The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits

Alison Fairbrass[1], Aidan O'Sullivan[1], Jillian Campbell[2], and Paul Ekins[1]

[1]University College London
[2]Convention on Biological Diversity

March 16, 2023

Abstract

The Sustainable Development Goals (SDGs) provide targets for humanity to achieve sustainable development by 2030. A monitoring framework of 248 environmental, social, and economic indicators, reported nationally by 193 UN Member States, tracks progress. The framework includes 92 environmental indicators, most of which refer to environmental policies. The SDG monitoring framework provides data to assess whether, across countries, environmental policies are: 1. Addressing environmental pressures, 2. Linked to environmental improvements, and 3. Linked with societal benefits delivered by healthy environments. We use statistical analysis and a generalized linear modeling approach to test for correlations between SDG indicators related to environmental policies, environmental pressures, the state of the environment, and social impacts delivered by healthy environments. Our results show that environmental policies, particularly protected areas and sustainable forest certification, are linked with environmental improvements, mainly in forest and water ecosystems. However, we find no evidence that environmental improvements are linked with positive social impacts. Finally, environmental pressures, including freshwater withdrawal, domestic material consumption, and tourism, are linked with environmental degradation. Environmental policy responses are generally increasing across countries. Despite this, the state of the environment globally continues to decline. Governments must focus on understanding why environmental policies have not been sufficient to reverse environmental decline, particularly concerning the pressures that continue to degrade the environment. To better track progress towards sustainable development, we recommend that the SDG monitoring framework is supplemented with additional indicators on the state of the environment.

The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits

Fairbrass, A.J.[1]*, O'Sullivan[2], A., Campbell, J.[3], Ekins, P.[1]

[1] Institute for Sustainable Resources, University College London, London, UK.

[2] Energy Institute, University College London, London, UK.

[3] United Nations Environment Programme, Nairobi, Kenya.

Corresponding author: Alison Fairbrass (alison.fairbrass.10@ucl.ac.uk)

Key Points:

- The state of the environment globally continues to decline despite increasing environmental policy responses.
- The SDG indicators provide no evidence that environmental policies deliver secondary social benefits.
- Protected areas and sustainable forest certification are linked with environmental improvements, mainly in forest and water ecosystems.

Abstract

The Sustainable Development Goals (SDGs) provide targets for humanity to achieve sustainable development by 2030. A monitoring framework of 248 environmental, social, and economic indicators, reported nationally by 193 UN Member States, tracks progress. The framework includes 92 environmental indicators, most of which refer to environmental policies. The SDG monitoring framework provides data to assess whether, across countries, environmental policies are: 1. Addressing environmental pressures, 2. Linked to environmental improvements, and 3. Linked with societal benefits delivered by healthy environments. We use statistical analysis and a generalized linear modeling approach to test for correlations between SDG indicators related to environmental policies, environmental pressures, the state of the environment, and social impacts delivered by healthy environments. Our results show that environmental policies, particularly protected areas and sustainable forest certification, are linked with environmental improvements, mainly in forest and water ecosystems. However, we find no evidence that environmental improvements are linked with positive social impacts. Finally, environmental pressures, including freshwater withdrawal, domestic material consumption, and tourism, are linked with environmental degradation. Environmental policy responses are generally increasing across countries. Despite this, the state of the environment globally continues to decline. Governments must focus on understanding why environmental policies have not been sufficient to reverse environmental decline, particularly concerning the pressures that continue to degrade the environment. To better track progress towards sustainable development, we recommend that the SDG monitoring framework is supplemented with additional indicators on the state of the environment.

Plain Language Summary

Governments implement environmental policies to reduce ecological degradation and sustain environmental benefits to humans, such as food and clean water. The Sustainable Development Goals (SDGs) call for all countries to commit to pathways that lead to sustainable development. Progress towards achieving the Goals is reported by governments using 231 indicators. The SDG indicators track the implementation of environmental policies, the state of the environment, and environmental benefits such as food security and drinking water access. Using the data underlying the SDG indicators reported by governments to date, we investigate whether the implementation of environmental policies correlates with improvements in the environment and the provision of environmental benefits to humans. Results show that most environmental policies are not associated with environmental improvements; worse, we find no evidence that environmental policies lead to more human benefits. However, we see two types of environmental policies, protected areas and sustainable forest certification, that lead to increasing the size of forest and water ecosystems which are essential for sustaining the lives of plants, animals, and humans that rely on them. Our findings highlight that governments must improve their use of environmental policies to achieve environmental improvements and the benefits humans derive from the environment.

1. Introduction

In September 2015, the United Nations Sustainable Development Summit adopted an international framework to guide development efforts, entitled Transforming our World: the 2030 Agenda for Sustainable Development (United Nations, 2015). The Agenda is built around 17 Sustainable Development Goals (SDGs), divided into 169 targets, which are a call to action from all countries to move the world onto a sustainable development trajectory. An underlying monitoring framework composed of 231 unique indicators (a further thirteen are repeated under different targets) tracks progress toward the goals and targets. The environmental dimension of the SDG monitoring framework is composed of 92 indicators (UNEP, 2021). These indicators encompass a range of topics, such as sustainable consumption, ocean acidification, and environmental education, and a range of environments, such as marine, freshwater, and mountain ecosystems. A dataset underlies the SDG monitoring framework and is composed of indicators reported to the UN by the Member States or derived by the UN from global datasets when nationally produced indicators are unavailable. However, some indicators still need more data, as discussed further below.

Environmental policies are intended to reduce environmental damage, incentivise positive environmental behaviour, and guide practices toward a more sustainable future (Schwartz & Goubran, 2020). The umbrella term 'environmental policy' encapsulates various environmental policy types, including regulatory instruments, market-based instruments, voluntary agreements, and information provision (Jordan et al., 2003). In addition, innovation policy may also be used to improve the environment (OECD, 2011). Most recently, a class of policy instruments called

'Nature-based solutions' has been defined as 'actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham et al., 2016).

The SDG monitoring framework uses SDG indicators to track the national use of environmental policy instruments. For example, indicator 15.8.1 covers legislation about invasive alien species (a regulatory instrument), indicator 15.4.1 covers the protection of mountain biodiversity (a Nature-based Solution), and indicator 12.1.1 covers sustainable consumption policies (the indicator does not specify instrument type).

If the aim of environmental policies is 'to prevent or reduce harmful effects of human activities on ecosystems' (Bueren, 2019) and to 'address societal challenges…by providing human well-being benefits' (Cohen-Shacham et al., 2016), we should expect that environmental improvements would follow the use of environmental policies. In addition, environmental improvements would also benefit human society via ecosystem services. Indeed, the natural environment provides various services that benefit humans, such as providing food and fibre, mitigating the effects of extreme weather events, and cultural connections to nature (Millennium Ecosystem Assessment, 2005). In this study, we use the SDG monitoring framework data to investigate, at the national scale, the relationships between the use of environmental policies, the state of the environment, and the provision of environmental benefits to society.

The DPSIR indicator framework describes the interactions between society and the environment (Kristensen, 2004; UN Environment, 2019). The framework provides a structure to understand the causal links between 'driving forces' [D] (economic sectors, human activities), 'pressures' [P] (emissions, waste, resource use), environmental 'states' [S] (physical, chemical, and biological), 'impacts' [I] (on ecosystems, human health, and functions), and political 'responses' [R] (policies, and other actions at different levels). In this study, we investigate whether the SDG monitoring framework's data provides evidence for relationships, at a national level, between political 'responses,' the 'state' of the environment, and the 'impacts' of the environment on society. In addition, we investigate relationships between environmental 'pressures' (UN Environment, 2019) and environmental 'state' indicators to highlight which environmental pressures require increased policy attention to reduce their harmful impacts. Finally, this investigation allows us to leverage the SDG monitoring framework data to investigate whether national environmental policies are delivering their primary objective of improving the state of the environment and their secondary objective of reducing the negative impacts of environmental degradation on people.

Several studies have already investigated the relationships between the Goals and Targets of the SDGs (Breuer et al., 2019; Fuso Nerini et al., 2018; International Council for Science (ICSU), 2017; PwC, 2016; Scharlemann et al., 2020; Weitz et al., 2019). However, only one study has investigated the relationships between the SDG indicators underlying the entire SDG monitoring framework (Pradhan et al., 2017). This study took SDG indicators in pairs for all countries and, given the availability of time-series data, calculated correlations between the indicator pairs using Spearman's rank. We go beyond the Pradhan et al. study in two ways. Firstly, we weed out all indicator pairs where there is no evidence in the scientific literature of likely correlation or causation along the DPSIR (Driving forces to Pressures to States to Impacts to Responses) chain. Then, the indicator pairs are selected on this basis, which both aids our interpretation of our results and strengthens the probability that any correlations may have at least some causal elements. Secondly, we used a modelling approach to investigate the relationship between indicator pairs, rather than a correlation test as used by Pradhan et al.. A modelling approach enables us to control for potentially confounding factors that may influence the SDG indicators, such as economic development, demographics, or geolocation of a country (Breuer et al., 2019).

Therefore, this study uses the SDG monitoring framework data to investigate whether national environmental policies deliver their intended primary environmental and secondary social benefits and identify which environmental pressures require increased political attention. First, we apply the DPSIR framework to identify SDG indicators representing environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts.' Secondly, we identify plausible relationships between indicators of environmental pressures, environmental policy responses, the state of the environment, and secondary societal impacts. Finally, we use statistical tests and multivariate analysis to test relationships between SDG indicators while controlling for confounding factors of countries' development and geographic status. Leveraging the dataset underlying the SDG monitoring framework, our approach allows us to ask the questions:

Are environmental policies correlated with improvements in the state of the environment? These results will suggest where political efforts have the desired impact on the environment.

Are improvements in the state of the environment correlated with reductions in the impacts of poor environmental quality on society? These results will highlight where environmental policies can deliver additional societal benefits.

Is there evidence of negative impacts from environmental pressures on the state of the environment? These results will highlight where additional efforts need to focus.

2. Materials and Methods

2.1. Classifying SDG indicators and assessing data availability

We classified the 231 unique SDG indicators and their underlying sub-indicators into one of four groups (Table 1). Some SDG indicators are composed of a single indicator, and others are disaggregated into sub-indicators. For example, SDG indicator 2.5.1 'Secure genetic resources for food' is produced by aggregating two underlying sub-indicators: 1. The number of local breeds for which sufficient genetic resources are stored for reconstitution, and 2. Plant breeds for which sufficient genetic resources are stored. In contrast, SDG 6.6.1 includes sub-indicators related to water body extent, wetland extent, and mangrove extent, which are used without aggregation. In addition to our classification, Table 1 shows the smaller number of indicators with sufficient data to carry out our analysis.

Table 1. Classification and data availability of the SDG indicators and sub-indicators

Class	**Number of unique indicators (and sub-indicators)**	**Number of unique indicators (and sub-indicators) with sufficient data to include in the analysis**
Environmental policy responses	50 (85)	22 (38)
Environmental states	11 (36)	5 (9)
Social impacts	16 (44)	11 (31)
Environmental pressures	20 (41)	18 (38)

Data collection efforts to support the SDG monitoring framework vary significantly across the Targets and Indicators (UNEP, 2019). Tier 3 indicators still need an agreed methodology for collecting data; Tier 2 indicators are not yet supported by regular data collection (IAEG-SDGs, 2020). This means many SDG environmental indicators do not have the necessary datasets for robust statistical analysis.(UNEP, 2019). Therefore, we assessed the data availability of each SDG indicator and sub-indicator. In order to be included in our analysis, an indicator or sub-indicator must have data for at least two years since 2000 by at least 20 countries (Table 1). Between January and June 2020, we extracted the data underlying the SDG indicators from the UN's SDG Indicators Database. However, some underlying data was unavailable on the SDG Indicators Database, and we sourced this additional data from UNEP in July 2020.

2.1.1 Group 1: Environmental policy responses

We identified 50 unique SDG indicators related to environmental policies that cover issues such as sustainable agricultural management, renewable energy use, and action plans for sustainability. In addition, the SDG monitoring framework contains sufficient data to include 22 environmental policy indicators in this analysis.

2.1.2 Group 2: Environmental states

We identified 11 SDG indicators that relate to the state of the environment. These state of the environment indicators measure the quality and quantity of water resources, marine eutrophication, plastic concentration and acidity, fish stocks, forest cover, land degradation, green land cover in mountain ecosystems, and extinction risk of wild and domesticated species. The SDG monitoring framework contains sufficient data to include five environmental state indicators in this analysis.

2.1.3 Group 3: Social impacts

We identified 16 SDG indicators that relate to the social impacts of the environment. These social impacts indicators include the human and economic impacts of natural disasters, food, and water access, and mortality attributed to air pollution. The SDG monitoring framework contains sufficient data to include 11 social impact indicators in this analysis.

2.1.4 Group 4: Environmental pressures

We identified 20 SDG indicators related to environmental pressures. These environmental pressure indicators include water stress, domestic material consumption (DMC), tourism, and infrastructure development. The DMC indicator comprises numerous material-specific sub-indicators including, but not limited to, DMC of wood, minerals, fossil fuels, crops, wild catch, and harvested materials. The SDG monitoring framework contains sufficient data to include 18 environmental pressure indicators in this analysis.

2.2. Identifying potential synergies between indicator pairs

The IPBES Global Assessment (Watson et al., 2019) provides a global evidence review of the environmental and social effects of environmental pressures and policy responses; for example, the direct environmental impacts of sustainability certification schemes on forest ecosystems and the secondary social impacts on access to non-timber forest products (Shanley, 2002). For the indicators with sufficient data to include in our analysis (Table 1), we identify potential relationships between pairs of SDG indicators and their sub-indicators using this evidence base. To investigate the relationship between environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts' we identify 618 potential relationships between SDG indicators and their underlying sub-indicators. We detail these potential relationships in the Supplementary Information.

We supplemented the evidence presented in IPBES Global Assessment through consultation with experts from various environmental and social stakeholder groups. This consultation on selecting SDG indicator relationships took the form of an online meeting held on 21-22 April 2020 and an online survey held from 29 May to 13 June 2020. We provide the minutes of this meeting and an overview of the responses received from experts to the online survey in the Supplementary Information.

2.3. Determining how to interpret SDG indicators to identify improvements in environmental and social conditions

A good indicator has a clear relationship to the situation about which it is reporting. Of the environmental state and social impact indicators that we include in this investigation, we identify when they are showing improvements in the state of the environment and the social impacts of the environment (Figure 1). In terms of improving environmental and social conditions, some indicators would increase (e.g., forest area and schools with drinking water access), and other indicators would decrease (e.g., air pollution and food insecurity). Different correlation directions indicate desirable relationships between environmental pressure, environmental policy, environmental state, and social impact indicators. Environmental state indicators that show improvement when they increase should show a **positive correlation** with environmental policy indicators, e.g., an *increase* in forest areas should correlate positively with *increasing* the protection of forest ecosystems. Conversely, environmental indicators that show improvement when they decrease should show a **negative correlation** with environmental policy indicators, e.g., *decreasing* domestic species extinction risk should correlate negatively with *increasing* conservation of domestic species' genetic resources.

Environmental state indicators will tend to be negatively affected by environmental pressures, with the direction of the correlation depending on whether improvement in each indicator is represented by an increase or a decline.

Finally, the desirable correlation between an environmental state and a social impact indicator would suggest that social impacts are improving alongside improvements in the state of the environment. Again, the desirable direction of the correlation depends on whether improvement is associated with increasing or decreasing values of each indicator.

SDG Indicators		What we want to see	Direction of correlation in response to: Increasing environmental policies	Decreasing environmental pressures
State of the environment				
2.5.2	Local breeds extinction	*Decreasing* proportion of local breeds classified as being at risk of extinction	−	+
6.6.1	Water ecosystems	*Increasing* extent of water-related ecosystems	+	−
11.6.2	Air pollution	*Decreasing* levels of fine particular (e.g. PM2.5 and PM10) matter in cities	−	+
15.1.1	Forest area	*Increasing* forest area	+	−
15.5.1	Species at risk	*Increasing* Red List Index indicates decreasing species extinction risk	+	−

SDG Indicators		What we want to see	Direction of correlation in response to an environmental state indicator that shows improvement when values are: Increasing	Decreasing
Social impact				
1.5.1	Disasters: human impacts	*Decreasing* human impacts of disasters	−	+
1.5.2	Disasters: economic impacts	*Decreasing* economic impacts of disasters	−	+
2.1.1	Undernourishment	*Decreasing* prevalence of undernourishment	−	+
2.1.2	Food insecurity	*Decreasing* prevalence of moderate or severe food insecurity	−	+
2.2.2	Children wasted	*Decreasing* prevalence of children wasted	−	+
2.2.2	Children overweight	*Decreasing* prevalence of children overweight	−	+
4.a.1	Schools drinking water access	*Increasing* proportion of schools offering access to drinking water	+	−

Figure 1. The desirable direction of correlation between indicators (plus sign indicates a positive correlation, minus sign indicates a negative correlation) that show improvement in the state of the environment in response to increasing environmental policies and decreasing environmental pressures (upper table) and the social impacts of the state of the environment (lower table).

2.4. Investigating relationships between indicator pairs

We used generalized linear regression modelling (GLRM) to investigate whether there is evidence for a statistically significant relationship between our chosen indicator pairs within our model, controlling for two potentially confounding factors, population, and GDP. This methodology adapts the analysis we present in (UNEP, 2021), in which we combined a GLRM and correlation test to investigate SDG indicator interactions. Here we report only the results of our investigation of SDG indicator interactions using a GLRM approach. In addition, this approach enables us to investigate correlations while considering some confounding factors that a correlation test does not.

A GLRM produces a correlation coefficient, the sign of which indicates a positive or negative direction of the relationship between the two indicators. For example, one of our indicator pairs is clean fuels and air quality, both of which may change due to a change in GDP. A GLRM allows us to separate the different potential influences on our indicator variables, making it more likely that any correlation between the two indicators is not the result of some other factor. In addition to GDP and population, we included a fixed effect in our regressions to account for regional or other differences between the countries.

There are several points to note about our approach: 1. The GLRM approach is characterized by the assumption that the relationship between two indicators is linear. Therefore, any non-linear associations between the two indicators will not be captured adequately by the GLRM. 2. We applied a log transformation to several indicators to control for the substantial differences between some countries. The log transformation is appropriate to the data underlying the indicators because the values are generally positive, such as percentages and square kilometres. The log transformation also mitigates the impact of outliers by compressing the data. 3. We needed at least two data points at different times to estimate the relationships between our indicators 4. Finally, for each indicator pair we investigated, our analysis was limited to the number of countries reporting data for both indicators.

2.4.1 Generalised linear regression model (GLRM)

The complete model formulation is as follows:

$$\log(Y) = \beta_1 \log(X) + \beta_2 \log(pop) + \beta_3 \log(GDP) + I_{region}$$

Where:

Y: an indicator of either the environmental state OR a social impact

X: an indicator of either the environmental pressure OR an environmental policy OR the environmental state

pop and GDP: national population and GDP for each year, the potential confounding factors

I_{region}: a fixed effect variable for each country or geographical region
β1, β2, and β3: maximum likelihood estimates of the model coefficients. These measure the relationship between each independent variable in the model and the dependent Y variable. We conducted a hypothesis test on the coefficient of interest (β1) to assess whether there is evidence of a relationship between a pair of indicators (using a significance level of $\alpha = 0.05$) after accounting for the influence of the potential confounding factors. The GLRM model also calculates the R2 value, which shows how much of the variance in the dependent variable it captures. We did not consider regressions with an R2 of less than 0.2, which was our minimum goodness of fit threshold. We conducted all statistical analyses using R software (R Core Team, 2021).

3. Results

We identified significant correlations between the indicators on the state of the environment, with the indicators on environmental policies and pressures—some correlations aligned with our hypotheses, and others contrasted with our hypotheses. However, we identified no significant correlations between the indicators on the state of the environment and the social impacts of the environment. Therefore, the Results section presents only the findings of the analysis of the environmental policy, pressure, and state indicators, and no findings on the social impact indicators, as we found no significant relationships with these indicators.

3.1. Relationships between environmental policies, the state of the environment

Table 2. The environmental policy indicators that correlate significantly with the environmental state indicators. Correlations that show environmental improvement are presented in the upper half of the table. Correlations that show environmental degradation are presented in the lower half of the table. The middle column describes the causal relationship between environmental policies and environmental improvements based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental policy indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental policy, leading to environmental improvements**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
7.2.1 Renewable energy	11.6.2 Outdoor air pollution in cities	Greater reliance on clean fuels leads to less combustion of dirty fuels, which reduces the amount of air pollutants produced and leads to improvements in air quality	(IEA et al., 2022, p. 7)	*Increasing* renewable energy use correlates with *decreasing* levels of fine particulate matter in cities

Environmental policy indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental policy, leading to environmental improvements**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
7.2.1 Renewable energy	15.1.1 Forest area	Greater reliance on clean fuels reduces reliance on wood resources for energy which leads to less deforestation and a greater extent of forest ecosystems	(IEA et al., 2022, p. 7)	*Increasing* renewable energy use correlates with *increasing* forest area
15.1.2 Protection of Key Biodiversity Areas (KBAs)	6.6.1 Water ecosystems	Protection of KBAs reduces the abstraction of water from protected water ecosystems and leads to an increase in water ecosystem extent	(Chan et al., 2006; IUCN, 2012)	*Increasing* protection of KBAs is correlated with *increasing* water ecosystem extent
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.1.1 Forest area	Protection of KBAs reduces deforestation in protected forest ecosystems and leads to an increase in forest area	(Carranza et al., 2014; Geldmann et al., 2013)	*Increasing* protection of KBAs is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.1.1 Forest area	Sustainable forest certification reduces unsustainable deforestation, which increases forest area	(Auld et al., 2008; Damette & Delacote, 2011; Potapov et al., 2017; Rametsteiner & Simula, 2003)	*Increasing* sustainable forest certification is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.5.1 Species at risk	Sustainable forest certification reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Burivalova et al., 2017; Kalonga et al., 2016; van Kuijk et al., 2009)	*Increasing* sustainable forest certification is correlated with *increasing* Red List Index, which indicates *decreasing* species extinction risk
15.2.1 Protected forest area	15.1.1 Forest area	Protection of forest ecosystems reduces unsustainable deforestation, which increases forest area	(Carranza et al., 2014; Eklund et al., 2016)	*Increasing* the protection of forests correlates with *increasing* forest area
2.5.1 Secure genetic resources for food	2.5.2 Local breeds extinction	Conservation of genetic resources reduces the extinction risk of domesticated species	(*Coping with Climate Change*, 2015; Enjalbert et al., 2011)	*Increasing* conservation of genetic resources for food correlates with an *increasing* proportion of local breeds at risk of extinction
6.a.1 Investment in water and sanitation	6.6.1 Water ecosystems	Investment catalyses improved water resource management which reduces demand for, and abstraction of, water from water ecosystems and leads to an increase in water ecosystem extent	(Turral et al., 2010)	*Increasing* investment in water and sanitation correlates with *decreasing* water ecosystem extent
7.1.2 Primary reliance on clean fuels	11.6.2 Air pollution	Greater reliance on clean fuels and technologies leads to less non-renewable resource combustion, which reduces the amount of air pollutants produced and leads to improvements in air quality	(IEA et al., 2022, p. 7)	*Increasing* reliance on clean fuels correlates with *increasing* levels of fine particulate matter in cities
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.5.1 Species at risk	Protection of KBAs reduces human disturbance of biodiversity, which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al., 2016)	*Increasing* protection of KBAs is correlated with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.2.1 Sustainable	15.5.1 Species at risk	Sustainable forest management reduces human disturbance of biodiversity in forest ecosystems	(Burivalova et al., 2017)	*Increasing* the forests under sustainable long-

Environmental policy indicator	Environmental state indicator	Hypothesised outcomes of environmental policy, leading to environmental improvements	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
forest long-term management		which leads to a reduction in the number of species threatened with extinction		term management correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.2.1 Protected forest area	15.5.1 Species at risk	Protection of forest ecosystems reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al., 2016)	*Increasing* protection of forests correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.4.1 Mountain protected areas	15.5.1 Species at risk	Protection of mountain ecosystems reduces human disturbance of biodiversity in mountain ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Gray et al., 2016)	*Increasing* protection of mountain ecosystems correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.8.1 Invasive alien species	15.5.1 Species at risk	National legislation and adequate resourcing for the prevention or control of invasive alien species leads to a reduction in the negative impacts of invasive alien species on biodiversity and a reduction in the number of species threatened with extinction	(Butchart et al., 2006)	*Increasing* prevention and management of alien invasive species correlates with *decreasing* Red List Index, which indicates *increasing* species extinction risk.

3.1.1 Extinction risk of local breeds (2.5.2)

The extinction risk of local breeds was positively correlated with policies to secure genetic resources for food (2.5.1) (Table 2), suggesting that despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is going up.

3.1.2 Water ecosystem extent (6.6.1)

We found a positive correlation between the protection of important sites for terrestrial and freshwater biodiversity (15.1.2) and the extent of water ecosystems (Table 2). On the other hand, we found a negative correlation between water ecosystem extent and the value of development assistance for water supply and sanitation (6.a.1), suggesting that increased spending on water and sanitation is related to decreasing water ecosystem extent. Furthermore, there was no significant relationship between water ecosystem extent and water use efficiency (6.4.1).

3.1.3 Air pollution (11.6.2)

Air pollution, measured as levels of outdoor fine particulate matter in cities, was positively correlated with the proportion of the population with primary reliance on clean fuels and technology (7.1.2) (Table 2). This result suggests that despite the increasing use of clean fuels and technologies, urban air pollution levels continue to increase. Conversely, air pollution was negatively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1), suggesting that there may be a link between renewable energy use and air pollution in cities.

3.1.4 Forest ecosystem extent (15.1.1)

The extent of forest ecosystems was positively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1) (Table 2). This result suggests a relationship between increasing renewable energy use and increasing forest area, perhaps due to decreasing deforestation linked to the use of timber for energy production. We found no significant correlation between forest ecosystem extent and population with primary reliance on clean fuels and technology (7.1.2). However, forest ecosystem extent was positively correlated with the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of forests certified under an independently verified certification scheme (15.2.1), and the area of forest that is protected (15.2.1). These results suggest that protected area policies and forest certification schemes are related to increasing forest ecosystem extent.

3.1.5 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental policy indicators (Table 2), including the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of protected forest ecosystems (15.2.1), the extent of protection of mountain ecosystems (15.4.1), implementation of long-term forest management plans (15.2.1), and the prevention or control of Invasive Alien Species (15.8.1). These results suggest that despite implementing these environmental policies, several of which have the primary objective of conserving biodiversity, the number of species at risk of extinction continues to increase. Only the extent of forests certified under an independently verified certification scheme (15.2.1) correlated positively with decreased species extinction risk. There was no significant relationship between species extinction risk and the protection of marine ecosystems (14.5.1). We must highlight that SDG indicator 15.5.1, based on the IUCNs Red List

Index, does not include marine species. Therefore the link between this indicator and marine protected areas (indicator 14.5.1) is tenuous.

3.2. Relationships between environmental pressures and the state of the environment

Table 3. The environmental pressure indicators that correlate significantly with the environmental state indicators. Correlations that show environmental degradation are presented in the upper half of table. Correlations that show environmental improvements are presented in the lower half of table. The middle column describes the causal relationship between the environment and society based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental pressure indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental pressures, leading to environmental degradation**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
6.4.2 Water stress	6.6.1 Water ecosystems	More significant water stress increases demand for, and abstraction of, water from water ecosystems and leads to a decrease in water ecosystem extent	(Arroita et al., 2017; Pekel et al., 2016; Rosen et al., 2000)	*Increasing* water stress correlates with *decreasing* water ecosystem extent
8.4.2 DMC of crops	15.5.1 Species at risk	Greater consumption of crops promotes increased agricultural production, which increases human disturbance of natural ecosystems and biodiversity, which pushes more species toward extinction	(Foley et al., 2005; Lambertini, 2020)	*Increasing* consumption of domestically produced crops correlates with *increased* species extinction risk
8.4.2 DMC of fossil fuels	11.6.2 Air pollution	Greater consumption of fossil fuels involves the combustion of fossil fuels which produces air-borne pollutants which reduce air quality	(De Longueville et al., 2014)	*Increasing* consumption of domestically produced fossil fuels correlates with *increased* air pollution in cities
8.4.2 DMC of wild catch and harvest	15.5.1 Species at risk	Increased exploitation and consumption of wildlife reduces the population sizes of species and pushes more species toward extinction	(Bradshaw et al., 2009; Butchart et al., 2006; Fa et al., 2003; Nasi et al., 2011; Vliet et al., 2007)	*Increasing* consumption of wild-caught and harvested species correlates with *increased* species extinction risk
8.9.1 Tourism	6.6.1 Water ecosystems	Increased tourism increases demand for, and abstraction of, water from water ecosystems and lead to a decrease in water ecosystem extent	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* water ecosystem extent
8.9.1 Tourism	15.1.1 Forest area	Increased tourism promotes deforestation through the development of tourism infrastructure	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* forest area
8.9.1 Tourism	15.5.1 Species at risk	Increased tourism leads to land use change to develop tourism infrastructure, which disrupts ecosystems. Furthermore, it leads to more significant numbers of people visiting areas of high biodiversity value, which increases biodiversity disturbance and pushes more species toward extinction. Alternatively, nature-based tourism can promote biodiversity conservation.	(Bookbinder et al., 1998; Gössling, 2002)	*Increasing* tourism correlates with *increasing* species extinction risk
8.4.2 DMC of crops	15.1.1 Forest area	Greater consumption of crops promotes increased agricultural production, which	(Foley et al., 2005; Geist & Lambin,	*Increasing* consumption of domestically produced

Environmental pressure indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental pressures, leading to environmental degradation**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
		increases demand for land, which drives deforestation and decreases forest area	2002; Gibbs et al., 2010; Potapov et al., 2017)	crops correlates with *increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	6.6.1 Water ecosystems	Mining uses large quantities of freshwater. Therefore an increase in the DMC of minerals extracted by mining will decrease the extent of water ecosystems.	(Palmer et al., 2010)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* water ecosystem extent
8.4.2 DMC of metal ores and non-metallic minerals	15.1.1 Forest area	Mining drives deforestation. Therefore an increase in the DMC of minerals extracted by mining will decrease forest area.	(Potapov et al., 2017; Schueler et al., 2011; Sonter et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	15.5.1 Species at risk	Mining has a negative local effect on biodiversity due to habitat destruction and pollution. Therefore an increase in the DMC of minerals extracted by mining will increase the number of species at risk of extinction.	(Deikumah et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *decreasing* species extinction risk
8.4.2 DMC of wood	15.1.1 Forest area	Greater consumption of wood resources promotes deforestation, which reduces forest area. Conversely, greater wood consumption promotes the conversion of non-forested land to timber plantations which increases forest area	(Geist & Lambin, 2002; Payn et al., 2015; Potapov et al., 2017)	*Increasing* consumption of domestically produced wood correlates with *increasing* forest area
9.a.1 Infrastructure support	6.6.1 Water ecosystems	Support for dam infrastructure will increase the water ecosystem extent due to the creation of reservoirs associated with dams. Alternatively, support for, and construction of, other forms of infrastructure, such as urban development, degrades natural ecosystems and reduces water ecosystems' extent.	(Davis & Froend, 1999; Lehner et al., 2011; Wang et al., 2008; Žganec, 2012; Zhang, 2009)	*Increasing* financial support for infrastructure correlates with *increasing* water ecosystem extent.

3.2.1 Water ecosystem extent

The extent of water ecosystems was negatively correlated with water stress (6.4.2) (Table 3), measured as the proportion of freshwater withdrawals to available freshwater resources, and with tourism (8.9.1), measured as the proportion of tourism GDP in a country's total GDP. This result suggests that the extent of water ecosystems declines as freshwater withdrawals and tourism activities increase. On the other hand, the extent of water ecosystems was positively correlated with domestic material consumption (DMC) of crops (8.4.2), DMC of metal ores and non-metallic minerals, and international financial support for infrastructure (9.a.1). This result suggests that the extent of water ecosystems increases as consumption of domestically produced crops increases, perhaps due to increased area used for irrigation, with increasing consumption of domestically produced metal ores and non-metallic minerals, and with increasing financial support for infrastructure, perhaps due to the construction of dams and the reservoirs created by them.

3.2.2 Air pollution (11.6.2)

We found a positive correlation between air pollution levels and DMC of fossil fuels (8.4.2) (Table 3), suggesting that air quality in cities declines as consumption of domestically produced fossil fuels increases.

3.2.3 Forest ecosystem extent (15.1.1)

Forest ecosystem extent correlated positively with DMC of crops, wood, and metal ores and non-metallic minerals (8.4.2) (Table 3), suggesting that forest extent increases as consumption of these domestically produced materials increases. Conversely, forest ecosystem extent correlated negatively with tourism (8.9.1), suggesting that forest extent decreases as a country's economic reliance on tourism increases, potentially due to deforestation associated with the tourism industry. There was no significant relationship between forest extent and infrastructure support (9.a.1).

3.2.4 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental pressures (Table 3), including DMC of crops (8.4.2), DMC of wild catch and harvest materials (8.4.2), and tourism (8.9.1). This result suggests that the number of species at risk of extinction increases as consumption of domestically produced crops increases, as the amount of wild materials extracted from a country's territory increases, and as tourism increases. Conversely, there was a positive correlation between species extinction risk and consumption of domestically produced metal ores and non-metallic minerals. Finally, there was no significant relationship between species extinction risk and water stress (6.4.2).

4. Discussion

In this study, we use the dataset underlying the SDG monitoring framework to investigate the relationship, across countries, between environmental policies, the state of the environment, the impact of the environment on society, and the pressures that continue to impact the environment. We used a correlation analysis combined with a statistical modelling approach to investigate the correlations between pairs of SDG indicators that we hypothesised to have a relationship based on evidence in the scientific literature and expert opinion. Where the results of the statistical analyses agreed with the scientific rationale, we inferred that this is evidence of a causative relationship between the indicator pairs. Our results highlight where environmental policies may be achieving their intended goals. For example, protecting Key Biodiversity Areas is linked with the increasing extent of forest and water ecosystems. Our results suggest that more effort is required to increase the positive environmental impacts of policies, such as conserving genetic resources to decrease the extinction risk of domesticated species. Surprisingly, our results provide no evidence for the social impacts of the state of the environment, potentially due to the complexity of ecosystems and the difficulty of detecting relationships between the non-market benefits humans derive from the environment and the state of ecosystems. Finally, our results suggest that environmental pressures, including freshwater withdrawals, tourism, and domestic material consumption of crops, fossil fuels, and wild catch and harvest, continue negatively impacting the environment.

This study gives us a flavour of the relationships, across countries, between governmental approaches to tackling environmental degradation and the state of the environment to understand where environmental responses may be achieving their intended aims and where they are falling short. For example, a policy response that appears to be working for conserving forest and water ecosystems is protecting important sites for terrestrial and freshwater biodiversity. Indeed there is convincing evidence that protected areas reduce deforestation (Geldmann et al., 2013; Joppa & Pfaff, 2011). However, the impact of protecting freshwater ecosystems is more challenging to understand than in forest ecosystems and there is less evidence of the benefits of protecting freshwater ecosystems (Adams et al., 2015). Our results offer new evidence about the benefits of protected areas on the extent of freshwater ecosystems.

Our results also highlight policies that may not be having their desired impact. For example, despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is increasing. This result suggests that policymakers must do more to conserve domesticated species from the threat of extinction. Indeed the latest reports from the FAO on this topic highlight numerous shortcomings in the state of genetic resource conservation, including missing risk status assessments for the majority of breeds and a lack of early warning systems for genetic erosion (Scherf et al., 2015). In addition, SDG indicators 2.5.1 and 2.5.2 need more data for many countries (Gil et al., 2019). Ultimately, conservation efforts, and the indicators used to monitor them, must be improved to mitigate and monitor the genetic extinction risk of economically and socially valuable species (Gandini & Hiemstra, 2021).

Our results regarding the relationship between species extinction risk and environmental responses were sobering yet not unexpected. Only a single environmental response (forest certification) correlated in a direction that suggests that extinction risk is declining in response to an environmental policy, which aligns with empirical evidence that forest certification contributes positively to biodiversity conservation (Lehtonen et al., 2021). However, the extent of protected areas of forest ecosystems, mountain ecosystems, and Key Biodiversity Areas all correlated with an *increase* in species extinction risk, which aligns with the criticisms that protected areas have fallen short of their conservation goals over the past decade (Maxwell et al., 2020). Regarding the environmental pressures that drive biodiversity loss, our results agree with the contemporary evidence that agricultural land use change and direct exploitation of wildlife remain the main drivers of terrestrial biodiversity declines (Balvanera et al., 2019; Jaureguiberry et al., 2022). Our results highlight that countries need to do more to holistically tackle the multiple drivers of biodiversity loss using environmental policies that are socially just and align with countries' climate change ambitions. At the 15th Conference of Parties to the UN Convention on Biological Diversity, UN Member States agreed to a new set of Goals and Targets to address biodiversity loss and restore natural ecosystems (CBD, 2022a), progress towards which will be tracked by an underlying monitoring framework of indicators (CBD, 2022b). Adopting the monitoring framework is a significant achievement as it is the first time an officially agreed monitoring framework has accompanied the CBD's international biodiversity agreements. A rigorous mechanism for tracking countries' progress on biodiversity will push governments to prioritise the effective design and implementation of environmental policies that bend the curve of biodiversity decline.

We investigated the environment's social impacts, including the human and economic impacts of natural disasters, food insecurity, health impacts of food access, and drinking water access. We found no evidence for relationships between the state of the environment and its impacts on society. Although alarming, this is somewhat not surprising, considering the complexity of ecosystems and their relationships with the goods and benefits that humans derive from the environment. Ecosystems are characterised by 'feedback loops, non-linearities, and alternative states' (Mace, 2019), which makes it challenging to delineate simple relationships between the state of the environment, the ecological functions that support ecosystem services, and the final environmental goods and benefits that society enjoys. It may also be harder to detect a direct link between humans and environmental goods and benefits at a national scale, (the scale of our analysis in this study), because less people now directly depend on the goods and benefits produced by their local ecosystems. Most people now live in cities(UNDESA, 2019) and consume food and materials that are produced by ecosystems outside their local area, and often far outside their national jurisdictions(Folke et al., 1997). There has also been less research on the social impacts of some types of environmental policies than on their environmental impacts (Johnson et al., 2022). Finally, the methods that are used to produce national statistics can be inappropriate for surveying the population groups that do directly depend on their local ecosystems for food and water such as indigenous communities(Walter & Andersen, 2016).

We also investigated environmental pressures, and our results suggest that the human activities that cause environmental degradation, including freshwater withdrawals, tourism, consumption of domestically produced crops, mined minerals, fossil fuels, and wild materials, continue to degrade the environment. Indeed, our findings align with the IPBES global assessment which details freshwater withdrawals, harvesting of materials from nature, mining of fossil fuels, agricultural land-use change, and tourism as direct drivers of environmental change that continue to threaten the state of nature globally (Balvanera et al., 2019). To improve environmental outcomes, countries will need to continue to mitigate these human activities' negative environmental impacts.

Policy responses and environmental pressures continue to increase while the state of the environment continues to decline (Lambertini, 2020; UN Environment, 2019), which illustrates that, to improve the environment, national governments need to do more. Existing policies need to do more to achieve their intended goals and require greater stringency or redesign (UN Environment, 2019). Others may need to be implemented correctly or enforced adequately. Moreover, policies must tackle the underlying drivers of environmental change, such as values, technology, demography, the economy, and governance, which often subvert well-meaning environmental policies. Environmental policies need to engage sufficiently with land and sea use policies, including agriculture, fisheries, renewable energy, and transport (European Habitats Forum, 2019). In addition, countries must respond holistically to environmental declines by integrating environmental policies into agriculture, fisheries, and energy policies that drive environmental change.

We make some recommendations for future improvements to the SDG monitoring framework. First, indicators on policy responses dominate the environmental dimension of the SDG monitoring framework (50 out of 92 indicators), while only 11 measure the state of the environment (Campbell et al., 2020). We recommend that the framework be supplemented with additional environmental state indicators to better track whether policy responses lead to environmental improvements. Secondly, we recommend that indicator 15.5.1, the Red List Index on wild species extinction risk, is disaggregated into multiple sub-indicators of terrestrial, freshwater, and marine species. Currently, indicator 15.5.1 only includes terrestrial species, so it is unsuitable for assessing the success of indicator 14.5.1 on marine protected areas and sub-indicator 15.1.2 on the protection of freshwater Key Biodiversity Areas. The Red List Index for marine species (see, for example, (Nieto et al., 2015)) and a sub-indicator for freshwater species would be more suitable for monitoring the success of marine and freshwater conservation interventions than indicator 15.5.1 in its current form. Finally, national environmental monitoring agencies should adopt science-based standards for the environmental state indicators to provide clear targets for achievement (Usubiaga-Liaño & Ekins, 2022). Standards for some indicators will be uniform across all countries, such as the WHO's safe air pollution levels (World Health Organization & WHO European Centre for Environment, 2021). The standards of other indicators will need to be country-specific and defined through scientific investigation of environmental thresholds in the unique environmental context of each country.

The SDG monitoring framework's data is a valuable resource of indicators for tracking countries' progress toward environmental sustainability. By testing the relationships between indicators of countries' responses to environmental pressures, the state of the environment, and the impacts of the environment on society, we show that governments are making some progress toward sustainable development in some areas, but there are many areas for improvement. If governments wish to maintain nature's contributions to people into perpetuity, they need to improve their policy responses to environmental pressures.

Acknowledgments

The French Development Agency (Agence Française de Développement, AFD) funded this research through the partnership agreement number 554-2020 between AFD and University College London and financed on the Research Programme for a Pro Nature Economy (ECOPRONAT) number CZZ2687. We thank the United Nations Environment Programme for supporting this study. In addition, we thank the experts who contributed to the stakeholder meetings and online survey that informed the selection of indicator pairs for investigation.

Open Research

The SDG indicators data used for the study is available in both a private FigShare repository (https://figshare.com/s/83dc27cba88c5c7d91e3) and publicly available on the SDG Indicator Database (www.unstat.un.org/sdgs/dataportal/database). The R software used for the statistical analysis is available at https://www.r-project.org/ (R Core Team, 2021) and the R code used to conduct the statictial analysis will be made publically available on a GitHub repository on publication.

References

Adams, V. M., Setterfield, S. A., Douglas, M. M., Kennard, M. J., & Ferdinands, K. (2015). Measuring benefits of protected area management: Trends across realms and research gaps for freshwater systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1681). Scopus. https://doi.org/10.1098/rstb.2014.0274

Arroita, M., Flores, L., Larrañaga, A., Martínez, A., Martínez-Santos, M., Pereda, O., Ruiz-Romera, E., Solagaistua, L., & Elosegi, A. (2017). Water abstraction impacts stream ecosystem functioning via wetted-channel contraction. *Freshwater Biology*, *62*(2), 243–257. https://doi.org/10.1111/fwb.12864

Auld, G., Gulbrandsen, L. H., & McDermott, C. L. (2008). Certification schemes and the impacts on forests and forestry. *Annual Review of Environment and Resources*, *33*(1), 187–211.

Balvanera, P., Pfaff, A., Viña, A., García-Frapolli, E., Merino, L., Minang, P., Nagabhatla, N., Hussain, S., & Sidorovich, A. (2019). Chapter 2.1. Status and Trends – Drivers of Change. In *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (p. 152). IPBES secretariat. 10.5281/zenodo.3831881

Barnes, M. D., Craigie, I. D., Harrison, L. B., Geldmann, J., Collen, B., Whitmee, S., Balmford, A., Burgess, N. D., Brooks, T., Hockings, M., & Woodley, S. (2016). Wildlife population trends in protected areas predicted by national socio-economic metrics and body size. *Nature Communications*, *7*(1), Article 1. https://doi.org/10.1038/ncomms12747

Bookbinder, M. P., Dinerstein, E., Rijal, A., Cauley, H., & Rajouria, A. (1998). Ecotourism's Support of Biodiversity Conservation. *Conservation Biology*, *12*(6), 1399–1404. https://doi.org/10.1111/j.1523-1739.1998.97229.x

Bradshaw, C. J., Sodhi, N. S., & Brook, B. W. (2009). Tropical turmoil: A biodiversity tragedy in progress. *Frontiers in Ecology and the Environment*, *7*(2), 79–87. https://doi.org/10.1890/070193

Breuer, A., Janetschek, H., & Malerba, D. (2019). Translating Sustainable Development Goal (SDG) Interdependencies into Policy Advice. *Sustainability*, *11*(7), Article 7. https://doi.org/10.3390/su11072092

Bueren, E. van. (2019). *Environmental policy. History, Concepts, Instruments, & Examples*. Britannica. https://www.britannica.com/topic/environmental-policy

Burivalova, Z., Hua, F., Koh, L. P., Garcia, C., & Putz, F. (2017). A Critical Comparison of Conventional, Certified, and Community Management of Tropical Forests for Timber in

Terms of Environmental, Economic, and Social Variables. *Conservation Letters*, *10*(1), 4–14. https://doi.org/10.1111/conl.12244

Butchart, S. H., Akçakaya, H. R., Kennedy, E., & HILTON-TAYLOR, C. (2006). Biodiversity indicators based on trends in conservation status: Strengths of the IUCN Red List Index. *Conservation Biology*, *20*(2), 579–581.

Campbell, J., Neuner, J., See, L., Fritz, S., Fraisl, D., Espey, J., & Kim, A. (2020). The role of combining national official statistics with global monitoring to close the data gaps in the environmental SDGs. *Statistical Journal of the IAOS 36*. https://doi.org/10.3233/SJI-200648

Carranza, T., Balmford, A., Kapos, V., & Manica, A. (2014). Protected Area Effectiveness in Reducing Conversion in a Rapidly Vanishing Ecosystem: The Brazilian Cerrado. *Conservation Letters*, *7*(3), 216–223. https://doi.org/10.1111/conl.12049

CBD. (2022a). *COP15: Nations Adopt Four Goals, 23 Targets for 2030 In Landmark UN Biodiversity Agreement*. Convention on Biological Diversity. https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022

CBD. (2022b). *Monitoring framework for the Kunming-Montreal global biodiversity framework*. CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY Fifteenth meeting, Montreal, Canada. https://www.cbd.int/doc/c/179e/aecb/592f67904bf07dca7d0971da/cop-15-l-26-en.pdf

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation Planning for Ecosystem Services. *PLOS Biology*, *4*(11), e379. https://doi.org/10.1371/journal.pbio.0040379

Coad, L., Leverington, F., Knights, K., Geldmann, J., Eassom, A., Kapos, V., Kingston, N., de Lima, M., Zamora, C., Cuardros, I., Nolte, C., Burgess, N. D., & Hockings, M. (2015). Measuring impact of protected area management interventions: Current and future use of the Global Database of Protected Area Management Effectiveness. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1681), 20140281. https://doi.org/10.1098/rstb.2014.0281

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Coping with climate change: The roles of genetic resources for food and agriculture. (2015). FAO.

Damette, O., & Delacote, P. (2011). Unsustainable timber harvesting, deforestation and the role of certification. *Ecological Economics*, *70*(6), 1211–1219. https://doi.org/10.1016/j.ecolecon.2011.01.025

Davis, J. A., & Froend, R. (1999). Loss and degradation of wetlands in southwestern Australia: Underlying causes, consequences and solutions. *Wetlands Ecology and Management*, *7*(1), 13–23. https://doi.org/10.1023/A:1008400404021

De Longueville, F., Hountondji, Y., Ozer, P., & Henry, S. (2014). The Air Quality in African Rural Environments. Preliminary Implications for Health: The Case of Respiratory Disease in the Northern Benin. *Water, Air, & Soil Pollution*, *225*(11), 2186. https://doi.org/10.1007/s11270-014-2186-4

Deikumah, J. P., McAlpine, C. A., & Maron, M. (2014). Mining matrix effects on West African rainforest birds. *Biological Conservation*, *169*, 334–343. https://doi.org/10.1016/j.biocon.2013.11.030

Eklund, J., Blanchet, F. G., Nyman, J., Rocha, R., Virtanen, T., & Cabeza, M. (2016). Contrasting spatial and temporal trends of protected area effectiveness in mitigating deforestation in Madagascar. *Biological Conservation*, *203*, 290–297. https://doi.org/10.1016/j.biocon.2016.09.033

Enjalbert, J., Dawson, J. C., Paillard, S., Rhoné, B., Rousselle, Y., Thomas, M., & Goldringer, I. (2011). Dynamic management of crop diversity: From an experimental approach to on-farm conservation. *Comptes Rendus Biologies*, *334*(5), 458–468. https://doi.org/10.1016/j.crvi.2011.03.005

European Habitats Forum. (2019). *The implementation of the EU 2020 Biodiversity Strategy and recommendations for the post 2020 Biodiversity Strategy* (p. 8). European Habitats Forum. https://www.iucn.org/sites/dev/files/content/documents/eu_2020_biodiversity_strategy_and_recommendations_for_post_2020.pdf

Fa, J. E., Currie, D., & Meeuwig, J. (2003). Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future. *Environmental Conservation*, *30*(1), 71–78. https://doi.org/10.1017/S0376892903000067

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., & Gibbs, H. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574.

Folke, C., Jansson, Å., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio*, *26*(3), 167–172. Scopus.

Fuso Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán Broto, V., Anandarajah, G., Milligan, B., & Mulugetta, Y. (2018). Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy*, *3*(1), Article 1. https://doi.org/10.1038/s41560-017-0036-5

Gandini, G., & Hiemstra, S. J. (2021). Farm animal genetic resources and the COVID-19 pandemic. *Animal Frontiers*, *11*(1), 54–56. https://doi.org/10.1093/af/vfaa049

Geist, H. J., & Lambin, E. F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation: Tropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations. *BioScience*, *52*(2), 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Geldmann, J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M., & Burgess, N. D. (2013). Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation*, *161*, 230–238. https://doi.org/10.1016/j.biocon.2013.02.018

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, *107*(38), 16732–16737. https://doi.org/10.1073/pnas.0910275107

Gil, J. D. B., Reidsma, P., Giller, K., Todman, L., Whitmore, A., & van Ittersum, M. (2019). Sustainable development goal 2: Improved targets and indicators for agriculture and food security. *Ambio*, *48*(7), 685–698. https://doi.org/10.1007/s13280-018-1101-4

Gössling, S. (2002). Global environmental consequences of tourism. *Global Environmental Change*, *12*(4), 283–302. https://doi.org/10.1016/S0959-3780(02)00044-4

Gössling, S., & Peeters, P. (2015). Assessing tourism's global environmental impact 1900–2050. *Journal of Sustainable Tourism*, *23*(5), 639–659. https://doi.org/10.1080/09669582.2015.1008500

Gray, C. L., Hill, S. L. L., Newbold, T., Hudson, L. N., Börger, L., Contu, S., Hoskins, A. J., Ferrier, S., Purvis, A., & Scharlemann, J. P. W. (2016). Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications*, *7*(1), Article 1. https://doi.org/10.1038/ncomms12306

IAEG-SDGs. (2020). *SDG Indicator changes (15 October 2018 and onward)*. Tier Classification for Global SDG Indicators. https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/

IEA, IRENA, UNSD, World Bank, & WHO. (2022). *Tracking SDG 7: The Energy Progress Report*. World Bank.

International Council for Science (ICSU). (2017). *A Guide to "SDG" Interactions: From Science to Implementation* (p. 12). International Council for Science (ICSU). http://pure.iiasa.ac.at/id/eprint/14591/

IUCN. (2012). *Natural Solutions: Protected Areas Maintaining Essential Water Supplies*. IUCN. https://www.iucn.org/sites/dev/files/import/downloads/natsols_water_flyer_final.pdf

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances*, *8*(45), eabm9982. https://doi.org/10.1126/sciadv.abm9982

Johnson, B. A., Kumar, P., Okano, N., Dasgupta, R., & Shivakoti, B. R. (2022). Nature-based solutions for climate change adaptation: A systematic review of systematic reviews. *Nature-Based Solutions*, *2*, 100042. https://doi.org/10.1016/j.nbsj.2022.100042

Joppa, L. N., & Pfaff, A. (2011). Global protected area impacts. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1712), 1633–1638. https://doi.org/10.1098/rspb.2010.1713

Jordan, A., Wurzel, R. K. W., & Zito, A. R. (2003). 'New' Instruments of Environmental Governance: Patterns and Pathways of Change. *Environmental Politics*, *12*(1), 1–24. https://doi.org/10.1080/714000665

Kalonga, S. K., Midtgaard, F., & Klanderud, K. (2016). Forest certification as a policy option in conserving biodiversity: An empirical study of forest management in Tanzania. *Forest Ecology and Management*, *361*, 1–12. https://doi.org/10.1016/j.foreco.2015.10.034

Kristensen, P. (2004). *The DPSIR Framework*. The 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach, Nairobi, Kenya. https://wwz.ifremer.fr/dce/content/download/69291/913220/.../DPSIR.pdf

Lambertini, M. (2020). *Living Planet Report 2020: Bending the Curve of Biodiversity Loss*. http://www.deslibris.ca/ID/10104983

Lehner, B., Liermann, C. R., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P., Endejan, M., Frenken, K., Magome, J., Nilsson, C., Robertson, J. C., Rödel, R., Sindorf, N., & Wisser, D. (2011). High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment*, *9*(9), 494–502. https://doi.org/10.1890/100125

Lehtonen, E., Gustafsson, L., Lõhmus, A., & von Stedingk, H. (2021). What does FSC forest certification contribute to biodiversity conservation in relation to national legislation? *Journal of Environmental Management*, *299*. Scopus. https://doi.org/10.1016/j.jenvman.2021.113606

Mace, G. M. (2019). The ecology of natural capital accounting. *Oxford Review of Economic Policy*, *35*(1), 54–67. https://doi.org/10.1093/oxrep/gry023

Maxwell, S. L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A. S. L., Stolton, S., Visconti, P., Woodley, S., Kingston, N., Lewis, E., Maron, M., Strassburg, B. B. N., Wenger, A., Jonas, H. D., Venter, O., & Watson, J. E. M. (2020). Area-based conservation in the twenty-first century. *Nature*, *586*(7828), 217–227. Scopus. https://doi.org/10.1038/s41586-020-2773-z

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Nasi, R., Taber, A., & Van Vliet, N. (2011). Empty forests, empty stomachs? Bushmeat and livelihoods in the Congo and Amazon Basins. *International Forestry Review*, *13*(3), 355–368. https://doi.org/10.1505/146554811798293872

Nieto, A., Ralph, G. M., Comeros-Raynal, M., Heessen, H., & Rijnsdorp, A. (2015). *European Red List of marine fishes*. Publications Office of the European Union.

OECD. (2011). *Better Policies to Support Eco-innovation*. OECD Publishing. https://www.oecd.org/environment/consumption-innovation/betterpoliciestosupporteco-innovation.htm

Palmer, M. A., Bernhardt, E. S., Schlesinger, W. H., Eshleman, K. N., Foufoula-Georgiou, E., Hendryx, M. S., Lemly, A. D., Likens, G. E., Loucks, O. L., Power, M. E., White, P. S., & Wilcock, P. R. (2010). Mountaintop Mining Consequences. *Science*, *327*(5962), 148–149. https://doi.org/10.1126/science.1180543

Payn, T., Carnus, J.-M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Silva, L. N., & Wingfield, M. J. (2015). Changes in planted forests and future global implications. *Forest Ecology and Management*, *352*, 57–67. https://doi.org/10.1016/j.foreco.2015.06.021

Pekel, J.-F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, *540*(7633), Article 7633. https://doi.org/10.1038/nature20584

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S., & Esipova, E. (2017). The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances*, *3*(1), e1600821. https://doi.org/10.1126/sciadv.1600821

Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Future*, *5*(11), 1169–1179. https://doi.org/10.1002/2017EF000632

PwC. (2016). *Navigating the SDGs: A business guide to engaging with the UN Global Goals* (p. 96). Price Waterhouse Cooper. https://www.pwc.com/gx/en/sustainability/publications/PwC-sdg-guide.pdf

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rametsteiner, E., & Simula, M. (2003). Forest certification—An instrument to promote sustainable forest management? *Journal of Environmental Management*, *67*(1), 87–98. https://doi.org/10.1016/S0301-4797(02)00191-3

Rosen, C., Tunstall, D., White, R., Ottke, C., Revenga, C., Rohweder, M., Murray, S., Kassem, K., Kura, Y., Sebastian, K., Henninger, N., Reid, W. V., Lenton, R., McNeil, C., Schmidt, R., Becker, S., Lewis, K., Claasen, D., Singh, A., … Axelrod, E. (2000). *A Guide to World Resources 2000–2001: People and Ecosystems: The Fraying Web of Life*. UNDP-UNEP-World Bank.

Scharlemann, J. P. W., Brock, R. C., Balfour, N., Brown, C., Burgess, N. D., Guth, M. K., Ingram, D. J., Lane, R., Martin, J. G. C., Wicander, S., & Kapos, V. (2020). Towards understanding interactions between Sustainable Development Goals: The role of environment–human linkages. *Sustainability Science*. https://doi.org/10.1007/s11625-020-00799-6

Scherf, B. D., Pilling, D., & Commission on Genetic Resources for Food and Agriculture. (2015). *The second report on the state of the world's animal genetic resources for food and agriculture*. http://www.fao.org/3/a-i4787e.pdf

Schueler, V., Kuemmerle, T., & Schröder, H. (2011). Impacts of Surface Gold Mining on Land Use Systems in Western Ghana. *AMBIO*, *40*(5), 528–539. https://doi.org/10.1007/s13280-011-0141-9

Schwartz, T., & Goubran, S. (2020). An Introduction to the Current Landscape: Environmental Policy and the Economy. In *Environmental policy: An economic perspective*. Hoboken, New Jersey ; West, Sussex, England : Wiley Blackwell. http://onlinelibrary.wiley.com/doi/epub/10.1002/9781119402619

Shanley, P. (2002). *Tapping the green market: Management and certification of non-timber forest products*. Earthscan Publications; Library Hub Discover. http://ebookcentral.proquest.com/lib/abdn/detail.action?docID=429917

Sonter, L. J., Moran, C. J., Barrett, D. J., & Soares-Filho, B. S. (2014). Processes of land use change in mining regions. *Journal of Cleaner Production*, *84*, 494–501. https://doi.org/10.1016/j.jclepro.2014.03.084

Turral, H., Svendsen, M., & Faures, J. M. (2010). Investing in irrigation: Reviewing the past and looking to the future. *Agricultural Water Management*, *97*(4), 551–560. https://doi.org/10.1016/j.agwat.2009.07.012

UN Environment. (2019). *Global Environment Outlook—GEO-6: Healthy Planet, Healthy People*. Un Environment. https://doi.org/10.1017/9781108627146

UNDESA. (2019). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*. United Nations, Department of Economic and Social Affairs, Population Division.

UNEP. (2019). *Measuring Progress: Towards Achieving the Environmental Dimension of the SDGs*. United Nations Environment Programme.

UNEP. (2021). *Measuring Progress: Environment and the SDGs*. United Nations Environment Programme. https://www.unep.org/resources/publication/measuring-progress-environment-and-sdgs

United Nations. (2015). *Transforming our World: The 2030 Agenda for Sustainable Development. General Assembly Resolution A/RES/70/1.* https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

Usubiaga-Liaño, A., & Ekins, P. (2022). Are we on the right path? Measuring progress towards environmental sustainability in European countries. *Sustainability Science*.

van Kuijk, M., Putz, F., & Zagt, R. (2009). *Effects of forest certification on biodiversity*. Tropenbos International. https://www.tropenbos.org/resources/publications/effects+of+forest+certification+on+biodiversity

Vliet, N. van, Nasi, R., Emmons, L., Feer, F., Mbazza, P., & Bourgarel, M. (2007). Evidence for the local depletion of bay duiker Cephalophus dorsalis, within the Ipassa Man and Biosphere Reserve, north-east Gabon. *African Journal of Ecology*, *45*(3), 440–443.

Walter, M., & Andersen, C. (2016). *Indigenous statistics: A quantitative research methodology*. Routledge.

Wang, X., Ning, L., Yu, J., Xiao, R., & Li, T. (2008). Changes of urban wetland landscape pattern and impacts of urbanization on wetland in Wuhan City. *Chinese Geographical Science*, *18*(1), 47–53. https://doi.org/10.1007/s11769-008-0047-z

Watson, R. T., Baste, I. A., Larigauderie, A., Leadley, P., Pascual, U., Baptiste, B., Demissew, S., Dziba, L., Erpul, G., Fazel, A. M., Fischer, M., Hernández, A. M., Karki, M., Mathur, V., Pataridze, T., Pinto, I. S., Stenseke, M., Török, K., & Vilá, B. (2019). *The global assessment report on biodiversity and ecosystem services. Summary for policymakers*. IPBES Secretariat. https://ipbes.net/global-assessment

Weitz, N., Carlsen, H., Skånberg, K., Dzebo, A., & Viaud, V. (2019). *SDGs and the environment in the EU: A systems view to improve coherence* (p. 36). Stockholm Environment Institute. https://www.sei.org/wp-content/uploads/2019/10/sei-2019-pr-weitz-sdg-synergies-eu-env.pdf

World Health Organization & WHO European Centre for Environment. (2021). *WHO global air quality guidelines: Particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.

Žganec, K. (2012). The effects of water diversion and climate change on hydrological alteration and temperature regime of karst rivers in central Croatia. *Environmental Monitoring and Assessment*, *184*(9), 5705–5723. https://doi.org/10.1007/s10661-011-2375-1

Zhang, Q. (2009). The South-to-North Water Transfer Project of China: Environmental Implications and Monitoring Strategy1. *JAWRA Journal of the American Water Resources Association*, *45*(5), 1238–1247. https://doi.org/10.1111/j.1752-1688.2009.00357.x

The SDG monitoring framework provides limited evidence that environmental policies are delivering multiple ecological and social benefits

Fairbrass, A.J.[1]*, O'Sullivan[2], A., Campbell, J.[3], Ekins, P.[1]

[1] Institute for Sustainable Resources, University College London, London, UK.

[2] Energy Institute, University College London, London, UK.

[3] United Nations Environment Programme, Nairobi, Kenya.

Corresponding author: Alison Fairbrass (alison.fairbrass.10@ucl.ac.uk)

Key Points:

- The state of the environment globally continues to decline despite increasing environmental policy responses.
- The SDG indicators provide no evidence that environmental policies deliver secondary social benefits.
- Protected areas and sustainable forest certification are linked with environmental improvements, mainly in forest and water ecosystems.

Abstract

The Sustainable Development Goals (SDGs) provide targets for humanity to achieve sustainable development by 2030. A monitoring framework of 248 environmental, social, and economic indicators, reported nationally by 193 UN Member States, tracks progress. The framework includes 92 environmental indicators, most of which refer to environmental policies. The SDG monitoring framework provides data to assess whether, across countries, environmental policies are: 1. Addressing environmental pressures, 2. Linked to environmental improvements, and 3. Linked with societal benefits delivered by healthy environments. We use statistical analysis and a generalized linear modeling approach to test for correlations between SDG indicators related to environmental policies, environmental pressures, the state of the environment, and social impacts delivered by healthy environments. Our results show that environmental policies, particularly protected areas and sustainable forest certification, are linked with environmental improvements, mainly in forest and water ecosystems. However, we find no evidence that environmental improvements are linked with positive social impacts. Finally, environmental pressures, including freshwater withdrawal, domestic material consumption, and tourism, are linked with environmental degradation. Environmental policy responses are generally increasing across countries. Despite this, the state of the environment globally continues to decline. Governments must focus on understanding why environmental policies have not been sufficient to reverse environmental decline, particularly concerning the pressures that continue to degrade the environment. To better track progress towards sustainable development, we recommend that the SDG monitoring framework is supplemented with additional indicators on the state of the environment.

Plain Language Summary

Governments implement environmental policies to reduce ecological degradation and sustain environmental benefits to humans, such as food and clean water. The Sustainable Development Goals (SDGs) call for all countries to commit to pathways that lead to sustainable development. Progress towards achieving the Goals is reported by governments using 231 indicators. The SDG indicators track the implementation of environmental policies, the state of the environment, and environmental benefits such as food security and drinking water access. Using the data underlying the SDG indicators reported by governments to date, we investigate whether the

implementation of environmental policies correlates with improvements in the environment and the provision of environmental benefits to humans. Results show that most environmental policies are not associated with environmental improvements; worse, we find no evidence that environmental policies lead to more human benefits. However, we see two types of environmental policies, protected areas and sustainable forest certification, that lead to increasing the size of forest and water ecosystems which are essential for sustaining the lives of plants, animals, and humans that rely on them. Our findings highlight that governments must improve their use of environmental policies to achieve environmental improvements and the benefits humans derive from the environment.

1. Introduction

In September 2015, the United Nations Sustainable Development Summit adopted an international framework to guide development efforts, entitled Transforming our World: the 2030 Agenda for Sustainable Development (United Nations, 2015). The Agenda is built around 17 Sustainable Development Goals (SDGs), divided into 169 targets, which are a call to action from all countries to move the world onto a sustainable development trajectory. An underlying monitoring framework composed of 231 unique indicators (a further thirteen are repeated under different targets) tracks progress toward the goals and targets. The environmental dimension of the SDG monitoring framework is composed of 92 indicators (UNEP, 2021). These indicators encompass a range of topics, such as sustainable consumption, ocean acidification, and environmental education, and a range of environments, such as marine, freshwater, and mountain ecosystems. A dataset underlies the SDG monitoring framework and is composed of indicators reported to the UN by the Member States or derived by the UN from global datasets when nationally produced indicators are unavailable. However, some indicators still need more data, as discussed further below.

Environmental policies are intended to reduce environmental damage, incentivise positive environmental behaviour, and guide practices toward a more sustainable future (Schwartz & Goubran, 2020). The umbrella term 'environmental policy' encapsulates various environmental policy types, including regulatory instruments, market-based instruments, voluntary agreements, and information provision (Jordan et al., 2003). In addition, innovation policy may also be used to improve the environment (OECD, 2011). Most recently, a class of policy instruments called

'Nature-based solutions' has been defined as 'actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham et al., 2016).

The SDG monitoring framework uses SDG indicators to track the national use of environmental policy instruments. For example, indicator 15.8.1 covers legislation about invasive alien species (a regulatory instrument), indicator 15.4.1 covers the protection of mountain biodiversity (a Nature-based Solution), and indicator 12.1.1 covers sustainable consumption policies (the indicator does not specify instrument type).

If the aim of environmental policies is 'to prevent or reduce harmful effects of human activities on ecosystems' (Bueren, 2019) and to 'address societal challenges…by providing human well-being benefits' (Cohen-Shacham et al., 2016), we should expect that environmental improvements would follow the use of environmental policies. In addition, environmental improvements would also benefit human society via ecosystem services. Indeed, the natural environment provides various services that benefit humans, such as providing food and fibre, mitigating the effects of extreme weather events, and cultural connections to nature (Millennium Ecosystem Assessment, 2005). In this study, we use the SDG monitoring framework data to investigate, at the national scale, the relationships between the use of environmental policies, the state of the environment, and the provision of environmental benefits to society.

The DPSIR indicator framework describes the interactions between society and the environment (Kristensen, 2004; UN Environment, 2019). The framework provides a structure to understand the causal links between 'driving forces' [D] (economic sectors, human activities), 'pressures' [P] (emissions, waste, resource use), environmental 'states' [S] (physical, chemical, and biological), 'impacts' [I] (on ecosystems, human health, and functions), and political 'responses' [R] (policies, and other actions at different levels). In this study, we investigate whether the SDG monitoring framework's data provides evidence for relationships, at a national level, between political 'responses,' the 'state' of the environment, and the 'impacts' of the environment on society. In addition, we investigate relationships between environmental 'pressures' (UN Environment, 2019) and environmental 'state' indicators to highlight which environmental pressures require increased policy attention to reduce their harmful impacts. Finally, this investigation allows us to leverage the SDG monitoring framework data to investigate whether national environmental policies are delivering their primary objective of improving the state of the environment and their secondary objective of reducing the negative impacts of environmental degradation on people.

Several studies have already investigated the relationships between the Goals and Targets of the SDGs (Breuer et al., 2019; Fuso Nerini et al., 2018; International Council for Science (ICSU), 2017; PwC, 2016; Scharlemann et al., 2020; Weitz et al., 2019). However, only one study has investigated the relationships between the SDG indicators underlying the entire SDG monitoring framework (Pradhan et al., 2017). This study took SDG indicators in pairs for all countries and, given the availability of time-series data, calculated correlations between the indicator pairs using Spearman's rank. We go beyond the Pradhan et al. study in two ways. Firstly, we weed out all indicator pairs where there is no evidence in the scientific literature of likely correlation or causation along the DPSIR (Driving forces to Pressures to States to Impacts to Responses) chain. Then, the indicator pairs are selected on this basis, which both aids our interpretation of our results and strengthens the probability that any correlations may have at least some causal elements. Secondly, we used a modelling approach to investigate the relationship between indicator pairs, rather than a correlation test as used by Pradhan et al.. A modelling approach enables us to control for potentially confounding factors that may influence the SDG indicators, such as economic development, demographics, or geolocation of a country (Breuer et al., 2019).

Therefore, this study uses the SDG monitoring framework data to investigate whether national environmental policies deliver their intended primary environmental and secondary social benefits and identify which environmental pressures require increased political attention. First, we apply the DPSIR framework to identify SDG indicators representing environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts.' Secondly, we identify plausible relationships between indicators of environmental pressures, environmental policy responses, the state of the environment, and secondary societal impacts. Finally, we use statistical tests and multivariate analysis to test relationships between SDG indicators while controlling for confounding factors of countries' development and geographic status. Leveraging the dataset underlying the SDG monitoring framework, our approach allows us to ask the questions:

Are environmental policies correlated with improvements in the state of the environment? These results will suggest where political efforts have the desired impact on the environment.

Are improvements in the state of the environment correlated with reductions in the impacts of poor environmental quality on society? These results will highlight where environmental policies can deliver additional societal benefits.

Is there evidence of negative impacts from environmental pressures on the state of the environment? These results will highlight where additional efforts need to focus.

2. Materials and Methods

2.1. Classifying SDG indicators and assessing data availability

We classified the 231 unique SDG indicators and their underlying sub-indicators into one of four groups (Table 1). Some SDG indicators are composed of a single indicator, and others are disaggregated into sub-indicators. For example, SDG indicator 2.5.1 'Secure genetic resources for food' is produced by aggregating two underlying sub-indicators: 1. The number of local breeds for which sufficient genetic resources are stored for reconstitution, and 2. Plant breeds for which sufficient genetic resources are stored. In contrast, SDG 6.6.1 includes sub-indicators related to water body extent, wetland extent, and mangrove extent, which are used without aggregation. In addition to our classification, Table 1 shows the smaller number of indicators with sufficient data to carry out our analysis.

Table 1. Classification and data availability of the SDG indicators and sub-indicators

Class	**Number of unique indicators (and sub-indicators)**	**Number of unique indicators (and sub-indicators) with sufficient data to include in the analysis**
Environmental policy responses	50 (85)	22 (38)
Environmental states	11 (36)	5 (9)
Social impacts	16 (44)	11 (31)
Environmental pressures	20 (41)	18 (38)

Data collection efforts to support the SDG monitoring framework vary significantly across the Targets and Indicators (UNEP, 2019). Tier 3 indicators still need an agreed methodology for collecting data; Tier 2 indicators are not yet supported by regular data collection (IAEG-SDGs, 2020). This means many SDG environmental indicators do not have the necessary datasets for robust statistical analysis.(UNEP, 2019). Therefore, we assessed the data availability of each SDG indicator and sub-indicator. In order to be included in our analysis, an indicator or sub-indicator must have data for at least two years since 2000 by at least 20 countries (Table 1). Between January and June 2020, we extracted the data underlying the SDG indicators from the UN's SDG Indicators Database. However, some underlying data was unavailable on the SDG Indicators Database, and we sourced this additional data from UNEP in July 2020.

2.1.1 Group 1: Environmental policy responses

We identified 50 unique SDG indicators related to environmental policies that cover issues such as sustainable agricultural management, renewable energy use, and action plans for sustainability. In addition, the SDG monitoring framework contains sufficient data to include 22 environmental policy indicators in this analysis.

2.1.2 Group 2: Environmental states

We identified 11 SDG indicators that relate to the state of the environment. These state of the environment indicators measure the quality and quantity of water resources, marine eutrophication, plastic concentration and acidity, fish stocks, forest cover, land degradation, green land cover in mountain ecosystems, and extinction risk of wild and domesticated species. The SDG monitoring framework contains sufficient data to include five environmental state indicators in this analysis.

2.1.3 Group 3: Social impacts

We identified 16 SDG indicators that relate to the social impacts of the environment. These social impacts indicators include the human and economic impacts of natural disasters, food, and water access, and mortality attributed to air pollution. The SDG monitoring framework contains sufficient data to include 11 social impact indicators in this analysis.

2.1.4 Group 4: Environmental pressures

We identified 20 SDG indicators related to environmental pressures. These environmental pressure indicators include water stress, domestic material consumption (DMC), tourism, and infrastructure development. The DMC indicator comprises numerous material-specific sub-indicators including, but not limited to, DMC of wood, minerals, fossil fuels, crops, wild catch, and harvested materials. The SDG monitoring framework contains sufficient data to include 18 environmental pressure indicators in this analysis.

2.2. Identifying potential synergies between indicator pairs

The IPBES Global Assessment (Watson et al., 2019) provides a global evidence review of the environmental and social effects of environmental pressures and policy responses; for example, the direct environmental impacts of sustainability certification schemes on forest ecosystems and the secondary social impacts on access to non-timber forest products (Shanley, 2002). For the indicators with sufficient data to include in our analysis (Table 1), we identify potential relationships between pairs of SDG indicators and their sub-indicators using this evidence base. To investigate the relationship between environmental 'pressures,' policy 'responses,' environmental 'states,' and social 'impacts' we identify 618 potential relationships between SDG indicators and their underlying sub-indicators. We detail these potential relationships in the Supplementary Information.

We supplemented the evidence presented in IPBES Global Assessment through consultation with experts from various environmental and social stakeholder groups. This consultation on selecting SDG indicator relationships took the form of an online meeting held on 21-22 April 2020 and an online survey held from 29 May to 13 June 2020. We provide the minutes of this meeting and an overview of the responses received from experts to the online survey in the Supplementary Information.

2.3. Determining how to interpret SDG indicators to identify improvements in environmental and social conditions

A good indicator has a clear relationship to the situation about which it is reporting. Of the environmental state and social impact indicators that we include in this investigation, we identify when they are showing improvements in the state of the environment and the social impacts of the environment (Figure 1). In terms of improving environmental and social conditions, some indicators would increase (e.g., forest area and schools with drinking water access), and other indicators would decrease (e.g., air pollution and food insecurity). Different correlation directions indicate desirable relationships between environmental pressure, environmental policy, environmental state, and social impact indicators. Environmental state indicators that show improvement when they increase should show a **positive correlation** with environmental policy indicators, e.g., an *increase* in forest areas should correlate positively with *increasing* the protection of forest ecosystems. Conversely, environmental indicators that show improvement when they decrease should show a **negative correlation** with environmental policy indicators, e.g., *decreasing* domestic species extinction risk should correlate negatively with *increasing* conservation of domestic species' genetic resources.

Environmental state indicators will tend to be negatively affected by environmental pressures, with the direction of the correlation depending on whether improvement in each indicator is represented by an increase or a decline.

Finally, the desirable correlation between an environmental state and a social impact indicator would suggest that social impacts are improving alongside improvements in the state of the environment. Again, the desirable direction of the correlation depends on whether improvement is associated with increasing or decreasing values of each indicator.

SDG Indicators		What we want to see	Direction of correlation in response to: Increasing environmental policies	Decreasing environmental pressures
State of the environment				
2.5.2	Local breeds extinction	*Decreasing* proportion of local breeds classified as being at risk of extinction	−	+
6.6.1	Water ecosystems	*Increasing* extent of water-related ecosystems	+	−
11.6.2	Air pollution	*Decreasing* levels of fine particular (e.g. PM2.5 and PM10) matter in cities	−	+
15.1.1	Forest area	*Increasing* forest area	+	−
15.5.1	Species at risk	*Increasing* Red List Index indicates decreasing species extinction risk	+	−

SDG Indicators		What we want to see	Direction of correlation in response to an environmental state indicator that shows improvement when values are: Increasing	Decreasing
Social impact				
1.5.1	Disasters: human impacts	*Decreasing* human impacts of disasters	−	+
1.5.2	Disasters: economic impacts	*Decreasing* economic impacts of disasters	−	+
2.1.1	Undernourishment	*Decreasing* prevalence of undernourishment	−	+
2.1.2	Food insecurity	*Decreasing* prevalence of moderate or severe food insecurity	−	+
2.2.2	Children wasted	*Decreasing* prevalence of children wasted	−	+
2.2.2	Children overweight	*Decreasing* prevalence of children overweight	−	+
4.a.1	Schools drinking water access	*Increasing* proportion of schools offering access to drinking water	+	−

Figure 1. The desirable direction of correlation between indicators (plus sign indicates a positive correlation, minus sign indicates a negative correlation) that show improvement in the state of the environment in response to increasing environmental policies and decreasing environmental pressures (upper table) and the social impacts of the state of the environment (lower table).

2.4. Investigating relationships between indicator pairs

We used generalized linear regression modelling (GLRM) to investigate whether there is evidence for a statistically significant relationship between our chosen indicator pairs within our model, controlling for two potentially confounding factors, population, and GDP. This methodology adapts the analysis we present in (UNEP, 2021), in which we combined a GLRM and correlation test to investigate SDG indicator interactions. Here we report only the results of our investigation of SDG indicator interactions using a GLRM approach. In addition, this approach enables us to investigate correlations while considering some confounding factors that a correlation test does not.

A GLRM produces a correlation coefficient, the sign of which indicates a positive or negative direction of the relationship between the two indicators. For example, one of our indicator pairs is clean fuels and air quality, both of which may change due to a change in GDP. A GLRM allows us to separate the different potential influences on our indicator variables, making it more likely that any correlation between the two indicators is not the result of some other factor. In addition to GDP and population, we included a fixed effect in our regressions to account for regional or other differences between the countries.

There are several points to note about our approach: 1. The GLRM approach is characterized by the assumption that the relationship between two indicators is linear. Therefore, any non-linear associations between the two indicators will not be captured adequately by the GLRM. 2. We applied a log transformation to several indicators to control for the substantial differences between some countries. The log transformation is appropriate to the data underlying the indicators because the values are generally positive, such as percentages and square kilometres. The log transformation also mitigates the impact of outliers by compressing the data. 3. We needed at least two data points at different times to estimate the relationships between our indicators 4. Finally, for each indicator pair we investigated, our analysis was limited to the number of countries reporting data for both indicators.

2.4.1 Generalised linear regression model (GLRM)

The complete model formulation is as follows:

$$\log(Y) = \beta_1 \log(X) + \beta_2 \log(pop) + \beta_3 \log(GDP) + I_{region}$$

Where:

Y: an indicator of either the environmental state OR a social impact

X: an indicator of either the environmental pressure OR an environmental policy OR the environmental state

pop and GDP: national population and GDP for each year, the potential confounding factors

I_{region}: a fixed effect variable for each country or geographical region

β1, β2, and β3: maximum likelihood estimates of the model coefficients. These measure the relationship between each independent variable in the model and the dependent Y variable. We conducted a hypothesis test on the coefficient of interest (β1) to assess whether there is evidence of a relationship between a pair of indicators (using a significance level of $\alpha = 0.05$) after accounting for the influence of the potential confounding factors. The GLRM model also calculates the R2 value, which shows how much of the variance in the dependent variable it captures. We did not consider regressions with an R2 of less than 0.2, which was our minimum goodness of fit threshold. We conducted all statistical analyses using R software (R Core Team, 2021).

3. Results

We identified significant correlations between the indicators on the state of the environment, with the indicators on environmental policies and pressures—some correlations aligned with our hypotheses, and others contrasted with our hypotheses. However, we identified no significant correlations between the indicators on the state of the environment and the social impacts of the environment. Therefore, the Results section presents only the findings of the analysis of the environmental policy, pressure, and state indicators, and no findings on the social impact indicators, as we found no significant relationships with these indicators.

3.1. Relationships between environmental policies, the state of the environment

Table 2. The environmental policy indicators that correlate significantly with the environmental state indicators. Correlations that show environmental improvement are presented in the upper half of the table. Correlations that show environmental degradation are presented in the lower half of the table. The middle column describes the causal relationship between environmental policies and environmental improvements based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental policy indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental policy, leading to environmental improvements**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
7.2.1 Renewable energy	11.6.2 Outdoor air pollution in cities	Greater reliance on clean fuels leads to less combustion of dirty fuels, which reduces the amount of air pollutants produced and leads to improvements in air quality	(IEA et al., 2022, p. 7)	*Increasing* renewable energy use correlates with *decreasing* levels of fine particulate matter in cities

Environmental policy indicator	Environmental state indicator	Hypothesised outcomes of environmental policy, leading to environmental improvements	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
7.2.1 Renewable energy	15.1.1 Forest area	Greater reliance on clean fuels reduces reliance on wood resources for energy which leads to less deforestation and a greater extent of forest ecosystems	(IEA et al., 2022, p. 7)	*Increasing* renewable energy use correlates with *increasing* forest area
15.1.2 Protection of Key Biodiversity Areas (KBAs)	6.6.1 Water ecosystems	Protection of KBAs reduces the abstraction of water from protected water ecosystems and leads to an increase in water ecosystem extent	(Chan et al., 2006; IUCN, 2012)	*Increasing* protection of KBAs is correlated with *increasing* water ecosystem extent
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.1.1 Forest area	Protection of KBAs reduces deforestation in protected forest ecosystems and leads to an increase in forest area	(Carranza et al., 2014; Geldmann et al., 2013)	*Increasing* protection of KBAs is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.1.1 Forest area	Sustainable forest certification reduces unsustainable deforestation, which increases forest area	(Auld et al., 2008; Damette & Delacote, 2011; Potapov et al., 2017; Rametsteiner & Simula, 2003)	*Increasing* sustainable forest certification is correlated with *increasing* forest area
15.2.1 Sustainable forest certification	15.5.1 Species at risk	Sustainable forest certification reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Burivalova et al., 2017; Kalonga et al., 2016; van Kuijk et al., 2009)	*Increasing* sustainable forest certification is correlated with *increasing* Red List Index, which indicates *decreasing* species extinction risk
15.2.1 Protected forest area	15.1.1 Forest area	Protection of forest ecosystems reduces unsustainable deforestation, which increases forest area	(Carranza et al., 2014; Eklund et al., 2016)	*Increasing* the protection of forests correlates with *increasing* forest area
2.5.1 Secure genetic resources for food	2.5.2 Local breeds extinction	Conservation of genetic resources reduces the extinction risk of domesticated species	(*Coping with Climate Change*, 2015; Enjalbert et al., 2011)	*Increasing* conservation of genetic resources for food correlates with an *increasing* proportion of local breeds at risk of extinction
6.a.1 Investment in water and sanitation	6.6.1 Water ecosystems	Investment catalyses improved water resource management which reduces demand for, and abstraction of, water from water ecosystems and leads to an increase in water ecosystem extent	(Turral et al., 2010)	*Increasing* investment in water and sanitation correlates with *decreasing* water ecosystem extent
7.1.2 Primary reliance on clean fuels	11.6.2 Air pollution	Greater reliance on clean fuels and technologies leads to less non-renewable resource combustion, which reduces the amount of air pollutants produced and leads to improvements in air quality	(IEA et al., 2022, p. 7)	*Increasing* reliance on clean fuels correlates with *increasing* levels of fine particulate matter in cities
15.1.2 Protection of Key Biodiversity Areas (KBAs)	15.5.1 Species at risk	Protection of KBAs reduces human disturbance of biodiversity, which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al., 2016)	*Increasing* protection of KBAs is correlated with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.2.1 Sustainable	15.5.1 Species at risk	Sustainable forest management reduces human disturbance of biodiversity in forest ecosystems	(Burivalova et al., 2017)	*Increasing* the forests under sustainable long-

Environmental policy indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental policy, leading to environmental improvements**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
forest long-term management		which leads to a reduction in the number of species threatened with extinction		term management correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.2.1 Protected forest area	15.5.1 Species at risk	Protection of forest ecosystems reduces human disturbance of biodiversity in forest ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Coad et al., 2015; Geldmann et al., 2013; Gray et al., 2016)	*Increasing* protection of forests correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.4.1 Mountain protected areas	15.5.1 Species at risk	Protection of mountain ecosystems reduces human disturbance of biodiversity in mountain ecosystems which leads to a reduction in the number of species threatened with extinction	(Barnes et al., 2016; Butchart et al., 2006; Gray et al., 2016)	*Increasing* protection of mountain ecosystems correlates with *decreasing* Red List Index, which indicates an *increasing* species extinction risk
15.8.1 Invasive alien species	15.5.1 Species at risk	National legislation and adequate resourcing for the prevention or control of invasive alien species leads to a reduction in the negative impacts of invasive alien species on biodiversity and a reduction in the number of species threatened with extinction	(Butchart et al., 2006)	*Increasing* prevention and management of alien invasive species correlates with *decreasing* Red List Index, which indicates *increasing* species extinction risk.

3.1.1 Extinction risk of local breeds (2.5.2)

The extinction risk of local breeds was positively correlated with policies to secure genetic resources for food (2.5.1) (Table 2), suggesting that despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is going up.

3.1.2 Water ecosystem extent (6.6.1)

We found a positive correlation between the protection of important sites for terrestrial and freshwater biodiversity (15.1.2) and the extent of water ecosystems (Table 2). On the other hand, we found a negative correlation between water ecosystem extent and the value of development assistance for water supply and sanitation (6.a.1), suggesting that increased spending on water and sanitation is related to decreasing water ecosystem extent. Furthermore, there was no significant relationship between water ecosystem extent and water use efficiency (6.4.1).

3.1.3 Air pollution (11.6.2)

Air pollution, measured as levels of outdoor fine particulate matter in cities, was positively correlated with the proportion of the population with primary reliance on clean fuels and technology (7.1.2) (Table 2). This result suggests that despite the increasing use of clean fuels and technologies, urban air pollution levels continue to increase. Conversely, air pollution was negatively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1), suggesting that there may be a link between renewable energy use and air pollution in cities.

3.1.4 Forest ecosystem extent (15.1.1)

The extent of forest ecosystems was positively correlated with the share of renewable energy in a country's total final energy consumption (7.2.1) (Table 2). This result suggests a relationship between increasing renewable energy use and increasing forest area, perhaps due to decreasing deforestation linked to the use of timber for energy production. We found no significant correlation between forest ecosystem extent and population with primary reliance on clean fuels and technology (7.1.2). However, forest ecosystem extent was positively correlated with the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of forests certified under an independently verified certification scheme (15.2.1), and the area of forest that is protected (15.2.1). These results suggest that protected area policies and forest certification schemes are related to increasing forest ecosystem extent.

3.1.5 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental policy indicators (Table 2), including the protection of important sites for terrestrial and freshwater biodiversity (15.1.2), the extent of protected forest ecosystems (15.2.1), the extent of protection of mountain ecosystems (15.4.1), implementation of long-term forest management plans (15.2.1), and the prevention or control of Invasive Alien Species (15.8.1). These results suggest that despite implementing these environmental policies, several of which have the primary objective of conserving biodiversity, the number of species at risk of extinction continues to increase. Only the extent of forests certified under an independently verified certification scheme (15.2.1) correlated positively with decreased species extinction risk. There was no significant relationship between species extinction risk and the protection of marine ecosystems (14.5.1). We must highlight that SDG indicator 15.5.1, based on the IUCNs Red List

Index, does not include marine species. Therefore the link between this indicator and marine protected areas (indicator 14.5.1) is tenuous.

3.2.Relationships between environmental pressures and the state of the environment

Table 3. The environmental pressure indicators that correlate significantly with the environmental state indicators. Correlations that show environmental degradation are presented in the upper half of table. Correlations that show environmental improvements are presented in the lower half of table. The middle column describes the causal relationship between the environment and society based on scientific evidence. The right-hand column describes how to interpret the results of the statistical analysis.

Environmental pressure indicator	**Environmental state indicator**	**Hypothesised outcomes of environmental pressures, leading to environmental degradation**	**Evidence for the hypothesised relationship**	**What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)**
6.4.2 Water stress	6.6.1 Water ecosystems	More significant water stress increases demand for, and abstraction of, water from water ecosystems and leads to a decrease in water ecosystem extent	(Arroita et al., 2017; Pekel et al., 2016; Rosen et al., 2000)	*Increasing* water stress correlates with *decreasing* water ecosystem extent
8.4.2 DMC of crops	15.5.1 Species at risk	Greater consumption of crops promotes increased agricultural production, which increases human disturbance of natural ecosystems and biodiversity, which pushes more species toward extinction	(Foley et al., 2005; Lambertini, 2020)	*Increasing* consumption of domestically produced crops correlates with *increased* species extinction risk
8.4.2 DMC of fossil fuels	11.6.2 Air pollution	Greater consumption of fossil fuels involves the combustion of fossil fuels which produces air-borne pollutants which reduce air quality	(De Longueville et al., 2014)	*Increasing* consumption of domestically produced fossil fuels correlates with *increased* air pollution in cities
8.4.2 DMC of wild catch and harvest	15.5.1 Species at risk	Increased exploitation and consumption of wildlife reduces the population sizes of species and pushes more species toward extinction	(Bradshaw et al., 2009; Butchart et al., 2006; Fa et al., 2003; Nasi et al., 2011; Vliet et al., 2007)	*Increasing* consumption of wild-caught and harvested species correlates with *increased* species extinction risk
8.9.1 Tourism	6.6.1 Water ecosystems	Increased tourism increases demand for, and abstraction of, water from water ecosystems and lead to a decrease in water ecosystem extent	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* water ecosystem extent
8.9.1 Tourism	15.1.1 Forest area	Increased tourism promotes deforestation through the development of tourism infrastructure	(Gössling & Peeters, 2015)	*Increasing* tourism correlates with *decreasing* forest area
8.9.1 Tourism	15.5.1 Species at risk	Increased tourism leads to land use change to develop tourism infrastructure, which disrupts ecosystems. Furthermore, it leads to more significant numbers of people visiting areas of high biodiversity value, which increases biodiversity disturbance and pushes more species toward extinction. Alternatively, nature-based tourism can promote biodiversity conservation.	(Bookbinder et al., 1998; Gössling, 2002)	*Increasing* tourism correlates with *increasing* species extinction risk
8.4.2 DMC of crops	15.1.1 Forest area	Greater consumption of crops promotes increased agricultural production, which	(Foley et al., 2005; Geist & Lambin,	*Increasing* consumption of domestically produced

Environmental pressure indicator	Environmental state indicator	Hypothesised outcomes of environmental pressures, leading to environmental degradation	Evidence for the hypothesised relationship	What our results suggest (green/red shading indicates agreement/disagreement with our hypotheses)
		increases demand for land, which drives deforestation and decreases forest area	2002; Gibbs et al., 2010; Potapov et al., 2017)	crops correlates with *increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	6.6.1 Water ecosystems	Mining uses large quantities of freshwater. Therefore an increase in the DMC of minerals extracted by mining will decrease the extent of water ecosystems.	(Palmer et al., 2010)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* water ecosystem extent
8.4.2 DMC of metal ores and non-metallic minerals	15.1.1 Forest area	Mining drives deforestation. Therefore an increase in the DMC of minerals extracted by mining will decrease forest area.	(Potapov et al., 2017; Schueler et al., 2011; Sonter et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *increasing* forest area
8.4.2 DMC of metal ores and non-metallic minerals	15.5.1 Species at risk	Mining has a negative local effect on biodiversity due to habitat destruction and pollution. Therefore an increase in the DMC of minerals extracted by mining will increase the number of species at risk of extinction.	(Deikumah et al., 2014)	*Increasing* consumption of domestically produced metal ores and non-metallic minerals correlates with *decreasing* species extinction risk
8.4.2 DMC of wood	15.1.1 Forest area	Greater consumption of wood resources promotes deforestation, which reduces forest area. Conversely, greater wood consumption promotes the conversion of non-forested land to timber plantations which increases forest area	(Geist & Lambin, 2002; Payn et al., 2015; Potapov et al., 2017)	*Increasing* consumption of domestically produced wood correlates with *increasing* forest area
9.a.1 Infrastructure support	6.6.1 Water ecosystems	Support for dam infrastructure will increase the water ecosystem extent due to the creation of reservoirs associated with dams. Alternatively, support for, and construction of, other forms of infrastructure, such as urban development, degrades natural ecosystems and reduces water ecosystems' extent.	(Davis & Froend, 1999; Lehner et al., 2011; Wang et al., 2008; Žganec, 2012; Zhang, 2009)	*Increasing* financial support for infrastructure correlates with *increasing* water ecosystem extent.

3.2.1 Water ecosystem extent

The extent of water ecosystems was negatively correlated with water stress (6.4.2) (Table 3), measured as the proportion of freshwater withdrawals to available freshwater resources, and with tourism (8.9.1), measured as the proportion of tourism GDP in a country's total GDP. This result suggests that the extent of water ecosystems declines as freshwater withdrawals and tourism activities increase. On the other hand, the extent of water ecosystems was positively correlated with domestic material consumption (DMC) of crops (8.4.2), DMC of metal ores and non-metallic minerals, and international financial support for infrastructure (9.a.1). This result suggests that the extent of water ecosystems increases as consumption of domestically produced crops increases, perhaps due to increased area used for irrigation, with increasing consumption of domestically produced metal ores and non-metallic minerals, and with increasing financial support for infrastructure, perhaps due to the construction of dams and the reservoirs created by them.

3.2.2 Air pollution (11.6.2)

We found a positive correlation between air pollution levels and DMC of fossil fuels (8.4.2) (Table 3), suggesting that air quality in cities declines as consumption of domestically produced fossil fuels increases.

3.2.3 Forest ecosystem extent (15.1.1)

Forest ecosystem extent correlated positively with DMC of crops, wood, and metal ores and non-metallic minerals (8.4.2) (Table 3), suggesting that forest extent increases as consumption of these domestically produced materials increases. Conversely, forest ecosystem extent correlated negatively with tourism (8.9.1), suggesting that forest extent decreases as a country's economic reliance on tourism increases, potentially due to deforestation associated with the tourism industry. There was no significant relationship between forest extent and infrastructure support (9.a.1).

3.2.4 Species at risk (15.5.1)

We found a negative correlation between the extinction risk of wild species and several environmental pressures (Table 3), including DMC of crops (8.4.2), DMC of wild catch and harvest materials (8.4.2), and tourism (8.9.1). This result suggests that the number of species at risk of extinction increases as consumption of domestically produced crops increases, as the amount of wild materials extracted from a country's territory increases, and as tourism increases. Conversely, there was a positive correlation between species extinction risk and consumption of domestically produced metal ores and non-metallic minerals. Finally, there was no significant relationship between species extinction risk and water stress (6.4.2).

4. Discussion

In this study, we use the dataset underlying the SDG monitoring framework to investigate the relationship, across countries, between environmental policies, the state of the environment, the impact of the environment on society, and the pressures that continue to impact the environment. We used a correlation analysis combined with a statistical modelling approach to investigate the correlations between pairs of SDG indicators that we hypothesised to have a relationship based on evidence in the scientific literature and expert opinion. Where the results of the statistical analyses agreed with the scientific rationale, we inferred that this is evidence of a causative relationship between the indicator pairs. Our results highlight where environmental policies may be achieving their intended goals. For example, protecting Key Biodiversity Areas is linked with the increasing extent of forest and water ecosystems. Our results suggest that more effort is required to increase the positive environmental impacts of policies, such as conserving genetic resources to decrease the extinction risk of domesticated species. Surprisingly, our results provide no evidence for the social impacts of the state of the environment, potentially due to the complexity of ecosystems and the difficulty of detecting relationships between the non-market benefits humans derive from the environment and the state of ecosystems. Finally, our results suggest that environmental pressures, including freshwater withdrawals, tourism, and domestic material consumption of crops, fossil fuels, and wild catch and harvest, continue negatively impacting the environment.

This study gives us a flavour of the relationships, across countries, between governmental approaches to tackling environmental degradation and the state of the environment to understand where environmental responses may be achieving their intended aims and where they are falling short. For example, a policy response that appears to be working for conserving forest and water ecosystems is protecting important sites for terrestrial and freshwater biodiversity. Indeed there is convincing evidence that protected areas reduce deforestation (Geldmann et al., 2013; Joppa & Pfaff, 2011). However, the impact of protecting freshwater ecosystems is more challenging to understand than in forest ecosystems and there is less evidence of the benefits of protecting freshwater ecosystems (Adams et al., 2015). Our results offer new evidence about the benefits of protected areas on the extent of freshwater ecosystems.

Our results also highlight policies that may not be having their desired impact. For example, despite increasing numbers of genetic resources secured in conservation facilities, the proportion of local breeds at risk of extinction is increasing. This result suggests that policymakers must do more to conserve domesticated species from the threat of extinction. Indeed the latest reports from the FAO on this topic highlight numerous shortcomings in the state of genetic resource conservation, including missing risk status assessments for the majority of breeds and a lack of early warning systems for genetic erosion (Scherf et al., 2015). In addition, SDG indicators 2.5.1 and 2.5.2 need more data for many countries (Gil et al., 2019). Ultimately, conservation efforts, and the indicators used to monitor them, must be improved to mitigate and monitor the genetic extinction risk of economically and socially valuable species (Gandini & Hiemstra, 2021).

Our results regarding the relationship between species extinction risk and environmental responses were sobering yet not unexpected. Only a single environmental response (forest certification) correlated in a direction that suggests that extinction risk is declining in response to an environmental policy, which aligns with empirical evidence that forest certification contributes positively to biodiversity conservation (Lehtonen et al., 2021). However, the extent of protected areas of forest ecosystems, mountain ecosystems, and Key Biodiversity Areas all correlated with an *increase* in species extinction risk, which aligns with the criticisms that protected areas have fallen short of their conservation goals over the past decade (Maxwell et al., 2020). Regarding the environmental pressures that drive biodiversity loss, our results agree with the contemporary evidence that agricultural land use change and direct exploitation of wildlife remain the main drivers of terrestrial biodiversity declines (Balvanera et al., 2019; Jaureguiberry et al., 2022). Our results highlight that countries need to do more to holistically tackle the multiple drivers of biodiversity loss using environmental policies that are socially just and align with countries' climate change ambitions. At the 15th Conference of Parties to the UN Convention on Biological Diversity, UN Member States agreed to a new set of Goals and Targets to address biodiversity loss and restore natural ecosystems (CBD, 2022a), progress towards which will be tracked by an underlying monitoring framework of indicators (CBD, 2022b). Adopting the monitoring framework is a significant achievement as it is the first time an officially agreed monitoring framework has accompanied the CBD's international biodiversity agreements. A rigorous mechanism for tracking countries' progress on biodiversity will push governments to prioritise the effective design and implementation of environmental policies that bend the curve of biodiversity decline.

We investigated the environment's social impacts, including the human and economic impacts of natural disasters, food insecurity, health impacts of food access, and drinking water access. We found no evidence for relationships between the state of the environment and its impacts on society. Although alarming, this is somewhat not surprising, considering the complexity of ecosystems and their relationships with the goods and benefits that humans derive from the environment. Ecosystems are characterised by 'feedback loops, non-linearities, and alternative states' (Mace, 2019), which makes it challenging to delineate simple relationships between the state of the environment, the ecological functions that support ecosystem services, and the final environmental goods and benefits that society enjoys. It may also be harder to detect a direct link between humans and environmental goods and benefits at a national scale, (the scale of our analysis in this study), because less people now directly depend on the goods and benefits produced by their local ecosystems. Most people now live in cities(UNDESA, 2019) and consume food and materials that are produced by ecosystems outside their local area, and often far outside their national jurisdictions(Folke et al., 1997). There has also been less research on the social impacts of some types of environmental policies than on their environmental impacts (Johnson et al., 2022). Finally, the methods that are used to produce national statistics can be inappropriate for surveying the population groups that do directly depend on their local ecosystems for food and water such as indigenous communities(Walter & Andersen, 2016).

We also investigated environmental pressures, and our results suggest that the human activities that cause environmental degradation, including freshwater withdrawals, tourism, consumption of domestically produced crops, mined minerals, fossil fuels, and wild materials, continue to degrade the environment. Indeed, our findings align with the IPBES global assessment which details freshwater withdrawals, harvesting of materials from nature, mining of fossil fuels, agricultural land-use change, and tourism as direct drivers of environmental change that continue to threaten the state of nature globally (Balvanera et al., 2019). To improve environmental outcomes, countries will need to continue to mitigate these human activities' negative environmental impacts.

Policy responses and environmental pressures continue to increase while the state of the environment continues to decline (Lambertini, 2020; UN Environment, 2019), which illustrates that, to improve the environment, national governments need to do more. Existing policies need to do more to achieve their intended goals and require greater stringency or redesign (UN Environment, 2019). Others may need to be implemented correctly or enforced adequately. Moreover, policies must tackle the underlying drivers of environmental change, such as values, technology, demography, the economy, and governance, which often subvert well-meaning environmental policies. Environmental policies need to engage sufficiently with land and sea use policies, including agriculture, fisheries, renewable energy, and transport (European Habitats Forum, 2019). In addition, countries must respond holistically to environmental declines by integrating environmental policies into agriculture, fisheries, and energy policies that drive environmental change.

We make some recommendations for future improvements to the SDG monitoring framework. First, indicators on policy responses dominate the environmental dimension of the SDG monitoring framework (50 out of 92 indicators), while only 11 measure the state of the environment (Campbell et al., 2020). We recommend that the framework be supplemented with additional environmental state indicators to better track whether policy responses lead to environmental improvements. Secondly, we recommend that indicator 15.5.1, the Red List Index on wild species extinction risk, is disaggregated into multiple sub-indicators of terrestrial, freshwater, and marine species. Currently, indicator 15.5.1 only includes terrestrial species, so it is unsuitable for assessing the success of indicator 14.5.1 on marine protected areas and sub-indicator 15.1.2 on the protection of freshwater Key Biodiversity Areas. The Red List Index for marine species (see, for example, (Nieto et al., 2015)) and a sub-indicator for freshwater species would be more suitable for monitoring the success of marine and freshwater conservation interventions than indicator 15.5.1 in its current form. Finally, national environmental monitoring agencies should adopt science-based standards for the environmental state indicators to provide clear targets for achievement (Usubiaga-Liaño & Ekins, 2022). Standards for some indicators will be uniform across all countries, such as the WHO's safe air pollution levels (World Health Organization & WHO European Centre for Environment, 2021). The standards of other indicators will need to be country-specific and defined through scientific investigation of environmental thresholds in the unique environmental context of each country.

The SDG monitoring framework's data is a valuable resource of indicators for tracking countries' progress toward environmental sustainability. By testing the relationships between indicators of countries' responses to environmental pressures, the state of the environment, and the impacts of the environment on society, we show that governments are making some progress toward sustainable development in some areas, but there are many areas for improvement. If governments wish to maintain nature's contributions to people into perpetuity, they need to improve their policy responses to environmental pressures.

Acknowledgments

The French Development Agency (Agence Française de Développement, AFD) funded this research through the partnership agreement number 554-2020 between AFD and University College London and financed on the Research Programme for a Pro Nature Economy (ECOPRONAT) number CZZ2687. We thank the United Nations Environment Programme for supporting this study. In addition, we thank the experts who contributed to the stakeholder meetings and online survey that informed the selection of indicator pairs for investigation.

Open Research

The SDG indicators data used for the study is available in both a private FigShare repository (https://figshare.com/s/83dc27cba88c5c7d91e3) and publicly available on the SDG Indicator Database (www.unstat.un.org/sdgs/dataportal/database). The R software used for the statistical analysis is available at https://www.r-project.org/ (R Core Team, 2021) and the R code used to conduct the statictial analysis will be made publically available on a GitHub repository on publication.

References

Adams, V. M., Setterfield, S. A., Douglas, M. M., Kennard, M. J., & Ferdinands, K. (2015). Measuring benefits of protected area management: Trends across realms and research gaps for freshwater systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1681). Scopus. https://doi.org/10.1098/rstb.2014.0274

Arroita, M., Flores, L., Larrañaga, A., Martínez, A., Martínez-Santos, M., Pereda, O., Ruiz-Romera, E., Solagaistua, L., & Elosegi, A. (2017). Water abstraction impacts stream ecosystem functioning via wetted-channel contraction. *Freshwater Biology*, *62*(2), 243–257. https://doi.org/10.1111/fwb.12864

Auld, G., Gulbrandsen, L. H., & McDermott, C. L. (2008). Certification schemes and the impacts on forests and forestry. *Annual Review of Environment and Resources*, *33*(1), 187–211.

Balvanera, P., Pfaff, A., Viña, A., García-Frapolli, E., Merino, L., Minang, P., Nagabhatla, N., Hussain, S., & Sidorovich, A. (2019). Chapter 2.1. Status and Trends – Drivers of Change. In *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (p. 152). IPBES secretariat. 10.5281/zenodo.3831881

Barnes, M. D., Craigie, I. D., Harrison, L. B., Geldmann, J., Collen, B., Whitmee, S., Balmford, A., Burgess, N. D., Brooks, T., Hockings, M., & Woodley, S. (2016). Wildlife population trends in protected areas predicted by national socio-economic metrics and body size. *Nature Communications*, *7*(1), Article 1. https://doi.org/10.1038/ncomms12747

Bookbinder, M. P., Dinerstein, E., Rijal, A., Cauley, H., & Rajouria, A. (1998). Ecotourism's Support of Biodiversity Conservation. *Conservation Biology*, *12*(6), 1399–1404. https://doi.org/10.1111/j.1523-1739.1998.97229.x

Bradshaw, C. J., Sodhi, N. S., & Brook, B. W. (2009). Tropical turmoil: A biodiversity tragedy in progress. *Frontiers in Ecology and the Environment*, *7*(2), 79–87. https://doi.org/10.1890/070193

Breuer, A., Janetschek, H., & Malerba, D. (2019). Translating Sustainable Development Goal (SDG) Interdependencies into Policy Advice. *Sustainability*, *11*(7), Article 7. https://doi.org/10.3390/su11072092

Bueren, E. van. (2019). *Environmental policy. History, Concepts, Instruments, & Examples*. Britannica. https://www.britannica.com/topic/environmental-policy

Burivalova, Z., Hua, F., Koh, L. P., Garcia, C., & Putz, F. (2017). A Critical Comparison of Conventional, Certified, and Community Management of Tropical Forests for Timber in

Terms of Environmental, Economic, and Social Variables. *Conservation Letters*, *10*(1), 4–14. https://doi.org/10.1111/conl.12244

Butchart, S. H., Akçakaya, H. R., Kennedy, E., & HILTON-TAYLOR, C. (2006). Biodiversity indicators based on trends in conservation status: Strengths of the IUCN Red List Index. *Conservation Biology*, *20*(2), 579–581.

Campbell, J., Neuner, J., See, L., Fritz, S., Fraisl, D., Espey, J., & Kim, A. (2020). The role of combining national official statistics with global monitoring to close the data gaps in the environmental SDGs. *Statistical Journal of the IAOS 36*. https://doi.org/10.3233/SJI-200648

Carranza, T., Balmford, A., Kapos, V., & Manica, A. (2014). Protected Area Effectiveness in Reducing Conversion in a Rapidly Vanishing Ecosystem: The Brazilian Cerrado. *Conservation Letters*, *7*(3), 216–223. https://doi.org/10.1111/conl.12049

CBD. (2022a). *COP15: Nations Adopt Four Goals, 23 Targets for 2030 In Landmark UN Biodiversity Agreement*. Convention on Biological Diversity. https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022

CBD. (2022b). *Monitoring framework for the Kunming-Montreal global biodiversity framework*. CONFERENCE OF THE PARTIES TO THE CONVENTION ON BIOLOGICAL DIVERSITY Fifteenth meeting, Montreal, Canada. https://www.cbd.int/doc/c/179e/aecb/592f67904bf07dca7d0971da/cop-15-l-26-en.pdf

Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., & Daily, G. C. (2006). Conservation Planning for Ecosystem Services. *PLOS Biology*, *4*(11), e379. https://doi.org/10.1371/journal.pbio.0040379

Coad, L., Leverington, F., Knights, K., Geldmann, J., Eassom, A., Kapos, V., Kingston, N., de Lima, M., Zamora, C., Cuardros, I., Nolte, C., Burgess, N. D., & Hockings, M. (2015). Measuring impact of protected area management interventions: Current and future use of the Global Database of Protected Area Management Effectiveness. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1681), 20140281. https://doi.org/10.1098/rstb.2014.0281

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). *Nature-based solutions to address global societal challenges*. IUCN International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Coping with climate change: The roles of genetic resources for food and agriculture. (2015). FAO.

Damette, O., & Delacote, P. (2011). Unsustainable timber harvesting, deforestation and the role of certification. *Ecological Economics*, *70*(6), 1211–1219. https://doi.org/10.1016/j.ecolecon.2011.01.025

Davis, J. A., & Froend, R. (1999). Loss and degradation of wetlands in southwestern Australia: Underlying causes, consequences and solutions. *Wetlands Ecology and Management*, *7*(1), 13–23. https://doi.org/10.1023/A:1008400404021

De Longueville, F., Hountondji, Y., Ozer, P., & Henry, S. (2014). The Air Quality in African Rural Environments. Preliminary Implications for Health: The Case of Respiratory Disease in the Northern Benin. *Water, Air, & Soil Pollution*, *225*(11), 2186. https://doi.org/10.1007/s11270-014-2186-4

Deikumah, J. P., McAlpine, C. A., & Maron, M. (2014). Mining matrix effects on West African rainforest birds. *Biological Conservation*, *169*, 334–343. https://doi.org/10.1016/j.biocon.2013.11.030

Eklund, J., Blanchet, F. G., Nyman, J., Rocha, R., Virtanen, T., & Cabeza, M. (2016). Contrasting spatial and temporal trends of protected area effectiveness in mitigating deforestation in Madagascar. *Biological Conservation*, *203*, 290–297. https://doi.org/10.1016/j.biocon.2016.09.033

Enjalbert, J., Dawson, J. C., Paillard, S., Rhoné, B., Rousselle, Y., Thomas, M., & Goldringer, I. (2011). Dynamic management of crop diversity: From an experimental approach to on-farm conservation. *Comptes Rendus Biologies*, *334*(5), 458–468. https://doi.org/10.1016/j.crvi.2011.03.005

European Habitats Forum. (2019). *The implementation of the EU 2020 Biodiversity Strategy and recommendations for the post 2020 Biodiversity Strategy* (p. 8). European Habitats Forum. https://www.iucn.org/sites/dev/files/content/documents/eu_2020_biodiversity_strategy_and_recommendations_for_post_2020.pdf

Fa, J. E., Currie, D., & Meeuwig, J. (2003). Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future. *Environmental Conservation*, *30*(1), 71–78. https://doi.org/10.1017/S0376892903000067

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., & Gibbs, H. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574.

Folke, C., Jansson, Å., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio*, *26*(3), 167–172. Scopus.

Fuso Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán Broto, V., Anandarajah, G., Milligan, B., & Mulugetta, Y. (2018). Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy*, *3*(1), Article 1. https://doi.org/10.1038/s41560-017-0036-5

Gandini, G., & Hiemstra, S. J. (2021). Farm animal genetic resources and the COVID-19 pandemic. *Animal Frontiers*, *11*(1), 54–56. https://doi.org/10.1093/af/vfaa049

Geist, H. J., & Lambin, E. F. (2002). Proximate Causes and Underlying Driving Forces of Tropical Deforestation: Tropical forests are disappearing as the result of many pressures, both local and regional, acting in various combinations in different geographical locations. *BioScience*, *52*(2), 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Geldmann, J., Barnes, M., Coad, L., Craigie, I. D., Hockings, M., & Burgess, N. D. (2013). Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. *Biological Conservation*, *161*, 230–238. https://doi.org/10.1016/j.biocon.2013.02.018

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, *107*(38), 16732–16737. https://doi.org/10.1073/pnas.0910275107

Gil, J. D. B., Reidsma, P., Giller, K., Todman, L., Whitmore, A., & van Ittersum, M. (2019). Sustainable development goal 2: Improved targets and indicators for agriculture and food security. *Ambio*, *48*(7), 685–698. https://doi.org/10.1007/s13280-018-1101-4

Gössling, S. (2002). Global environmental consequences of tourism. *Global Environmental Change*, *12*(4), 283–302. https://doi.org/10.1016/S0959-3780(02)00044-4

Gössling, S., & Peeters, P. (2015). Assessing tourism's global environmental impact 1900–2050. *Journal of Sustainable Tourism*, *23*(5), 639–659. https://doi.org/10.1080/09669582.2015.1008500

Gray, C. L., Hill, S. L. L., Newbold, T., Hudson, L. N., Börger, L., Contu, S., Hoskins, A. J., Ferrier, S., Purvis, A., & Scharlemann, J. P. W. (2016). Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications*, *7*(1), Article 1. https://doi.org/10.1038/ncomms12306

IAEG-SDGs. (2020). *SDG Indicator changes (15 October 2018 and onward)*. Tier Classification for Global SDG Indicators. https://unstats.un.org/sdgs/iaeg-sdgs/tier-classification/

IEA, IRENA, UNSD, World Bank, & WHO. (2022). *Tracking SDG 7: The Energy Progress Report*. World Bank.

International Council for Science (ICSU). (2017). *A Guide to "SDG" Interactions: From Science to Implementation* (p. 12). International Council for Science (ICSU). http://pure.iiasa.ac.at/id/eprint/14591/

IUCN. (2012). *Natural Solutions: Protected Areas Maintaining Essential Water Supplies*. IUCN. https://www.iucn.org/sites/dev/files/import/downloads/natsols_water_flyer_final.pdf

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Coscieme, L., Golden, A. S., Guerra, C. A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., Molnár, Z., & Purvis, A. (2022). The direct drivers of recent global anthropogenic biodiversity loss. *Science Advances*, *8*(45), eabm9982. https://doi.org/10.1126/sciadv.abm9982

Johnson, B. A., Kumar, P., Okano, N., Dasgupta, R., & Shivakoti, B. R. (2022). Nature-based solutions for climate change adaptation: A systematic review of systematic reviews. *Nature-Based Solutions*, *2*, 100042. https://doi.org/10.1016/j.nbsj.2022.100042

Joppa, L. N., & Pfaff, A. (2011). Global protected area impacts. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1712), 1633–1638. https://doi.org/10.1098/rspb.2010.1713

Jordan, A., Wurzel, R. K. W., & Zito, A. R. (2003). 'New' Instruments of Environmental Governance: Patterns and Pathways of Change. *Environmental Politics*, *12*(1), 1–24. https://doi.org/10.1080/714000665

Kalonga, S. K., Midtgaard, F., & Klanderud, K. (2016). Forest certification as a policy option in conserving biodiversity: An empirical study of forest management in Tanzania. *Forest Ecology and Management*, *361*, 1–12. https://doi.org/10.1016/j.foreco.2015.10.034

Kristensen, P. (2004). *The DPSIR Framework*. The 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach, Nairobi, Kenya. https://wwz.ifremer.fr/dce/content/download/69291/913220/.../DPSIR.pdf

Lambertini, M. (2020). *Living Planet Report 2020: Bending the Curve of Biodiversity Loss*. http://www.deslibris.ca/ID/10104983

Lehner, B., Liermann, C. R., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P., Endejan, M., Frenken, K., Magome, J., Nilsson, C., Robertson, J. C., Rödel, R., Sindorf, N., & Wisser, D. (2011). High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment*, *9*(9), 494–502. https://doi.org/10.1890/100125

Lehtonen, E., Gustafsson, L., Lõhmus, A., & von Stedingk, H. (2021). What does FSC forest certification contribute to biodiversity conservation in relation to national legislation? *Journal of Environmental Management*, *299*. Scopus. https://doi.org/10.1016/j.jenvman.2021.113606

Mace, G. M. (2019). The ecology of natural capital accounting. *Oxford Review of Economic Policy*, *35*(1), 54–67. https://doi.org/10.1093/oxrep/gry023

Maxwell, S. L., Cazalis, V., Dudley, N., Hoffmann, M., Rodrigues, A. S. L., Stolton, S., Visconti, P., Woodley, S., Kingston, N., Lewis, E., Maron, M., Strassburg, B. B. N., Wenger, A., Jonas, H. D., Venter, O., & Watson, J. E. M. (2020). Area-based conservation in the twenty-first century. *Nature*, *586*(7828), 217–227. Scopus. https://doi.org/10.1038/s41586-020-2773-z

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Nasi, R., Taber, A., & Van Vliet, N. (2011). Empty forests, empty stomachs? Bushmeat and livelihoods in the Congo and Amazon Basins. *International Forestry Review*, *13*(3), 355–368. https://doi.org/10.1505/146554811798293872

Nieto, A., Ralph, G. M., Comeros-Raynal, M., Heessen, H., & Rijnsdorp, A. (2015). *European Red List of marine fishes*. Publications Office of the European Union.

OECD. (2011). *Better Policies to Support Eco-innovation*. OECD Publishing. https://www.oecd.org/environment/consumption-innovation/betterpoliciestosupporteco-innovation.htm

Palmer, M. A., Bernhardt, E. S., Schlesinger, W. H., Eshleman, K. N., Foufoula-Georgiou, E., Hendryx, M. S., Lemly, A. D., Likens, G. E., Loucks, O. L., Power, M. E., White, P. S., & Wilcock, P. R. (2010). Mountaintop Mining Consequences. *Science*, *327*(5962), 148–149. https://doi.org/10.1126/science.1180543

Payn, T., Carnus, J.-M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Silva, L. N., & Wingfield, M. J. (2015). Changes in planted forests and future global implications. *Forest Ecology and Management*, *352*, 57–67. https://doi.org/10.1016/j.foreco.2015.06.021

Pekel, J.-F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, *540*(7633), Article 7633. https://doi.org/10.1038/nature20584

Potapov, P., Hansen, M. C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S., & Esipova, E. (2017). The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances*, *3*(1), e1600821. https://doi.org/10.1126/sciadv.1600821

Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Future*, *5*(11), 1169–1179. https://doi.org/10.1002/2017EF000632

PwC. (2016). *Navigating the SDGs: A business guide to engaging with the UN Global Goals* (p. 96). Price Waterhouse Cooper. https://www.pwc.com/gx/en/sustainability/publications/PwC-sdg-guide.pdf

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rametsteiner, E., & Simula, M. (2003). Forest certification—An instrument to promote sustainable forest management? *Journal of Environmental Management*, *67*(1), 87–98. https://doi.org/10.1016/S0301-4797(02)00191-3

Rosen, C., Tunstall, D., White, R., Ottke, C., Revenga, C., Rohweder, M., Murray, S., Kassem, K., Kura, Y., Sebastian, K., Henninger, N., Reid, W. V., Lenton, R., McNeil, C., Schmidt, R., Becker, S., Lewis, K., Claasen, D., Singh, A., … Axelrod, E. (2000). *A Guide to World Resources 2000–2001: People and Ecosystems: The Fraying Web of Life*. UNDP-UNEP-World Bank.

Scharlemann, J. P. W., Brock, R. C., Balfour, N., Brown, C., Burgess, N. D., Guth, M. K., Ingram, D. J., Lane, R., Martin, J. G. C., Wicander, S., & Kapos, V. (2020). Towards understanding interactions between Sustainable Development Goals: The role of environment–human linkages. *Sustainability Science*. https://doi.org/10.1007/s11625-020-00799-6

Scherf, B. D., Pilling, D., & Commission on Genetic Resources for Food and Agriculture. (2015). *The second report on the state of the world's animal genetic resources for food and agriculture*. http://www.fao.org/3/a-i4787e.pdf

Schueler, V., Kuemmerle, T., & Schröder, H. (2011). Impacts of Surface Gold Mining on Land Use Systems in Western Ghana. *AMBIO*, *40*(5), 528–539. https://doi.org/10.1007/s13280-011-0141-9

Schwartz, T., & Goubran, S. (2020). An Introduction to the Current Landscape: Environmental Policy and the Economy. In *Environmental policy: An economic perspective*. Hoboken, New Jersey ; West, Sussex, England : Wiley Blackwell. http://onlinelibrary.wiley.com/doi/epub/10.1002/9781119402619

Shanley, P. (2002). *Tapping the green market: Management and certification of non-timber forest products*. Earthscan Publications; Library Hub Discover. http://ebookcentral.proquest.com/lib/abdn/detail.action?docID=429917

Sonter, L. J., Moran, C. J., Barrett, D. J., & Soares-Filho, B. S. (2014). Processes of land use change in mining regions. *Journal of Cleaner Production*, *84*, 494–501. https://doi.org/10.1016/j.jclepro.2014.03.084

Turral, H., Svendsen, M., & Faures, J. M. (2010). Investing in irrigation: Reviewing the past and looking to the future. *Agricultural Water Management*, *97*(4), 551–560. https://doi.org/10.1016/j.agwat.2009.07.012

UN Environment. (2019). *Global Environment Outlook—GEO-6: Healthy Planet, Healthy People*. Un Environment. https://doi.org/10.1017/9781108627146

UNDESA. (2019). *World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420)*. United Nations, Department of Economic and Social Affairs, Population Division.

UNEP. (2019). *Measuring Progress: Towards Achieving the Environmental Dimension of the SDGs*. United Nations Environment Programme.

UNEP. (2021). *Measuring Progress: Environment and the SDGs*. United Nations Environment Programme. https://www.unep.org/resources/publication/measuring-progress-environment-and-sdgs

United Nations. (2015). *Transforming our World: The 2030 Agenda for Sustainable Development. General Assembly Resolution A/RES/70/1.* https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

Usubiaga-Liaño, A., & Ekins, P. (2022). Are we on the right path? Measuring progress towards environmental sustainability in European countries. *Sustainability Science*.

van Kuijk, M., Putz, F., & Zagt, R. (2009). *Effects of forest certification on biodiversity*. Tropenbos International. https://www.tropenbos.org/resources/publications/effects+of+forest+certification+on+biodiversity

Vliet, N. van, Nasi, R., Emmons, L., Feer, F., Mbazza, P., & Bourgarel, M. (2007). Evidence for the local depletion of bay duiker Cephalophus dorsalis, within the Ipassa Man and Biosphere Reserve, north-east Gabon. *African Journal of Ecology*, *45*(3), 440–443.

Walter, M., & Andersen, C. (2016). *Indigenous statistics: A quantitative research methodology*. Routledge.

Wang, X., Ning, L., Yu, J., Xiao, R., & Li, T. (2008). Changes of urban wetland landscape pattern and impacts of urbanization on wetland in Wuhan City. *Chinese Geographical Science*, *18*(1), 47–53. https://doi.org/10.1007/s11769-008-0047-z

Watson, R. T., Baste, I. A., Larigauderie, A., Leadley, P., Pascual, U., Baptiste, B., Demissew, S., Dziba, L., Erpul, G., Fazel, A. M., Fischer, M., Hernández, A. M., Karki, M., Mathur, V., Pataridze, T., Pinto, I. S., Stenseke, M., Török, K., & Vilá, B. (2019). *The global assessment report on biodiversity and ecosystem services. Summary for policymakers*. IPBES Secretariat. https://ipbes.net/global-assessment

Weitz, N., Carlsen, H., Skånberg, K., Dzebo, A., & Viaud, V. (2019). *SDGs and the environment in the EU: A systems view to improve coherence* (p. 36). Stockholm Environment Institute. https://www.sei.org/wp-content/uploads/2019/10/sei-2019-pr-weitz-sdg-synergies-eu-env.pdf

World Health Organization & WHO European Centre for Environment. (2021). *WHO global air quality guidelines: Particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.

Žganec, K. (2012). The effects of water diversion and climate change on hydrological alteration and temperature regime of karst rivers in central Croatia. *Environmental Monitoring and Assessment*, *184*(9), 5705–5723. https://doi.org/10.1007/s10661-011-2375-1

Zhang, Q. (2009). The South-to-North Water Transfer Project of China: Environmental Implications and Monitoring Strategy1. *JAWRA Journal of the American Water Resources Association*, *45*(5), 1238–1247. https://doi.org/10.1111/j.1752-1688.2009.00357.x