for vegetated coastal wetland conservation. |
| Assume drivers of ecosystem loss act additively | Drivers of ecosystem loss can interact to accelerate or mitigate loss, so sub-national analysis of opportunities should consider the potential for interactions. |
| Indicator bias | Two engagement indicators, 'Biodiversity projects' and 'Environmental NGO projects' were biased towards middle and low-income countries, as high-income countries are less likely to receive Organisation for Economic Cooperation and Development (OECD) and non-governmental organisation (NGO) aid funding. |
| Seagrass drivers | Data on drivers of seagrass loss was obtained from a literature synthesis (Dunic et al. 2021) but was not systematically reviewed or comprehensive to the global distribution of seagrass. For instance, invasive fauna such as tunicates, crabs and lugworms were not reported in the peer-reviewed literature, and therefore we opted to exclude this driver category to avoid mis-representation. |

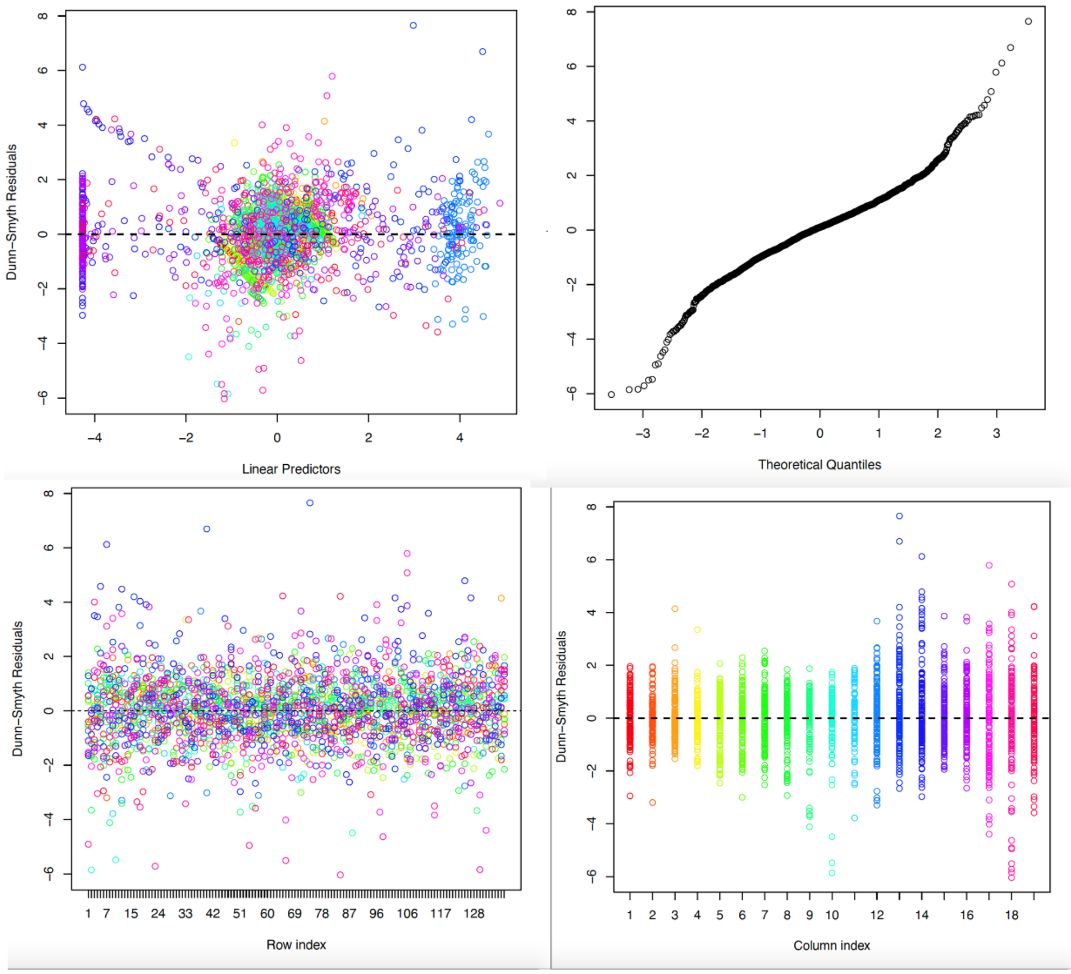


**Fig. S2. Randomised quantile residual plots for the latent variable model.**

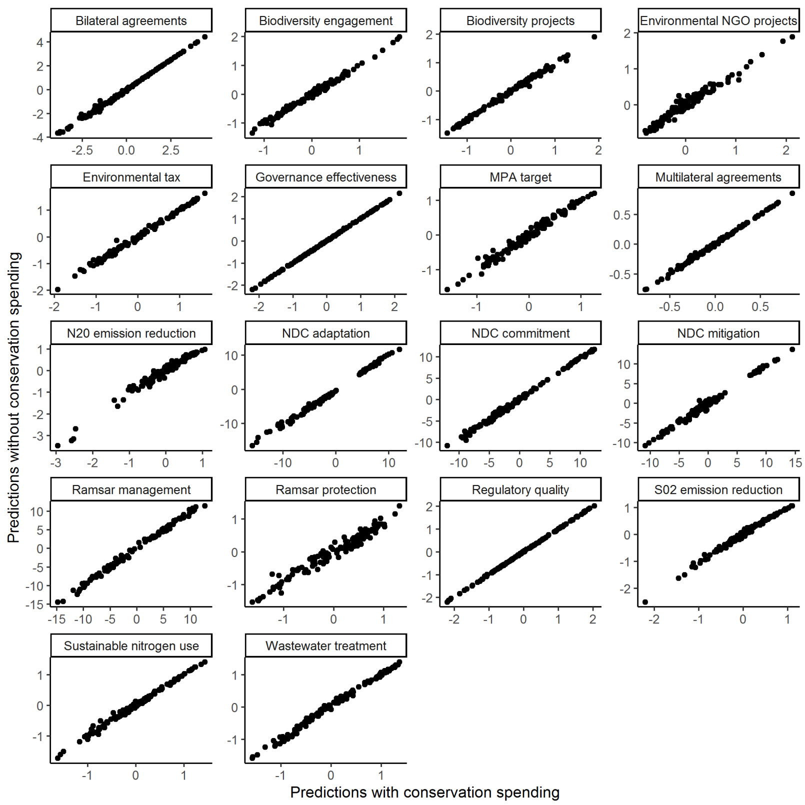


**Fig. S3. Correlation of predictions from latent variable models fit with and without the 'Conservation spending' indicator.**

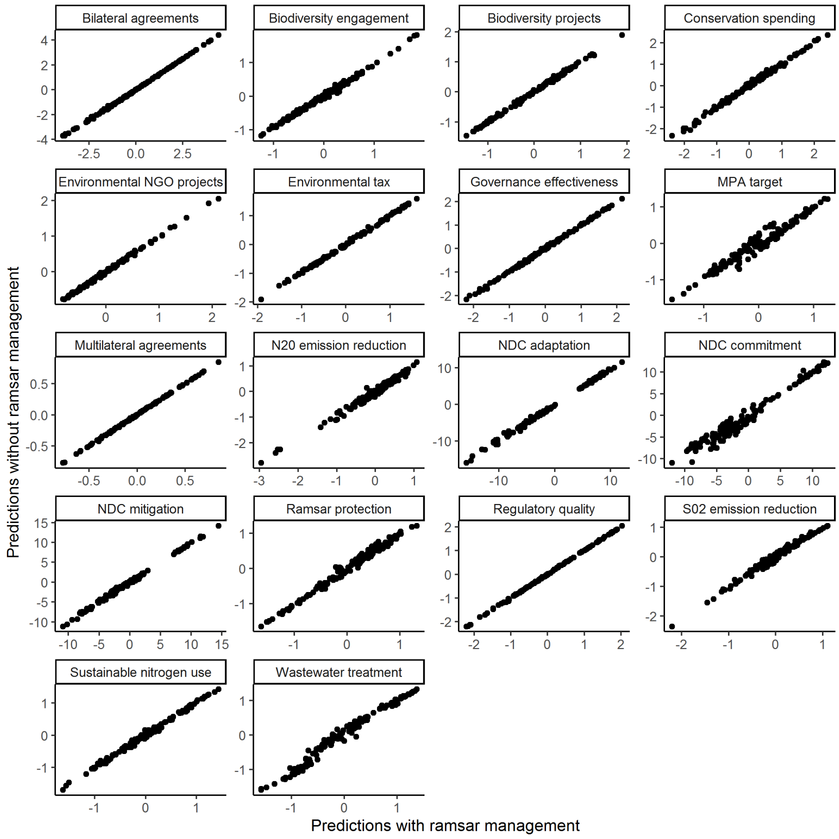


**Fig. S4. Correlation of predictions from latent variable models fit with and without the 'Ramsar Management' indicator.**

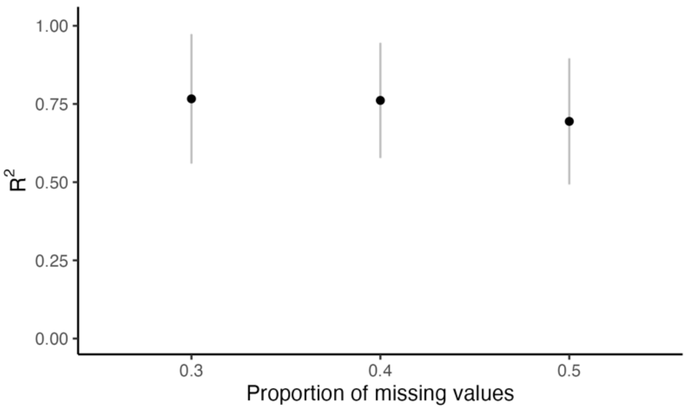


**Fig. S5. Simulation study of latent variable model (LVM) interpolation capacity under scenarios where large proportions of a response variable's values are 'missing not at random' (i.e., 30 to 50%).** Under each 'missing not at random' scenario, 100 datasets with 20 response variables (n = 100) were simulated by randomly drawing values from a multivariate normal distribution (correlation strengths varying between –0.5 and 0.5) and one variable was manipulated so that either 30, 40 or 50% of the values were missing not at random (i.e., values above the 70th, 60th and 50th percentiles were set to be missing). Correlation between the simulated response variable and LVM predictions under each scenario is displayed as the median coefficient of determination ($R^2$) value (± standard deviation; n = 100).

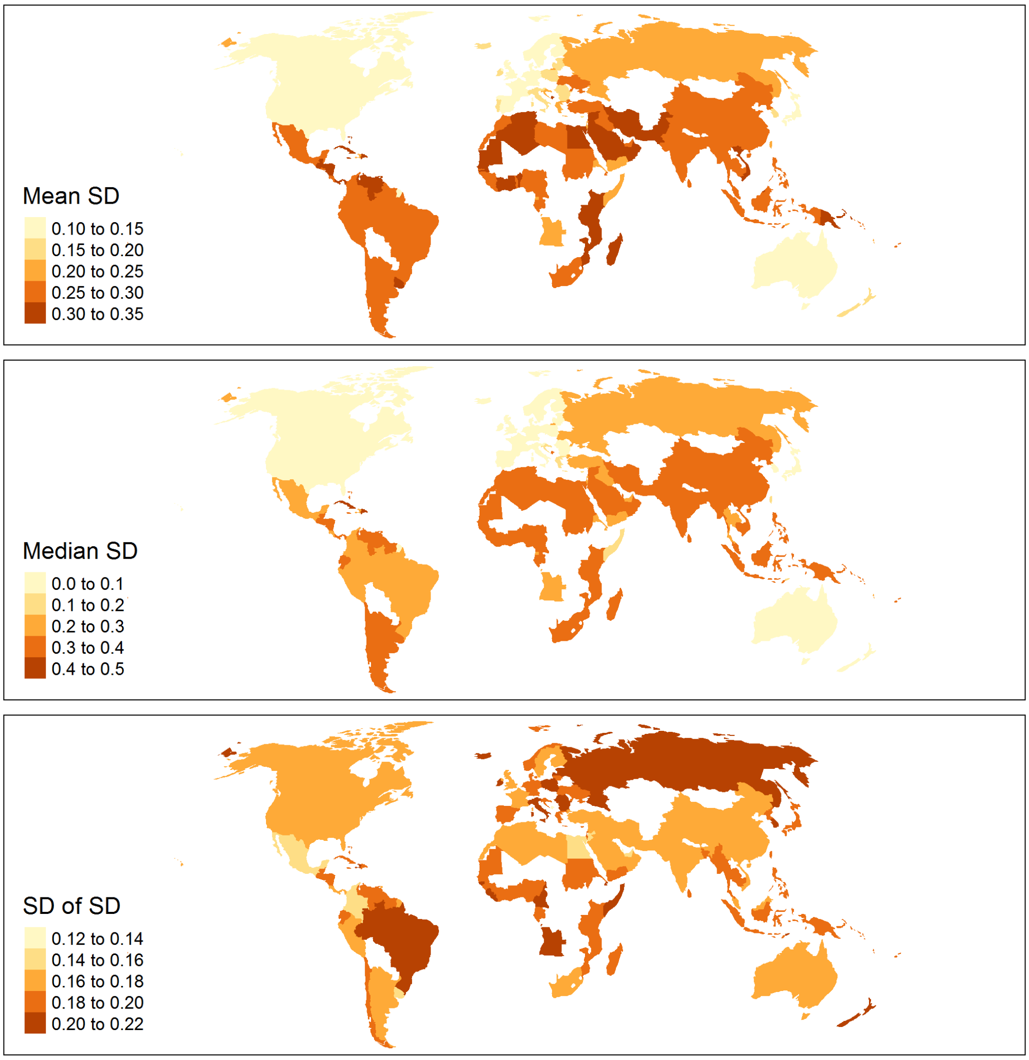


**Fig. S6. Maps showing statistics for each country that measure how much uncertainty there was in the inclusion or exclusion of other countries in its cluster.** Low mean or median SD values indicate that a country was highly likely to be clustered with the same countries across the full distribution of indicator values predicted by the latent variable model. Low standard deviation of SD values indicates that there was low variability in whether a country was likely to be clustered with the same countries. Mapped national boundaries are from (UIA 2015).

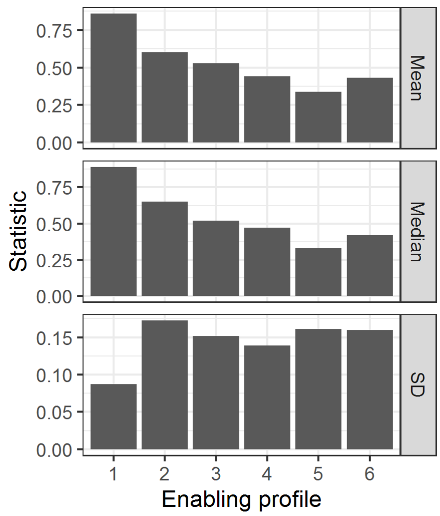


**Fig. S7. Statistics that measure how much uncertainty there was in the pairwise probability of countries being included in each enabling profile.** Higher mean and median values indicate there was higher probability of pairwise inclusion of countries in a profile. Higher standard deviation values indicates there was higher variation in the pairwise inclusion of countries in a profile.

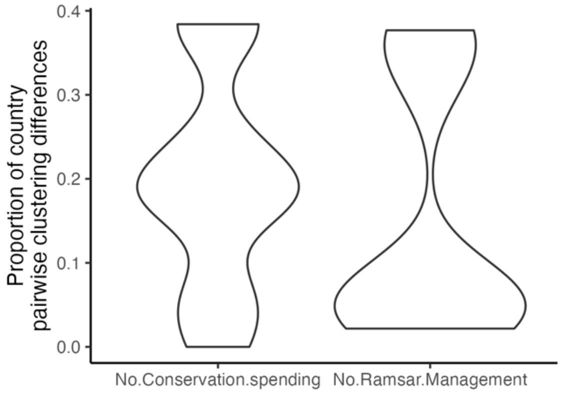


**Fig. S8. Proportion of country pairwise clustering differences when the Conservation spending and Ramsar Management variables are removed, relative to the 'full model' with all variables included.** When conservation spending was removed from the model, the pairwise clustering of the majority of countries differed in less than 20% of cases. When Ramsar Management was removed, pairwise clustering of the majority of countries differed in less than 10% of cases.

**Table S4. Description of drivers of mangrove loss (Goldberg et al. 2020) and seagrass trends (Dunic et al. 2021).**

| **Category** | **Driver** | **Seagrass sub-drivers (Dunic et al. 2021)** | **Description** |
|---|---|---|---|
| Mangrove | Human settlement | - | Human settlements such as cities and villages. |
| Mangrove | Commodities (agri/aquaculture) | - | Agriculture, aquaculture, oil palm, rice. |
| Mangrove | Erosion | - | Conversion to open water or mudflat. |
| Mangrove | Non-productive conversion | - | Mining, oil extraction, etc., and mangrove loss within a 5.5km of human settlements and roads. |
| Mangrove | Extreme weather event | - | Drought, cyclone, etc. |
| Seagrass | Aquaculture and fishing | Aquaculture/ fishing | Oyster farming, fish farming, bait grubbing, bivalve trawling, recreational bivalve harvesting. |
| Seagrass | Boating | Boating | Mooring, propellor scarring. |
| Seagrass | Catchment processes | Coastal development/ Management/restoration/ Water quality/ Pollution/ Hydrology | Land appropriation, shoreline armouring, coastline construction, land use change (e.g., logging, agriculture), dredging, port construction, urbanisation, removal of dikes/coastal armouring, storm water run-off regulations, relocation of wastewater outfalls, algae blooms, chlorophyll, depth, nutrients (nitrogen, phosphorous), oxygen, ocean acidification, salinity, sedimentation, turbidity, water quality metrics, herbicides, oil spills, land based pollution (non-nutrient), coastal erosion, flood, sea level, sediment deposition patterns (e.g., sand banks), water velocity. |
| Seagrass | Disease | Disease | Wasting disease (e.g., *Labyrinthula zosterae*). |

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|---|---|---|---|
| Seagrass | Climate and storms | Climate/Storms | Precipitation, temperature, drought, warming, above average wet seasons, El Niño, ice cover, hurricanes/typhoons, flooding, storm swell, wind velocity. |

**Appendix 1: Supplemental methods**

Azerbaijan, Turkmenistan and Kazakhstan EEZ boundaries intersected with seagrass in the landlocked Caspian Sea but were not included in our analysis due to lack of oceanic coastline. Indicator coefficients were estimated with Markov Chain Monte Carlo (MCMC) sampling using weakly informative normal priors (mean = 0 and variance = 10) and likelihoods appropriate to the distributions of each indicator (i.e., a normal distribution (with identity link) for continuous response variables, a Poisson (with log link) for count response variables, and a binomial (with probit link) for binary response variables). We set the length of the MCMC chain to 50,000, discarded 2,000 in the burn-in period, and used a thinning rate of 5, leaving 9,600 samples. The convergence of MCMC chains was verified with Geweke convergence diagnostics adjusted for multiple comparisons (Geweke 1992) and visual inspection of MCMC trace plots. Model fit was assessed with randomized quantile residuals (Dunn and Smyth 1996). Analyses were performed in R version 3.5.2 (R Core Team 2018). LVMs were fit in using the R package 'boral' ('Bayesian ordination and regression analysis'; Hui 2020), cluster analysis with the R package 'cluster' (Maechler et al. 2019), and classification trees with the R package 'rpart' (Therneau and Atkinson 2018).

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